Ph. D. THESIS **GEOGRAPHY**

AN APPRAISAL OF RAIN SHADOW EFFECTS AND LIVELIHOOD DYNAMICS IN THE ATTAPPADY HILLY REGION, WESTERN GHATS, KERALA

Thesis submitted to the

University of Calicut for the Award of the Degree of

DOCTOR OF PHILOSOPHY

in Geography

under the Faculty of Science

By

SURESH P.

Reg. No. CHATREY 001

Under the guidance of

Dr. RICHARD SCARIA

Associate professor in Geography

Govt. College Chittur, Palakkad

Department of Geography

Government College Chittur, Palakkad

University of Calicut

Kerala, India-678104

August 2025

SURESH P.
Research Scholar,
Department of Geography,
Government College Chittur,
University of Calicut,
Palakkad, Kerala.

DECLARATION

I, Suresh P., hereby declare that the Ph.D. thesis entitled "**AN APPRAISAL OF RAIN SHADOW EFFECTS AND LIVELIHOOD DYNAMICS IN THE ATTAPPADY HILLY REGION, WESTERN GHATS, KERALA**", submitted to University of Calicut in August 2025 for the partial fulfilment of the degree of Doctor of Philosophy in Geography under the supervision and guidance of Dr. Richard Scaria, Associate Professor, Department of Geography, Govt. College Chittur, University of Calicut. This thesis has not formed the basis fully or partially for the award of any Degree, Diploma or other similar titles earlier at the time of submission

Chittur

SURESH P.
(Research Scholar)

DECLARATION

I hereby declare that the work presented in the thesis entitled "**AN APPRAISAL OF RAIN SHADOW EFFECTS AND LIVELIHOOD DYNAMICS IN THE ATTAPPADY HILLY REGION, WESTERN GHATS, KERALA**" is based on the original work done by me under the guidance of Dr. Richard Scaria, Associate Professor, Department of Geography, Govt. College Chittur, University of Calicut, and has not been included in other thesis submitted previously for the award of any Degree. The contents of the thesis are undergone plagiarism check using iThenticate software at C.H.M.K. Library, University of Calicut, and the similarity index found within the permissible limit. I also declare that the thesis is free from AI generated contents.

Chittur

Signature

Name of the Scholar

SURESH P.

Signature

Name of the Supervising Teacher

Dr. RICHARD SCARIA

Dr. RICHARD SCARIA
Supervisor
Associate Professor
Department of Geography
Government College Chittur,
University of Calicut, Palakkad

CERTIFICATE

This is to certify that the thesis entitled "**AN APPRAISAL OF RAIN SHADOW EFFECTS AND LIVELIHOOD DYNAMICS IN THE ATTAPPADY HILLY REGION, WESTERN GHATS, KERALA**" submitted to University of Calicut for the award of the degree of Doctor of Philosophy in Geography is an original bonafide research work carried out in the Department of Geography, Govt. College Chittur, University of Calicut, by SURESH.P, under my supervision and guidance. This thesis has not previously formed the basis for the award of any Degree, Diploma and other similar title elsewhere at the time of submission

Chittur

Dr. RICHARD SCARIA

(Supervisor)

ACKNOWLEDGEMENT

First and foremost, I express my profound gratitude to my guide and mentor **Dr. Richard Scaria**, Associate Professor of Geography, Govt. College Chittur, for his scholarly guidance and constant encouragement throughout the conduct of this study. He has been a constant source of inspiration for his constructive suggestions and motivation. His creative guidance and seamless encouragement helped me in the successful completion of this research.

I record my sincere gratitude and earnest thanks to **Dr. C. Naseema**, Professor & Director, School of Education, University of Calicut, **Dr. Dhanya Vijayan,** Leibniz Centre for Agricultural Landscape Research (ZALF), Germany, for their constructive suggestions and encouragement to complete this study.

I am very thankful to Dr. **Gopakumar Cholayil** (Retd.), Scientific and Academic Officer, College of Climate Change and Environmental Science, Kerala Agricultural University, Vellanikkara, Thrissur, **Dr. Harikrishan T.** (Retd.), Asst. Field Officer, Soil and Land Use Survey of India, Govt. of India, Ministry of agriculture & Farmers, Bangalore, for their constructive suggestions and motivation.

I am thankful to **Mrs. Aswathy P.J.**, Assistant Professor and Head, Department of Commerce for her help in the field work of the study and in the statistical analysis of the research. I am grateful to **Dr. Suresh S.**, Assistant Professor (contract), Sree Sankaracharya University, Kalady for his valuable cartographic help.

I also thank to **Dr. R. Sunil Kumar**, Associate Professor of Geography, Govt. Arts and Science College Coimbatore, **Dr. Saju T. S.**, Associate Professor, Kalady University, **Dr. Prasad T. K.**, Associate Professor, Kannur University, **Dr. Satheesh Chothodi**, Assistant Professor at Dr. Harisingh Gour Vishwavidyalaya (A Central University), Sagar, Madhya Pradesh, **Dr. Jincy**, Assistant Professor (Contract), Govt.College Tholanur, Palakkad, for his constructive suggestions and motivation.

I express my gratitude to **Dr. Reji T.**, Professor and Principal (in charge), Govt. College Chittur for his possible support for the successful completion of this work. I express my sincere thanks to **Dr. Jayarajan. K**, Associate Professor and Head, Department of Geography, my colleagues, **Dr. Roobina A.**, **Pankjakshan P.**, **Dr. Prasad K.**, **Nazrin Begum S.**, **Dr. Reshma C. U.**, and **Vineesh V.** for their support and encouragement throughout the study.

I am thankful to the **Research Scholars and Students** of the department of Geography, Govt. College, Chittur for their support and encouragement. I owe a lot to all my teachers, friends and students for their encouragement, motivation and support for the successful completion of this research work.

Last, but not the least, my family members, who have been the pillar of the support and strength throughout the period of my research work with their love and help. I am also indebted to my wife, **Aswathy**, and my sons, **Adwaith** and **Adrij** who have encouraged me for timely completion of this research work. I dedicate my research work to my parents, **Pazhanikutty** (Late) and **Thanka Pazhanikutty** who lightened my path and strived hard to educate me.

SURESH P.

CONTENTS

List of Tables

List of Figures

CHAPTER 1

THEORETICAL FRAMEWORK OF THE RESEARCH

CHAPTER 1

THEORETICAL FRAMEWORK OF THE RESEARCH

1.1 Introduction

The life journey of human beings is inseparably associated (inextricably linked to) with the climate of their surroundings. Climate is considered a unique natural phenomenon that deeply influences both the genetic makeup and the day-to-day lives of the human population. The lasting imprints left on the land by civilized societies driven by expansion and advancement were also shaped by climate. The real-world experiences serve as a constant reminder of climatic phenomena throughout the history of humans in both aspects: as prospects and challenges. The trajectories of the success and failure of each civilization were synchronized with the climate. For example, prolonged droughts and unpredictable floods contributed to the decline of ancient civilizations like the Harappa and the Mycenaean civilization. Globally, even in the current era of artificial intelligence and machine learning, climate persists as a critical factor influencing human existence. The fact that current climate change-related disasters and hazards have not yet been mitigated to a satisfactory level by the scientific community indicates that climate remains a phenomenon of immense complexity. Therefore, climate studies need to be examined through multiple phases and dimensions, focusing on cause-and-effect relationships and addressing questions such as Where? (locations), How? (causes), and Why? (impacts). Not only the academic community but also the broader public acknowledges the tangible reality of climate change. Therefore, there should be a rational involvement in making policies and programs for thinning the hostile effects of climate change. So, climate studies and research are reflected to be the need of the hour to address questions such as whether human beings can continue to exist on this Earth. Macro-scale research on climate studies is satisfactory for planning and implementation. However, detailed scientific examinations and inquiries on the peculiarities of the climate and its variables that act upon a region are possible only through the lens and scale of a micro-level approach.

1.2 Context of the Study

Climate-based knowledge is essential for climate modeling and future climate prediction in an area (Hald, 2001). In recent times, though climate-related research has advanced significantly, research on climate variations at micro level is still in its infancy. There is an urgent need to study climate changes at the micro level. This is very important for understanding the adaptation capacity of local communities. It also helps to integrate their traditional knowledge of the environment. Climate change is a reality that accelerates the occurrence of climate-related extreme events, like increasing rainfall and rising temperatures, all over the world. Climate change creates various environmental consequences and threatens biodiversity. As a result, many species lost their habitat and are at threat as endangered or extinct (Thomas and Cheung 2024; Kolawole & Okonkwo, 2022). Due to climate change, fresh water also gets contaminated by the various effluents and surface runoff due to rising temperatures (Usman et al., 2024; Kolawole and Okonkwo, 2022).

These environmental problems directly affect human livelihoods, especially people from underdeveloped countries. Since climate variability diminishes water availability and deteriorates water quality, the communities mainly dependent on pastoralism and rain-fed agriculture are facing reduced agricultural production and increasing input costs (Nunow, 2024). These environmental degradation damages economic opportunities, leading to food insecurity and calling for the appropriate policies that support resilient livelihoods (Chatterjee and Dwivedi, 2022). Also, the rising temperature poses direct risks to human health, including heat stress and the spread of contagious diseases (Bhardwaj, 2024; Rusoke, 2024).

Attappady is hilly region located in the Palakkad district of Kerala. It lies in the eastern part of the Western Ghats. Administratively, it is one of the taluks in Palakkad district. This rain shadow region has been taken for the study of topo climate influence on livelihoods. Its locations are defined by the surrounding Western Ghats mountains which creates various microclimate pockets. In the microclimate zones rainfall, temperature, wind speed, and relative humidity are changing over short distances. This microclimatic variation directly reflects the region's socio-economic conditions, as this area is inhabited mainly by tribal populations who deeply depend on subsistence agriculture, forest resources, and other traditional activities. Attappady is currently going through rapid environmental changes. These includes deforestation, biodiversity loss, soil quality loss, and land degradation. These problems are driven by both anthropogenic pressure of the migrant population and changes in climate. The orographic influence on the rain shadow effect is directly associated with these challenges. As rainfall reduced automatically, the soil moisture also decreased which intensifies soil erosion and reduces agricultural fertility (Hende et al., 2021). Finally, the changing rainfall patterns disrupt local ecosystems by causing shifts in flora and fauna and changing the food chain relationship (Fernandes et al., 2022; Chen et al., 2019). From this background, it is understood that the relationship between Attappady's topography and its microclimate creates a unique environmental condition. These unique environmental conditions lead to various environmental problems that shape the community's livelihood strategies and resilience of its communities. These are the reasons that highlight the urgent need to focus on this study area.

1.3 Conceptual Base: - Rain Shadow Effects in the Western Ghats

Topographic features create distinct regional climate zones. Research by Anderson and Smith (2023) identifies several key effects. These are the creation of climate boundaries, establishing vertical climate zones, influence on precipitation distribution, and affecting atmospheric circulation patterns. Topo-climates are relatively obvious in the case of radiation and temperature, but second-order effects may also come into play through the influence of terrain on wind velocity and in setting up slope and mountain valley winds. These top-climatic influences are most evident over distances from a few kilometers to a few meters. The most direct topo-climatic influences are those between: (1) northern slopes, on one hand, and southern slopes, on the other hand; and (2) between valley bottoms and top of ridges. Other influences can also occur depending upon valley orientation as compared to the mountain range, and valley cross-profile. The principal control of conditions related to slope orientation is solar radiation, and effects of airflow and air drainage are major secondary influences for ridge top and valley bottom positions, especially for night and winter conditions (Anderson and Smith., 2023).

In the mountainous topography, due to decreasing air density with altitude, the atmosphere holds less heat at higher elevations, resulting in cooler conditions at mountaintops. When a mountain is sufficiently high, this cooling effect can extend to its surroundings, creating regional climatic impacts. Mountain ranges that rise above approximately three kilometers can significantly influence atmospheric circulation, particularly when oriented perpendicular to prevailing winds (Ollier D. Cliff. 2004). Local variations in plant cover are mostly determined by the interaction of Topo- and microclimatic factors. Because of the combined effects of radiation, evaporation, and wind speed, minor topographic irregularities and variations in slope angle and aspect result in noticeable disparities in vegetation. Regions with favorable microclimates attract human habitation, while areas with extreme conditions may remain underutilized. The Western Ghats modify the Indian monsoon by intercepting monsoon winds, creating distinct rainfall patterns along the coast, influencing moisture transport inland.

The Western Ghats of India are the mountain ranges located along the west coast of the Indian subcontinent. It extends from Gujarat state in the north to Tamil Nadu in the South. These ranges pass through the states of Gujarat, Maharashtra, Goa, Karnataka, Kerala and Tamil Nadu for a length of approximately 2300 km and are as wide as 100 km at some places. The Western Ghats of India are pivotal in the moderation of tropical climate in the Indian region. The Indian monsoon is highly influenced by the Western Ghats mountains and its characteristic forest ecosystems. It is best described in the tropical monsoon system. The mountain intercepts the rain bearing winds from the southwestern direction during late summer and the region reveals extensive variation in the spatial distribution of rainfall (Mudbhatkal, A., & Amai, M. (2018). Studies observed that the irregular patterns of rainfall are in association with irregular terrain in the Western Ghats (Sayli A. Tawde and Singh C, 2015). Oruga and Yoshizaki (1998) have discovered that the elevation of the Western Ghats is capable of deep convection well offshore in Arabian Sea. Konwar et al. (2014) have also supported the possibility that the strong orographic updraft provided by the Western Ghats barrier, invigorates growth of cloud droplets due to coalescence process in shallow convective clouds. Francis and Gadgil (2005) stated that extreme rain events are likely to occur near the orography. Rajendran et al (2012) addressed a decreasing trend in moderate to heavy rainfall because of the warming of upper troposphere resulting in decrease of lapse rate, vertical velocities, south westerly winds and moisture transport. They also stated that there will be decrement in the frequency of high to moderate rain events over wind ward side and increment over the leeward side of the Western Ghats in coming years. Prakash et al. (2013) reveals that the decreasing trend of monsoon rainfall over the west coast, the rainfall over the Western Ghats exhibits increasing trend after the year 2002. The study investigates the relationship between the topography of the Western Ghats and rainfall patterns, specifically focusing on the impact of mountain structure and elevation on precipitation. The region between 14°-21°N is characterized by a narrow, cascaded mountain range, with an elevation above 600 m typically spanning 100 km east-west and 600 km north-south. In contrast, the 11°-14°N region features a broader mountain range, while the 9°-10°N region has isolated mountains. Heavy rainfall is observed on the windward side of Karnataka (13°-14°N), followed by Maharashtra and Kerala. The study concludes that cascaded mountains, due to their larger spatial extent, induce more intense rainfall compared to isolated mountains. This can be explained by the concept of "advection timescale" (Ta), which is the ratio of the horizontal width of a mountain to the wind speed. Broader mountains allow more time for moisture to condense and precipitate before reaching the leeward side, leading to higher rainfall on the windward side and stronger rain shadows on the leeward side. For example, Karnataka receives significantly more rainfall on the windward side compared to Maharashtra and Kerala (Kirshbaum and Smith, 2008; Jiang and Smith, 2003; Elliott and Hovind, 1964). Rainfall intensity is also influenced by the mountain's north-south length and width. Notably, rainfall reaches its maximum before the summit of the mountain barrier, which may be due to the accumulation of moisture at the foot of the mountains, where uplifted air particles have more time to grow and coalesce. Additionally, there is a consumption of available water vapor as rain falls on the windward side. The study further observes that the highest rainfall (21.32 mm/day) occurs on the windward side of the broad, cascaded mountain range in Karnataka. In contrast, Maharashtra’s narrow mountain range receives 17.16 mm/day, and Kerala’s isolated mountains receive the least, at 15.28 mm/day (Suprit and Shankar, 2008; Konwar et al., 2012a, 2012b). Elevation also plays a significant role in rainfall patterns. The elevation above 600 m in the Western Ghat generally corresponds to higher rainfall, with the peak rainfall observed approximately 50 km from the mountain barrier. However, rainfall decreases near the summit, as the monsoon air starts rising about 50 km before reaching the mountain crest (Das, 1968). Locations with lower elevations, such as the Palghat gap in

Kerala, experience less rainfall (Raj and Azeez, 2010). The study also indicates that elevations around 800 m may act as a barrier to incoming winds, possibly due to atmospheric blocking or temperature inversion layers, which is consistent with previous research on the monsoon airflow over the Arabian Sea (AS) during the monsoon season (Rahman et al., 1990; Alapaty et al., 1994).

Kerala, the southernmost state of India faces severe natural disasters due to climate change. Geographically, the state's western portion is covered by the Arabian Sea, and the Eastern part covered by the steep gradient Western Ghats (KPDNA, 2018). Western Ghats influence the climatic patterns of Kerala. These mountains block the moisture-laden southwest winds. This leads to heavy rainfall on the windward side and the leeward side gets very little rainfall, creating a rain shadow effect. This mountain barrier leads to the convergence of moisture. It also causes variations in precipitation. These climatic changes are affecting the ecosystem and agriculture of the region (Yesubabu et al., 2024). During the southwest monsoon season, the windward side receives more than 75% of rainfall, and at the same time, the eastern parts of Western Ghats (leeward side), including Attappady, Marayur, and Chinnar, and the neighboring states receive very little rainfall, facing the rain shadow effect. This rain shadow effect has positive and negative impacts on Kerala. The lower rainfall affects groundwater levels as a result of reduced river flow. During the dry season, this area faces a shortage of water for drinking and irrigation purposes. Variation in rainfall creates a distinct ecosystem in Kerala, ranging from rainforest in the Western portion to scrub and thorny forest in the eastern margin of the rain shadow area. The goal of the current study is to advance theoretical knowledge of the rain shadow mechanisms development in the Western Ghats, namely in the Attappady Hilly regions, while taking topo climate and microclimate concepts and principles into account.

1.4 Conceptual Base: - Rain Shadow Induced Land Degradation

Land degradation is a complex process which involves both the natural ecosystem and the socioeconomic system, among which climate is one of the dominant driving factors. (Zhihui Li et al, 2015). Climatic variations are one of the major factors contributing to land degradation (Sivakumar 2010). Rainfall has the most impact on the weather variable that determines which regions are prone to land degradation and potential desertification. Rainfall is necessary for plant growth and establishment, but the unpredictability of rain and temperature influences where plants live are necessary in determining how soil forms and evolves over time. Rain also influences how much plants develop, which influences where and when animals are grazed and sustains a nomadic lifestyle. As declining annual rainfall is experienced, vegetation cover becomes less dense and fragmented. Typically, high temperatures and low rainfall in a region result in poor organic matter production and rapid oxidation. Low organic matter results in poor aggregation and low aggregate stability resulting in high potential for land erosion and land degradation. Unchecked over a period of time, this land degradation may result in desertification. The interaction of human activity with the distribution of vegetation by land management practices and apparently harmless rainfall events could render land more susceptible to degradation. These susceptibilities were further enhanced when the potential for climate change was added. Drought is also a frequent occurrence in the rain shadow regions resulting from a lack of precipitation resulting in a lack of water for some purpose or for some people. It is the result of a decrease in the quantity of precipitation over a long period of time, typically a season or longer in duration, typically complemented by other climatic factors such as high temperature, high winds and low relative humidity that may add to the severity of the event.

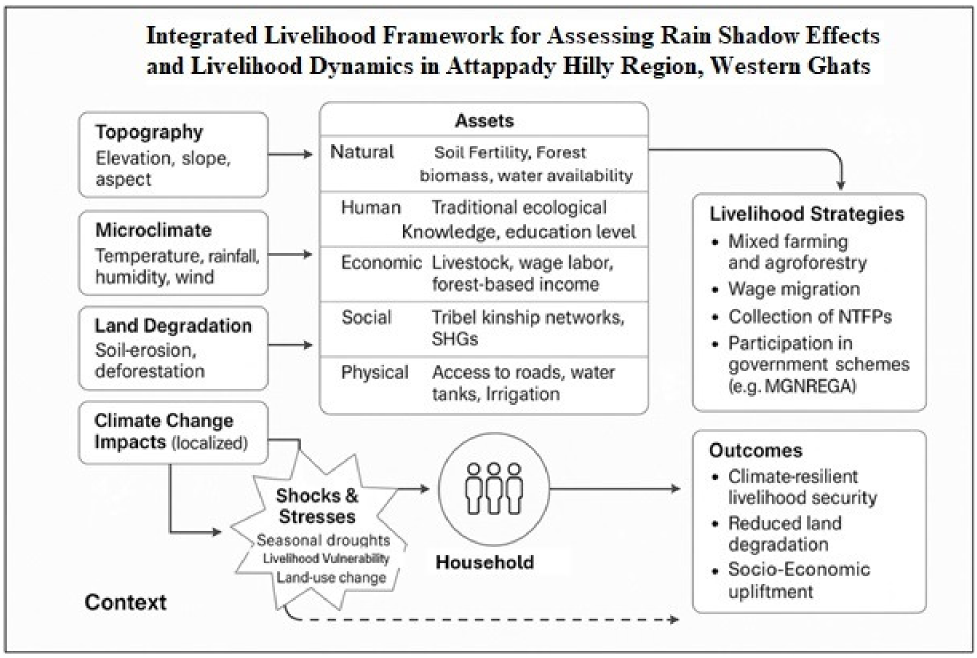
Attappady taluk straddling the ecological divide between the region of orographic precipitation to the west and the rain shadow to the east. Drought is a regular phenomenon in the eastern part of Attappady due to low rainfall. The process of deforestation, low rainfall, cultivation on steep slopes, over-grazing, and change in land use and land cover with the influx of non-indigenous settlers have badly affected the soil quality of this region and led to land degradation in Attappady. In the light of the concepts of the climate induced land degradation process, the research endeavours to evaluate the contribution of the rain shadow mechanism to the occurrence and intensification of land degradation process. The hilly region of Attappady is chosen for the experimental evaluation, and the processes are carried out at ground level.

1.5 Conceptual Base: - Climate Induced Land Degradation and Rural Livelihoods

The climate-induced rain shadow effect in the leeward side of a mountainous area significantly influences livelihoods, especially in areas where people mainly depend on agriculture as the main source of income. In such a region, the inhabitants mainly depend on rainfall-based agriculture. Failure of monsoon or inadequate rainfall in this region makes them vulnerable. This unprecedented rainfall variability is one of the major issues faced by the rural communities. Due to high variation in the amount of rainfall, the soil moisture and nutrient potential is affected, resulting in very low yields and farmers get less income from agriculture. Subsequently, the lower crop yield and economic losses disturb the farmers, making them more vulnerable, which turns into food shortage, land conversion, and land degradation in an area.

Land degradation is a challenging process caused by both anthropogenic activities and changes in climate. This degradation effect decreases the production capacity of the land and reduces the economic value of the land. In agrarian communities, land degradation increases the vulnerability of farmers and creates threats to food security in an area. Quantifying land degradation is a difficult one because so many other factors, such as migration, plantation crop cultivation, and unsustainable land use practices, are also directly or indirectly involved in this process, which affects our ecosystem severely. Since Attappady is a rain shadow area, studying land degradation in Attappady is important for understanding the effects on rural livelihoods. Increasing population growth due to the migration of people from the neighboring states and districts is causing significant land degradation in Attappady (Manikandan, 2016). In addition to this, climate change also amplified land degradation across the eastern slopes (leeward side of Western Ghats) of Attappady, further accelerating the loss of soil organic carbon, soil humus content, and other important soil quality components. Such a soil quality loss has reduced crop production and increased land deformation, including siltation and soil erosion (Manikandan et al., 2016).

Microclimate change over the eastern part of Attappady, especially from Mukkali, has had a severe impact on land degradation. The land conversion, deforestation, shifting cultivation, and loss of fertile land have resulted in soil moisture stress, water stress, and ecological imbalance (Fig.1.1). The degradation of land in Attappady has reduced agricultural productivity. Traditional food crops such as ragi, cholam, and other millets are replaced by cash crops of coffee, turmeric, pepper, and arecanut. These cash crops are changing food habits and creating malnutrition and food insecurity among tribals. Due to land degradation, farmers get less agricultural production, which leads to severe economic stress, eventually forcing them to convert land from cultivation of food crops to other purposes. Forests are increasingly being cleared for agricultural purposes, leading to rapid topsoil erosion and heightened vulnerability to landslides. These degradational effects create a profound impact on the socio-economic conditions of local communities (Kemalo Abdulmalik and Israel Zewide, 2021). Lack of rainfall and land degradation have increased the vulnerability of communities to food insecurity and economic distress. (Gina Ziervogel and Rebecca Calder, 2003). As the quality of agricultural land has diminished, the tenants have been forced to migrate and find other alternative livelihoods. These transformations have increased poverty, malnutrition, increased infant mortality rate, and economic instability in Attappady (Richard Scaria, et al., 2013, Sujith. A. V et al.,2014 and Manikandan. et al., 2016). Land degradation further increases social inequalities and difficulties in accessing the basic facilities of education and healthcare. In that context, this study assess livelihood matters of the people of rain shadow affected regions and prepares sustainable policies and programs to resolve the climate change induced threats.



Source: Prepared by Researcher

Fig. 1.1: Livelihood Framework

1.6 Significance of the Research Problem

Poor and vulnerable communities are often facing the impact of climate change, especially those who are completely dependent on agriculture and natural resources as their means of livelihood (Piya et al.,2019; Odufuwa et al., 2012). When environmental problems get intensified, many people from rural areas are forced to move away from their traditional farming practices and search for alternative sources of income in other areas for their survival (Piya et al., 2019). In the academic and research area, the rain shadow effect is lesser studied, yet it is important research area in the microclimate phenomena. When near-saturated maritime air is forced to rise and confronted by a coastal mountain barrier, mountains reduce the water holding capacity of rising air by enforced cooling and can increase the amounts of cyclonic rainfall by retarding the speed of depression movement. Rainfall amount increases where mountains are parallel to the coast, as it is in the Western Ghats. As air moves down the leeward side of a mountain, it gets compressed and warms up. This warmed wind stops condensation and ceases precipitation. As a result, rain shadow effect form where little rain falls (Waugh. D, 1995). This rain shadow effect increases the aridity, reduce agricultural production, and disturb the ecological balance. This relationship between rain shadow conditions and changing climate patterns shows a serious threat to food security, sustainable livelihoods, and rural ecosystems. From this, anyone can understand that an understanding of localised climatic change is very important for designing effective mitigation strategies and assuring the long-term adaptability measures of affected communities.

Attappady region is located in the Western Ghats of Kerala. It is a semi-arid region characterized by considerable climatic variations from west to east. The geographical extent of Attappady Taluk is 829.45 Km^2 and extends over three Panchayats; Agali, Pudur, and Sholayur, bridging the ecological gap between orographic precipitation regions to the west and rain shadow to the east. The average annual rainfall in the western part of Attappady is 2084 mm, whereas the eastern part receives only 839 mm. This stark difference in rainfall contributes to the water scarcity issues in the eastern region. Drought is a regular phenomenon in the eastern area, significantly impacting on the livelihoods of local communities. In Attappady, top-soil erosion by the dry windblown from west to east and runoff water from various springs and streams play a major role in land degradation

(Manikandan and Kurian, 2016). Indigenous people of Attappady, such as Irulas, Mudugas, and Kurumbas rear goats for their livelihood. But these practices face a threat due to the limited availability of grasslands and frequent drought conditions. Due to overgrazing, topsoil has been removed, which increases the vulnerability of the land to erosion and poses a serious threat to the ecosystem of Attappady. In addition to this, deforested slopes and the variations in microclimatic conditions accelerate soil degradation. This soil degradation create threat to farmers, especially the indigenous people who face a lack of access to modern agricultural techniques and sustainable development practices.

The socio-economic conditions of Attappady are closely associated with the climatic and environmental factors. In recent times, crop productions in Attappady have been drastically decreasing due to the variations in the microclimate. As a result, the income from agriculture is declining, and farmers feel that traditional agriculture is becoming unprofitable. Increasing population due to migration has also accelerated land degradation, which has forced the people to change their economic activities from food crop cultivation to other activities. They also face socio-economic marginalization (Manikandan and Kurian, 2016). The indigenous communities in Attappady earn income by collecting forest products, such as honey, medicinal roots and leaves. Various private and government bodies, including cooperative societies, extend their helping hand to support and sell their forest products (Alex and Vidyasagaran, 2016). Even though people are getting support from the cooperative societies, climate constraints and land degradation create a major challenge to these indigenous communities.

From these perspectives, this research tries to explore the connections between the nature of topography and its influence on climate variations. This study also analyzes the impact of climate-induced land degradation and its negative effect on the livelihoods of the indigenous communities through the application of geospatial technology and intensive fieldwork. Based on the detailed analysis of soil quality and land degradation, this study provides a detailed report of the study area. This report will provide a comprehensive plan for sustainable resource management and empowerment of people's socio-economic conditions.

1.7 Research Question

The basic research question of the study is: how rain shadow has evolved, what are the factors that aid to the occurrence of rain shadow phenomena, how can we delineate this rain shadow region, and what is the impact of rain shadow effect on the land and livelihood of Attappady?

The following are the major research questions of this research.

1. How do Attappady evolve as a rain shadow region in the eastern part of Western Ghats?
2. What methodology can be used to accurately delineate the rain shadow region in Attappady?
3. To what extent does the rain shadow influence the processes of land degradation and livelihood dynamics of the people of Attappady?
4. Are there any livelihood challenges faced by the people living in the Attappady rain shadow region?
5. What are the resilience measures needed for practical solutions to the challenges faced by the people of Attappady

1.8 Objectives of the study

The following are the major objectives of the study:

- To demarcate and map the rain shadow areas of Attappady hilly region.
- To develop a model and theoretical framework of the developmental phases of the rain shadow mechanism in the Attappady hilly region.
- To assess the intensity and severity of rain shadow induced land degradation in the Attappady hilly region.
- To evaluate the physical and chemical properties of soils and assess its impact on cultivated areas in the Attappady hilly region.
- To examine the livelihood dynamics and challenges in the rain shadow affected areas of Attappady.
- To recommend and suggest sustainable land management practices for the mitigation and resilience for the rain shadow affected regions of Attappady.

1.9 Methodology

This methodology section tries to explore the rain shadow effect and analyse how this rain shadow effect shapes the microclimate, land, and human life in the Attappady hilly region. This study applies geospatial techniques on rain shadow mapping, analyse climate related land degradation, appraise soil quality, and investigate the challenges faced by local livelihoods. Based on these findings, this study tries to suggest a sustainable solution to manage and improve the environmental and living conditions in the rain shadow regions of Attappady. To clearly mark the rain shadow zone, ten important map layers are used. This included information about rainfall, height of the land, wind speed, temperature, humidity, land use, vegetation, and soil moisture. All these layers are arranged in a logical framework using AHP techniques and to divide the area into dry and wet parts. Ground station data also helped in comparing rainfall and temperature across different areas.

For studying land degradation, various factors are considered, such as slope, amount of rainfall, how much groundwater is available, type of soil, drainage, and how roads and land use affect the area. Soil samples are collected from 28 places where the land is in poor condition. Only the top 15 cm of soil is taken for testing. These results are then used to create maps using QGIS software to show where the soil quality is better or worse. Through this step-by-step method, the study could find out how the natural landscape and human activity have affected the land and climate in the rain shadow zone. Detailed methods and techniques have been given in the respected chapters. Data sources, methodology and their purposes are given in table no 1.1 below.

Attappady hilly region is selected as a research area that is located on the eastern slopes of the Western Ghats in Palakkad district, Kerala having a unique terrain, climate, and livelihood. This study area experiences an exclusive rain shadow effect with the western part receiving heavy rainfall whereas the eastern part remains dry, which influences agriculture, vegetation, and livelihoods of Attappady hilly region. To study these aspects, maps and data are collected from various sources. Base maps and primary study area information are collected from Survey of India topographical maps (1:50,000 scale), Geomorphology and geology data vectorized from Palakkad district Mineral resource map (1: 2,50,000). Soil data are downloaded from http://kslublris.com/. Climatic data is downloaded from www.imdpune.com. ASTER Digital Elevation Model (DEM) with 30-meter resolution data is used to derive elevation profiles such as slope, relief, aspect, topographic wetness index and understand topographic features of the area. From this data, we can gain the geographical backgrounds of Attappady in a comprehensive manner. This information also helps to understand the challenges of land degradation, climate variability, and development issues faced by the people of Attappady discussed in the following chapters. Furthermore, each analysis chapters include the detailed descriptions of the materials and methods adapted for the present research. Therefore, short narratives of the methodology is only discussed in the following paragraph.

1.9.1 Materials and Methods for Rain Shadow Zone Modeling

Modelling of microclimate variability and analyse the effects in Attappady shows how the changes in climate are connected to the landscape of Attappady, especially from the windward to the leeward side. The main aim is to understand variation of temperature, rainfall, elevation, wind speed, humidity, and vegetation from west to east and to investigate the differences in the climatic variables form the rain shadow effect. These climatic data affect water availability, plant growth, and overall environment in the Attappady hilly areas. In this study, climate data such as temperature, humidity, and wind speed are downloaded from the NASA Power Data Access website. Rainfall data from 1981 to 2023 are also collected from the Indian Meteorological Department. Vegetation data is measured using NDVI indices. NDVI is calculated from Sentinel-2 satellite images through Google Earth Engine. These data are processed using QGIS and ArcGIS tools. First, all the climate data are changed into point data showing the values at each location. To understand how values change from one place to another, the IDW method is used to create smooth maps. To understand the variation from West to East, a sample line is drawn from Ponnani to Coimbatore, across the Attappady region. Points are placed at every 100 meters along this line, and climate values were collected for each point. These points are saved in a CSV file for further study. The collected data was then used to find the relationship between elevation and each climate factor using correlation and regression methods. This helped to identify how the climate changes from the windward to the leeward side. To see the trend in temperature and rainfall over time, the Mann-Kendall test is used. All this information helps in understanding how microclimate changes in Attappady and how it shapes the rain shadow region.

1.9.2 Materials and Methods for Rain Shadow Demarcation

To map this dry region correctly, the study used both ground-level and satellite-based data. Weather stations in Mannarkkad and Coimbatore provide a local level information of rainfall, and temperature. The rain shadow zone delineation in Attappady is a complex process that requires the integration of both ground based and satellite derived climatic and ecological data. To accurately demarcate the rain shadow region using geospatial technology, ten thematic layers were included: Rainfall, Elevation, Wind Speed, Relative Humidity, Temperature, Land Surface Temperature (LST), NDVI, Land Use/Land Cover, Soil Moisture Index (SMI), and Temperature Vegetation Dryness Index (TVPDI) derived from Landsat 8 OLI data. Using IMD data, rainfall and temperature variations were analyzed between wet and dry zones, allowing for the distinction of climatic zones within the study area.

To bring all these factors together, a method called AHP (Analytical Hierarchy Process) is applied. This method helps to give importance (or weight) to each factor. For example, rainfall and temperature are given more importance, because they directly affect whether an area becomes dry. By integrating all the data together and giving proper weight to each factor, a clear map of the rain shadow region in Attappady was drawn. This map will help in future planning by deciding where to grow crops, how to manage water, and how to protect natural resources in this sensitive region.

1.9.3 Materials and Methods for Land Degradation Assessment

This part of the study focuses on understanding how land is degraded in Attappady, especially due to changes in climate and human activities. Since Attappady lies on the drier side of the Western Ghats, it receives less rainfall than the western parts of Kerala. Because of this, the area often faces droughts. Along with this, deforestation, farming on steep slopes, overgrazing, and the arrival of non-tribal settlers have made the land weak and dry. These changes have badly affected the soil, making it less fertile and more prone to erosion. The tribal communities who live here are the most affected. They face poverty, food shortage, and health problems because the land they depend on is no longer productive.

To understand this situation, the study used various tools and data. Information is collected about the slope of the land, rainfall, groundwater, soil conditions, land use, road and drainage networks, vegetation, and more. These details are collected from different sources of government departments, satellite data, and maps. Each of these factors plays a role in causing land degradation. So, a method called the Multi Influencing Factor (MIF) technique is used. This method helps to find out which factors are more important and how they are connected to each other. Each factor is given weight based on how strongly it affects land degradation. For example, steep slopes and poor soil may have a bigger impact than road density. The values are calculated step by step and put together using a formula to prepare a land degradation map of the area. By using this method along with GIS (Geographic Information System) and satellite images, the study can identify the areas that are most affected by land degradation. This helps in understanding the severity and spread of the problem. The findings can support better land use planning and help protect the environment and livelihoods in Attappady. This study is important because it shows how both nature and human actions are causing long-term damage to the land, and how we can use scientific tools to study and manage it better.

1.9.4 Materials and Methods for Land Use and Land Cover (LULC) Mapping

In recent decades, land use changes in Attappady have accelerated deforestation, especially in higher altitudes, severely affecting the local environment. Forests, which are considered the most sustainable land use system due to their role in maintaining ecological balance, are being cleared extensively. This deforestation makes the region more susceptible to the impacts of the rain shadow effect. Additionally, intensive farming in these areas has resulted in increased soil erosion, sedimentation in water bodies, and the leaching of harmful agrochemicals into rivers and groundwater.

The conversion of evergreen forests and grasslands into agricultural fields, particularly within the rain shadow zones, is a significant contributor to environmental degradation. Such land cover changes release stored carbon into the atmosphere, exacerbating global warming. Moreover, these alterations in vegetation affect the region's energy and water balance, accelerating the degradation process. Hence, understanding land use and land cover dynamics is crucial for assessing the extent and impact of land degradation in Attappady.

To generate the Land use and land cover information, various data including Landsat imageries, sentinel-2 data and Survey of India topographical maps are used. The seven-fold classification approach of the National Remote Sensing Centre (NRSC) Level 1 is used. Before creating land use data, the data underwent some preprocessing, such as preparing multispectral data (30 metre) with the use of the band composite tool and then converting the multispectral data to 15 metre resolution data using the ERDAS Imagine platform's resolution merge analysis. Here, 15 PAN data and 30 metre multispectral data are combined, and the 30 metre multispectral data is then transformed to 15 metre data with the help of PAN sharpening (15 metre resolution) by applying resolution merge. After converting the satellite data, classification of land use is done using different methods. Supervised classification techniques like Parallel Piped and Maximum Likelihood methods are applied. In addition to this, machine learning-based classification methods are also used. These methods helped to classify satellite images taken at different time periods 1970, 1990, 2005, and 2024. This allowed for a clear comparison of how land use has changed over time in the region.

1.9.5 Materials and Methods for Soil Quality Assessment

The rain shadow effect on Attappady has a strong influence on soil quality, mainly by reducing rainfall. This affects soil moisture and the availability of essential nutrients in the soil. This lack of water weakens the soil and makes it less suitable for farming. At the same time, land degradation caused by deforestation, overgrazing, and unplanned land use changes have further affected the soil. When forests and natural lands are cleared up for farming, the soil loses its natural strength and fertility. To understand the soil quality is therefore important not only for improving agriculture but also for addressing the environmental and social challenges faced by local communities. To assess soil conditions in the Attappady, 28 soil samples are collected from various land use types. All collected samples are taken from the top 15 cm of soil and stored in clean bags. In the field, the samples are cleaned, then gently broken down by hand and air dried. After drying, the soil is crushed with a mortar and pestle and sieved through a 2 mm mesh and make it uniform for testing. These samples are then tested in the lab for various physical and chemical properties, such as pH, electrical conductivity (EC), and the presence of nutrients of boron, magnesium, and potassium, following standard procedures. To understand the soil quality across the region, the results are mapped using an Inverse Distance Weighting (IDW) method in ArcGIS. These maps help to identify the difference in soil health from one area to another, especially in degraded parts of Attappady, and provide the support to manage land and soil more effectively.

1.9.6 Materials and Methods for Socio Economic Analysis

In the rain shadow region of Attappady, most people depend on farming for their daily living. But over the years, their land has become less fertile, and the rains have become more unpredictable. This has made it difficult for them to grow enough food or earn a steady income. Many tribal families are now facing poverty, poor health, and even malnutrition. Some have been forced to leave their villages in search of work elsewhere. The changes in the land and climate have added more pressure to their already difficult lives. In many cases, people do not even realise their land is slowly getting worse. Deforestation, burning of forests for farming, and lack of proper land care have made the soil become dry and weak. Water sources are also drying up, and farming is becoming difficult every year. Therefore, this study tries to understand how local people see these changes and analyse how land problems caused by less rain are affecting their farms and daily life. This study also tries to investigate their experiences and their local knowledge to find better ways to take care of the land and improve their livelihoods. This study is carried out in the three main villages of Agali, Pudur, and Sholayur. The main details collected from the people were about their farming, income, problems they face, and how they feel the land and climate have changed over time. The information is collected by visiting homes, talking to families, conducting group discussions, and transect walks to understand what is happening in the field. A total of 384 households is chosen for the survey. Families are selected randomly from each village to make sure the results represent the whole population. A simple questionnaire is used, which is first tested with few people to make sure the questions are easy to understand. After careful examination and updation, a rollout survey is conducted in the entire villages. Their answers helped to improve the final version. The collected data are carefully checked and analysed in the SPSS software. The information derived from the people in Attappady helped to understand the people’s struggle with land degradation and changing weather. This study hopes to bring out their voices and help plan better future for them.

1.9.7 Tools, Techniques & Data Sources

This study mainly focused on understanding the environmental and livelihood challenges in the rain shadow region of Attappady, located in the Eastern part of the Western Ghats. Its main aim is to explore how the rain shadow effect influences local climate, land, and people's lives. This study mainly analyse land use changes, soil quality conditions, and its impact on farming and daily life. To get a better picture of the area, the research team walked through different parts of Attappady, observing the land closely. During the field visits, important locations are marked using handheld GPS and mobile-based Q Field app.

Local people's views are gathered through simple tools of interviews, group discussions, and surveys. These methods help to understand their daily struggles and how they cope with changes in the land and weather. Different tools are used to study maps, rainfall, temperature, land use, and other changes over time. Software such as ArcGIS, QGIS, and Google Earth tools are used for mapping and analysis. For studying patterns in people’s responses and basic statistics, SPSS is used. Data analysis is also carried out by coding methods.

The data used in this study came from many sources (table 1.1). Satellite images from Landsat and Sentinel helped study changes in greenery, land use, and altitude. The ASTER elevation model and Survey of India maps gave a base layout of the area. Rainfall and temperature data are taken from IMD Pune, while wind speed and humidity are taken from NASA’s climate platform. TRMM satellite data helped understand rainfall in more detail. Soil samples are also collected in the field to check soil quality and verify changes in land use. Information about people’s population, education, and communities is collected from the Census of India (2011). Most importantly, the opinions and life experiences of the local people are recorded through simple methods. By combining all these sources and approaches, the study is able to give a full picture of the problems and possibilities in Attappady's rain shadow region.

Table 1.1: Data Sources used for the Study

Sl.No	Data Type	Name	Source	Purpose
1	*Spatial data*	Landsat 5,7,8, and 9	www.earthexplorer.com	Support to generate vegetation conditions, LULC variations, and elevation related information to analyse the impact of rain shadow effect in Attappady
2		Sentinel 2 Data	www.copernicusdatahub.com	
3		ASTER DEM	www.earthdata.org	
4		Survey of India topographical maps (1: 50,000)	https://onlinemaps.surveyofindia.gov.in/	Generated base layer for Attappady
5		Rainfall & Temperature Data (17 km resolution)	www.imdpune.com	Helps to modelling and demarcate rain shadow region in Attappady
6		Windspeed, relative humidity	https://power.larc.nasa.gov/	
7		TRMM data (Rainfall (4 km Resolution)	www.earthdata.org	
8	*GPS Data*	Soil quality Sample Land use land cover Sample	Field Survey	Assessment of Soil Quality. Investigation of Land Degradation and Validation for LULC
9	*Non Spatial Data*	Demographic Details	https://censusindia.gov.in	Literacy, Population, Scheduled Caste and Scheduled Tribe for 2011
10		*People's perception data*	Questionnaires Survey Interview Focus Group Discussion Transect walk	Livelihood Assessment in the rain shadow region of Attappady

Source: Prepared by Researcher

1.10 Chapterization of the Study

The thesis is titled as "**An Appraisal of Rain Shadow Effects and Livelihood Dynamics in the Attappady Hilly Region, Western Ghats, Kerala**". This research is organized into nine chapters. Chapter one lays the foundation for the research by presenting the design of the study, which integrates climatic, microclimatic, and topo climatic perspectives relevant to the Attappady rain shadow region. This chapter then narrows its focus to the specific geographical and climatic context of the study area, offering a detailed understanding of topo climate and the unique characteristics of the rain shadow effect in the Western Ghats. It further explores how this climatic phenomenon contributes to land degradation and influences rural livelihoods, particularly in fragile hill environments like Attappady. The significance of the research problem is clearly articulated, followed by a set of research questions and specific objectives that guide the study. This chapter also outlines the data sources, tools, and techniques employed, as well as the overall methodological framework, including data collection strategies. This chapter concludes by introducing the structure of the thesis through a brief chapter wise organization, setting the stage for the detailed analyses that follow.

Chapter two presents a comprehensive review of literature, which plays a crucial role in shaping the foundation of this research. It aims to identify existing knowledge, explore new perspectives, and pinpoint gaps that this study intends to address. The review draws from a wide range of sources, including scholarly research articles, academic books, and newspaper reports at regional, national, and international levels. This chapter is structured around key thematic areas that are central to the study, namely: Topography and Climate with a special focus on the rain shadow phenomenon; Climate dynamics in the Western Ghats; Land use patterns and environmental concerns; the relationship between rain shadow regions and land degradation; land conversion and its impact on soil quality; and the intricate links between rain shadow zones and livelihood dynamics. Through this review, this chapter not only conceptualizes the study within the broader academic discourse but also provides insights into relevant data sources and methodological approaches, thereby reinforcing the relevance and originality of the research.

Chapter Three offers a detailed geographical profile of the study area, providing essential contextual understanding for the research. It outlines the location and administrative divisions of Attappady, followed by an analysis of its physical landscape, including relief features, slope characteristics, geomorphology, and underlying geology. Chapter three mainly documents the different geographical properties of Attappady. This chapter includes geographical position, administrative division, drainage system, relief characteristics, lithology, landforms, soil, and demographic characteristics. This study also incorporates natural vegetation types and their spatial distribution with the help of available spatial data sources such as 1:50,000 topographical maps and various satellite images. These datasets are the important input for various evaluations, including demarcation of rain shadow, analyzing land degradation, and estimating soil quality in the study area.

Chapter four deals with the rain shadow demarcation in the Attappady hills of the Western Ghats, Kerala. With the help of geospatial techniques and the support of various spatial data, this chapter precisely separates the dry region (rain shadow) and wet region in Attappady. From this analysis, we can understand the reliability of geospatial techniques by incorporating with Analytical Hierarchy Process (AHP) statistical method to demarcate the rain shadow region in Attappady. Different climatic variables and physiographic variables are included to demarcate the rain shadow region. Some of the important parameters are rainfall, temperature, wind speed, relative humidity, Land Surface Temperature (LST), vegetation conditions, and land use land cover. With the help of the above-given data, this chapter portrays all the climatic and physiographic variables in the form of maps, which show the spatial variation of all data and also illustrate the spatial connections between the factors.

Finally, this chapter precisely demarcates the wet and dry (rain shadow) regions in the Attappady hill region with the help of geospatial technology and AHP techniques.

Chapter five deals with the modeling of microclimate variability and helps to understand its influence on the rain shadow formation in the hilly terrain of Attappady. In the beginning, it deals with the orographic effect of the Western Ghats, and subsequently, the chapter examines the development of rain shadow over the eastern part of the Western Ghats. This chapter also outlines the correlation between elevation variation and corresponding values of rainfall, wind speed, relative humidity, and temperature from west to east. From this chapter, we can understand that there is a high correlation between climatic variables and elevation difference. For the detailed analysis of rain shadow phenomena in the Western Ghats, the selected area has been divided into three blocks from the windward side (Ponnani) to the leeward side (Karamadai). This chapter also deals with moisture transport dynamics with the help of various statistical techniques. With the help of the Mann-Kendall test, this chapter analyses the 70-year temperature and rainfall trend. From these techniques, this chapter portray the influence of the mountain barrier on the climatic variables of temperature, precipitation, wind speed, and relative humidity in Attappady.

Since land degradation is the main problem of Attappady, Chapter Six discusses the climate-induced land degradation in Attappady. To study land degradation and its impact on the environment, this research uses several thematic layers. These include rainfall, drainage density, road density, ground water level, changes in vegetation, relief, slope, and topographic wetness. This study also investigates the relevance of statistical techniques in Land degradation analysis. These data were synthesized and arranged in a logical framework using the Multi Influencing Factor (MIF) technique. Appropriate ranks and weights were calculated, and the final land degradation was generated. This study also tries to correlate the intricate relationship between temporal Land Use Land Cover (LULC) changes and land degradation. The machine learning based LULC reveals the potential land degradation hotspot and its geographical background. This chapter also recommends a suitable sustainable practice to conserve the natural resources and minimize the impact of land degradation.

Land degradation obviously affects soil quality both chemically and structurally. Therefore, chapter seven analyzed the soil quality and investigated the impact of land degradation on soil quality. This chapter outlines an effective method for collecting soil data and identifying the soil quality parameters that must be included in the study. After careful laboratory analysis, the quality data values for the parameters such as pH, Electrical Conductivity, Boron, Manganese, Potassium, Calcium, and Organic carbon have been generated. To create a spatial variation of all these factors, this chapter introduces the Inverse Distance Weighted (IDW) method in QGIS and maps all the data. For a detailed understanding of soil quality and land degradation relations, this study employed Principal Component Analysis (PCA) and generated the Soil Quality Index (SQI). This chapter provides a deep insight of soil quality and the impact of climatic and anthropogenic pressure over the Attappady hilly landscapes.

Chapter eight looks into the livelihood patterns and challenges faced by the people residing in the rain shadow region of Attappady. This chapter also envisages the methods adopted to understand the challenges experienced by the local communities. This chapter reveals the importance of a decentralized, people-oriented approach to document and generate research-oriented data. Some of the important techniques applied in the fieldwork are questionnaire surveys, discussions among the farmer communities, meetings, and interviews conducted among the stakeholders, and data vetting processes have been executed through a transect walk. This chapter also reveals the data processing techniques and explains the problems experienced by people due to land degradation and climate change. Particular attention is given to people’s perceptions of rainfall reduction due to the rain shadow effect. It also analyzed the changes in cultivated land area since 2000. In addition to that, it studies the changes in type of crop cultivation in Attappady. Respondents' insights on how rain shadow-induced climatic conditions have influenced agriculture, land degradation, and soil fertility are analyzed to assess the live realities of environmental stress. Additionally, the study records perceptions of groundwater depletion, the main causes of land degradation, and community-suggested strategies for its mitigation. Through this chapter, the research presents a sound understanding of how environmental changes, especially those linked to the rain shadow phenomenon, shape the socio-economic fabric and adaptive capacity of the people of Attappady.

Chapter Nine presents the summary, conclusion, and key suggestions derived from the study, offering a comprehensive closure to the research. It begins by consolidating the major findings of each chapter, highlighting the interconnected nature of topo climatic conditions, land degradation, and livelihood dynamics in the rain shadow region of Attappady. Building upon this, the chapter offers practical suggestions for the sustainable development of the Attappady rain shadow region. It critically examines the role and effectiveness of various government interventions, including Agricultural Development Programs, Watershed Development Programs, Hill Area Development Programs, and Resource Management Initiatives. Emphasis is placed on the integrated role of these programs in enhancing microclimatic resilience. This chapter also underscores the importance of decentralized community participation for the long-term sustainability of these initiatives.

CHAPTER 2

REVIEW OF LITERATURE

CHAPTER 2

REVIEW OF LITERATURE

2.1 Introduction

A review of literature is a vital component of this research and provides better ways of understanding and solving the proposed research questions and objectives. Any research is conceptualized only with relevant reviews and contextualized only with current reviews. This chapter discusses research papers and scientific books that are aligned with the topic 'An Appraisal of Rain Shadow Effect and Livelihood Dynamics of Attappady Hilly Region, Western Ghats, Kerala.' The literature review is carried out with five major sections with the consideration of the scope of the study: Topography and Climate, Climate and Western Ghats, Land Use-Land Cover Changes and Climate, Rain shadow and Land Degradation, and Rain shadow and Livelihood Dynamics. Each review in different sections is wrapped with basic scientific output and methodology.

2.2 Topography and Climate

Daly et al., (1994) explored climate mapping using the PRISM model, focusing on rain shadows and complex climatic gradients. The study aimed to enhance precipitation and temperature mapping accuracy. The methodology combined point data, digital elevation models, and topographic facets to model climatic variations. A theoretical gap exists in simulating rain shadow effects in coastal regions. Major findings highlighted PRISM's adaptability in handling spatial climate intricacies, including abrupt transitions. However, limitations in accounting for dynamic wind direction and refined proximity grids for coastal effects were noted. The study advanced climate modelling but left opportunities for further refinement.

Gunnell (1997) investigated the role of the Western Ghats in the climate of peninsular India. This study mainly focusing on the role of Western Ghats in rainfall patterns. This study also tries to understand the influence of Western Ghats on the monsoonal climates and the resultant agroclimatic diversity. With the help of statistical and climatic mapping techniques, the author identified a steep east west rainfall gradient and examined bioclimatic variations. This study also found that the Western Ghats act as a climatic barrier and filter. This effect creating a unique climatic condition across the Deccan Plateau. This research is very much important for understanding regional agriculture and biodiversity.

M. M. Miglietta and A. Buzzi (2001) studied the stratified airflow in Gaussian Mountain. The main aim of the study is to understand the orographic precipitation. The study also tries to analyse the role of moisture and its effects on flow regimes using three dimensional numerical simulations. The findings of the research revealed that latent heat release shifts the balance toward "low over" rather than "low around". For the prediction of precipitation, this research suggests a mesoscale meteorological model which incorporates moisture dynamics.

Erickson and West (2002) investigated the influence of climate and nightly weather on the activity patterns of insectivorous bats. The study aimed to understand how climatic conditions affect bat activity across temporal and spatial scales, particularly in rain-shadowed regions. Using bat detectors in the Pacific Northwest, the authors analysed data over multiple years at various sites. They identified a spatial gap in understanding bat activity across diverse microhabitats. Findings revealed that precipitation and temperature significantly influenced activity, with higher activity in drier, warmer areas. This study shows that climate data can help to conservation planning, but the short duration climatic data is inadequate to support it.

Paul J. Neiman et al., (2002) analysed the statistical relationship between windward movement and rainfall in coastal mountains of California. This study selects winter season for the CALJET experiment. With the help of rain gauge station and wind profilers, this study tries to quantify the impact of landfalling low level jets on orographic rainfall. A methodological gap was identified in low resolution studies of windward movements and precipitation. The generated findings revealed that rainfall highly correlates with windward flow at mountaintop levels. This study also finds that maximum rainfall rates occurring at low level jet altitudes. This study draws the importance of low-level jet in improving orographic precipitation and modifying rainfall prediction problems.

Adrian J. Hartley (2003) studied the uplift of Andean Mountain and its influence on climate and land degradation in South America. This study analysed the relationship between Andean elevation and rain shadow effects. From the sedimentological data and paleo-altitude records, this study analysed climatic and tectonic interactions in different geological time. From the result, it is noted that the uplift of the Andes Mountain blocked some of the existing dry conditions. The dry conditions in the Atacama Desert were mainly caused by global cooling and the Humbolt current. The result also says that the rain shadow effect is not the main reason for this aridity conditions. From this research we can understand that there is a complex relation of global and regional factors.

John Houston and Adrian J. Hartley (2003) studied the rain shadow effect in the central Andean Mountain. This study also assesses precipitation patterns and their relationship to elevation. From the precipitation data and elevation correlations, they identified a research gap in understanding the impact of upliftment of Andes Mountain and aridity. The research result revealed a strong exponential relationship between elevation and precipitation in arid zones. It was influenced by summer monsoons, Andes uplift, and the Peruvian Current. This study also explains the effect of rain shadow in the arid landscape.

Qingfang Jiang (2003) studied the relation between moist stratified airflow and mountainous terrain. This study helps to analyse the influence of precipitation patterns such as moist air movements, latent heat, and mountain geometry using a nonhydrostatic mesoscale model. The findings from the research revealed that latent heat delays flow stagnation, enhances upslope ascent, and increase precipitation in the windwards side. In the low mountain areas, precipitation increases with height. High mountains show reduced efficiency due to air flow change. This result reveals the relationship of moisture and terrain variation in precipitation distribution.

Roe, Montgomery, and Hallet (2003) studied how mountain influences the precipitation. They applied a coupled model of river erosion and precipitation patterns to understand this impact. Their aim was to quantify how precipitation patterns influence mountain and feedback mechanisms between topography and climate. Methodologically, they employed a longitudinal river profile model and precipitation parameterization to analyse topographic interactions. The study highlights a literature gap in exploring detailed precipitation-relief feedback. Key findings include the significant influence of precipitation near channel heads on relief and the dual effects of slope and elevation-dependent precipitation. While insightful, the study simplifies climatic and tectonic factors, limiting its real-world applicability.

Brian A. Colle (2004) studied the orographic precipitation through various mathematical models. This study tries to find out the impact of precipitation by mountain height, width, stability, and freezing levels. From the mathematical modelling, this study identified a research gap in terrain induced gravity waves with precipitation distribution. The derived results of the research showed that narrow barriers enhance warm rain processes, while wider and higher barriers increase precipitation efficiency due to extensive orographic clouds. This research also suggests the importance of freezing level and microphysical processes in determining precipitation distribution.

Ronald B. Smith and Idar Barstad (2004) developed a theory for orographic rainfall. This study focused on airflow dynamics, condensation, advection, and downslope evaporation. This study tries to improve precipitation modelling over complex terrains using Fourier transform techniques. The research findings showed that variation in terrain have a strong impact in precipitation distribution. This linear model also helps to understand the rainfall patterns and also support natural resource management in rain shadow regions.

Miglietta and Rotunno (2005) studied the moist neutral movement aspects over a mountain ridge. This study focuses on the modification of orographic movements under saturated conditions. The study also analyse the effects of mountain height and initial cloud water content on atmospheric stability. This research adopted numerical simulations model in understanding the relation between saturated and unsaturated flow management. The results from the study revealed that three flow categories based on mountain height. They are, 1. sustained saturation for small mountains 2. downstream unsaturation with windstorm features for tall mountains, and 3. desaturation disturbances for intermediate heights. This shows a complex process in moist orographic flows.

Sato (2005) investigated the rain shadow phenomenon's role in arid climate formation in the northwestern China using regional climate modelling. This study aimed to determine the influence of the Tianshan Mountains in rainfall distribution. From the comparative simulations with and without the mountain barrier, the author found that while the mountains increased precipitation in the windward side, the arid climate in the leeward areas persisted even without them. This shows a conceptual gap in the study which reveals that other than rain shadow effects some other factors also playing in aridity. The study showed that regional atmospheric subsidence plays a key role in maintaining aridity. This study also helps to understand climate patterns and how they influence desertification.

Idar Barstad et al., (2007) studied large scale orographic precipitation using linear and nonlinear models. This study tries to understand physical processes of moisture advection, condensation, and precipitation. The aim of the study is to analyse the accuracy of a linear model against nonlinear simulations in stable conditions. This study also identifys the methodological gap from the numerical experiments in different ridge dimensions, wind speed, and thermodynamic parameters. The results from this research showed that linear models are best for broad ridges but for narrow terrains it is unfit due to more evaporation in the leeward side. This research explains the microphysics relations and suggesting model improvements for precise predictions.

Qingfang Jiang (2007) studied the major aspects of stratiform precipitation over multiscale terrain. This study mainly focused on the interaction of airflow with two ridge topography. This study analysed the influence of ridges in precipitation patterns. With the help of COAMPS model, this study identified a research gap in wave induced precipitation processes. The results of the research revealed that terrain geometry significantly alter precipitation. This study explained that smaller ridges improves upslope rise and lee waves, which affects rainfall patterns on major ridges. These results explain the role of terrain in hydrological and atmospheric processes and describe the effects of rain shadow.

Colle (2008) conducted a study to identify the effects of windward ridges on orographic precipitation. He applied two dimensional idealized simulations with the MM5 model. This study tries to explore how ridge configurations influence precipitation distribution and microphysical processes. Ridge numbers, stratification, and freezing levels are some of the methodologies applied in the study area. The major research gap identified in this study are the limited real-world applicability of 2D modelling. This study identified an increase in rainfall about 35% in the windward slopes where ridges are closely aligned. This research also points out that the need for 3D modelling as well as field validations is essential in accurate rainfall predictions.

Heather Dawn Reeves et al., (2008) analysed mesoscale variability in heavy precipitation events in Sierra Nevada Mountains of California. This study helps to identify the factors triggering precipitation increase. With the help of numerical simulations and mesoscale model, this research provides an understanding of terrain influences on precipitation distribution. From this research, we can understand that windward moisture inclines and mesoscale terrain features affect rainfall significantly. This research also reveals that precipitation mainly depend on vertical movement induced by terrain. This study explains the interaction between atmospheric variables and terrain influence in the event of heavy precipitation.

Joseph Galewsky (2008) studied the processes governing orographic clouds in terrain blocked movements. This research mainly focused on the interplay of flow parameters such as Nh/U, aspect ratio, and rotation effects. This study tries to understand cloud formation in blocked flows through a numerical model. The major findings of the research revealed that higher Nh/U values reduce cloud formation over mountains ridges. At the same time, they increase condensation on the windward side. Moreover, this research suggest that terrain aspect ratios significantly influence the spatial distribution of clouds. This study also revealed the complexity of terrain blocked movements and their impact on hydrological cycles.

Joseph Galewsky (2009) studied the rain shadow development in the mountain range. This study shows the interaction between atmospheric aspects and topography. This study tries to explore the influence of atmospheric flows in rainfall and aridity patterns. This study also shows an idealized atmospheric model. This research also showed a gap in understanding the link between geological aridification records and atmospheric processes. The results of the study revealed that rain shadow effect mainly depend on mountain relief and atmospheric stability. This study also demonstrating the non-linear relationship between relief and rain shadow intensity. This result also proposes the need for integrating atmospheric models in geological studies.

Mimi R. Abel, Alex Hall, and Robert G. Fovell (2009) analysed the influence of orographic blocking on rainfall distribution in Southern California. This study includes the data having 6 km resolution for regional climate simulation. This study helps to evaluate the role of bulk Froude number variations in determining precipitation patterns. The results found that low Froude numbers were linked to blocked air movement leads to more even and widespread rainfall. Whereas high Froude numbers caused low rainfall due to elevation. This research also explains the limitations of linear models in blocked orographic precipitation.

Jessica D. Lundquist et al., (2010) studied orographic precipitation in the northern Sierra Nevada. This research evaluates the relationship with barrier jets and streamflow. This study also helps to understand the Sierra barrier jet influences on orographic variations. This study includes observational data, linear models, and precipitation records for one decade. This research found that the Sierra barrier jet height affect orographic precipitation significantly. Precipitation at higher elevations leads to flood and snow storage. This result representing the need for integrated hydrological models to analyse the annual precipitation variations with respect to atmospheric dynamics.

Paul J. Neiman et al., (2010) studied the climatology of the Sierra Barrier Jet (SBJ) in northern Sierra Nevada of California. The study tries to analyse SBJ changing aspects, seasonal variability, and their impact on precipitation distribution. This study used wind profiling and precipitation data. The study identified a temporal gap in understanding SBJ related precipitation impacts over a longtime. The research findings revealed that SBJs occur mainly during the cool season, which affects about 60% of regional precipitation and shifting rainfall downslope. This study also represents stronger, longer-lasting SBJs correlated with higher precipitation rates and helps hydrological management.

Adlakha et al., (2013) studied erosion in the rain shadow region of Shillong Plateau. The study tries to find the interactions between climate, erosion, and tectonic movement. This study also assesses the rainfall erosion rates and the contact of erosion to the deeper rocks. They examined cooling patterns by applying fission track thermochronology. This research identify erosion rates did not correlate with climatic conditions revealing a research gap. The major findings revealed that increasing erosion rate was caused by fault movement, not by changes in rainfall. This research also revealed the complexity of climate and tectonic links and suggests tectonic factors dominate to erosion in this region.

Sanchez-Moreno et al., (2013) examined the impact of topography on rainfall variability on Santiago Island, Cape Verde, focusing on its spatial and temporal influences. The study aimed to analyse rainfall patterns influenced by elevation, slope, and geographical position using multivariate regressions and kriging interpolation methods. A significant spatial gap was identified due to uneven rain gauge distribution. Findings revealed that moderate rainfall correlates well with elevation, while extreme events are less topographically dependent. Despite advancements in mapping methods, variability and insufficient monitoring stations limit accurate rainfall characterization, highlighting the need for enhanced data collection in coastal areas.

Harikishan et al., (2014) studied cloud microphysical and macro-physical properties in the rain shadow region of Mahabubnagar. This study tries to understand cloud dynamics in monsoon.

With the help of ground-based radiometers, and collected cloud optical depth, liquid water path, and droplet effective radii. This research identifies clear seasonal changes with lower amounts of liquid water and reduced cloud thickness during the post monsoon period. This study also revealed aerosol and cloud interactions in cloud formation. This study also suggests the need for spatially refined ground measurements in tropical climates.

Narkhedkar et al., (2014) investigates the rainfall mechanisms in the rain shadow region of North Peninsular India. The main aim of the study is to understand the role of dynamical, thermodynamical, and microphysical processes in the rain shadow region. This study identifies factors such as high aerosol content, limited cloud growth, and low cloud droplet radius are the main inhibitors of rainfall. This research also describes a spatial gap in understanding mesoscale phenomena specific to the region. To solve the drought conditions, this study suggests cloud seeding methods.

Harikishan et al., (2016) analysed the relationship between aerosol and cloud in Mahbubnagar, a rain shadow region of India. This study also attempts to quantify the aerosol indirect effect (AIE) on cloud microphysics during monsoon and post monsoon periods. This study used ground-based instruments and aircraft observations. From the data, the study revealed a temporal gap in AIE understanding for such regions. From the study, we can see an increases of AIE with liquid water path, reaching a maximum at high supersaturations. Due to the influence of AIE which significantly influenced rainfall deficiency through reduced cloud effective radii and suppressed precipitation processes. This study also suggests the need for observations in the study of complex aerosol cloud interactions in arid zones.

Lauren B. Wheeler (2017) studied atmosphere and mountain relations to improve stable isotope-based paleo-altimetry. This study analyses the isotope limitations based on elevation modernisations. This study also focusing on flow deflection and lapse rates. With the help of numerical simulations, WRF model and paleo data comparisons, this research identified a research gap in atmospheric movements and isotopic lapse rates. The result of the research showed that atmospheric movement impacts leeside isotopes. These results emphasize that isotopic models are most dependable for simple terrains with less climatic difference.

Rani Bhagat, V. B. Shimpale, and R. B. Deshmukh (2017) studied floristic diversity and conservation in Baramati, a rain-shadow area in Maharashtra. The research aimed to create an inventory of plant species and assess conservation needs of rare and endangered species. Through extensive surveys and herbarium consultations over five years, they documented 938 species, identifying new state and science records. A key research gap is the lack of temporal studies linking human activities to habitat loss. Findings highlight the area's unique xerophytic flora, with conservation urgency for endemic and critically endangered species like *Eriocaulon baramaticum* under anthropogenic threats.

Carolyn L. Gleason (2018) studied groundwater flow and its ecological impact in the rain shadow region of Panamint Range in California. This study attempts to identify the sources of groundwater recharge and flow paths, by applying stable isotopes, geochemical tracers, and environmental data. The result of this study revealed high elevation snowmelt act as a dominant recharge source and carbonate units as a primary aquifer. Groundwater flow times significantly varied which influenced the spring ecosystems. This research revealed the relationship between hydrogeology and ecology. The findings of this research show the importance of resource management in arid landscapes and ecosystems dependent on springs for their survival.

Djordje Grujic et al., (2018) examined the impact of the Shillong Plateau's uplift on rain-shadow formation and precipitation patterns in Bhutan's Himalayan foreland. Their goal was to analyse the isotopic composition of paleo soil clays to reconstruct paleoclimate changes. This study applied an isotope analysis on clay minerals in Siwalik sediments. From the result, it is observed that Shillong's elevation is the main reason for rain shadow effects. This rain shadow effect reducing precipitation from the historical past. This effect reveals tectonic and climatic interactions plays a major role in land degradation and their primary activities.

Jubuli Sahu J. L et al., (2018) studied rainfall-based crop planning in the rain shadow districts of Rajnandgaon and Kawardha in India. This study analyses rainfall variability and its effects on crop productivity using long term rainfall and crop data. This research used Mann Kendall test for trend analysis in Weather Cock software. This research helps to understand rainfall variations and its effects on crop planning. The result derived from the research are high rainfall occurred during the southwest monsoon (June-September), and significant variations identified in the remaining months. This study also finds the increasing trends of rice and gram productivity in the study area.

Damseaux et al., (2019) analysed the effect of rain shadow in Patagonia. This study focusing on the impact of Digital Elevation Model (DEM) in climate simulations. This research tries to improve the accuracy of localised climate models by including Foehn events and testing DEM with three algorithms. They are percentile 90, envelope maximum, and thalweg and crests. The result shows that the advance DEM methods increased temperature predictions and reduced rainfall biases. This study also helps to fine tune climate models in the hilly regions by minimise mistakes in forecasting rainfall and temperature.

The study by Mangisoni, Chigowo, and Katengeza (2019) investigates the adoption of rainwater-harvesting technologies in a rain shadow area of southern Malawi. The research focuses on understanding factors influencing the use of in situ and ex situ methods like box ridges, swales, and dams. Using Tobit and nested logit models, the study identifies environmental, socio-economic, and institutional factors affecting adoption. A significant empirical gap was noted regarding technology adoption under diverse farm conditions. Major findings reveal that ease of operation, security of land tenure, and extension services are key drivers, emphasizing the potential of extension strategies for effective adoption.

Jayachandran et al., (2020) analysed Cloud Condensation Nuclei (CCN) in the rain shadow region during monsoon. This study helps to understand the interaction between aerosol and cloud. This study used CCN measurements data, aerosol size distributions and absorption coefficients. These data help to observe the CCN properties change in different meteorological conditions. A spatial gap was addressed by focusing on underexplored semi-arid zones. Findings showed CCN activation influenced by aerosol size and composition, with aged aerosols enhancing CCN activity. However, limitations were noted in representing freshly emitted aerosols. The study highlights regional aerosol complexities and their implications for precipitation processes.

Lucas B. Harris and Alan H. Taylor (2020) explored forest resilience at rain-shadow margins in California under varying fire severities. The study aimed to assess how fire severity, topo-climate, and post-fire vegetation influence tree regeneration, using field surveys and statistical modelling across 397 plots. A major theoretical gap identified was limited understanding of fire-driven compositional shifts in tree species. Findings revealed low-severity fires allow resilience to climate change, while high-severity fires risk transforming forests into steppe or grasslands, emphasizing the role of water balance and surviving tree cover in regeneration. Further spatial analysis could enhance insights into forest recovery dynamics.

Mercy Varghese et al., (2020) studied the new particle formation in the rain shadow region of the Western Ghats. This study mainly focused on aerosol growth and cloud condensation nuclei formation. This study also analyses new particle formation events using ground-based instruments. From the data, it reveals a temporal gap, with new particle formation events. This particle occurred during post monsoon seasons under calm southeasterly winds. The newly formed particles contributing about 80% of total aerosols. This research also proposed the need for temporal studies to analyse the interactions between aerosol and cloud in semi-arid regions.

2.3 Climate and Western Ghats

K. Rajendran et al., (2012) analysed monsoon circulation interactions with the Western Ghats. This study evaluates the rainfall changes over the region due to global warming. This research used past climatic datasets and high-resolution climate models. The results show a major decrease in orographic rainfall by the 21st century. This study also explains the weakened south westerly winds, reduced vertical velocities, and increased atmospheric stability. This research underlines the need of high-resolution models and data which is essential to assess climate change effectively.

Sayli A. Tawde and Charu Singh (2015) studied the impact of orographic features in monsoonal rainfall distribution over the Western Ghats. This study tries to examine the influence of topography, slope, and altitude on rainfall intensity using TRMM data and ASTER DEM. This study identifies cascaded mountain ranges enhance rainfall through prolonged advection and gradual slopes, In Kerala, the peaks receive less rainfall. This study identified heavy rainfall events mainly occur before reaching mountain summits. This research suggests that orography shows an important role in rainfall distribution and hazard management.

Flynn et al., (2017) analysed mesoscale precipitation characteristics in Western Ghats. This study focusing on orographic and diurnal rainfall patterns. This study tries to reveal the local processes influencing precipitation using the Weather Research and Forecasting model. For the ground truth validation, this research incorporates rain gauge data. The interesting part of the study is diurnal rainfall cycles with maximum rainfall in offshore during morning and afternoon in inland. This study also noted that orography was found to enhance rainfall along the escarpment, and it is influenced by land and sea breezes and soil moisture. This study explains the use of high-resolution models for regional precipitation forecasting.

S. B. Morwal et al., (2017) analysed the characteristics of monsoon clouds over the rain shadow region of Vidarbha district in Maharashtra. This research assesses cloud types, dynamics, and potential for cloud seeding during active and break monsoon periods. With the help of C-band radar data and statistical analysis, this study tries to understand monsoon convection in these regions. This research findings represents trimodal cloud top distributions, dominance of congestus clouds, and oceanic-land convection. This study underlined mesoscale convective systems and seeding opportunities, provide a deep insight for rainfall enhancement programs.

B. Padmakumari et al., (2018) analysed the microphysical characteristics of monsoon convective clouds over the rain shadow region in North Peninsular India. This study tries to assess cloud efficiency and rainfall potential with the help of 15 research flights during the CAIPEEX campaign. This research measured parameters of liquid water content, cloud droplet concentration, and vertical motions. The research findings revealed that “Gray Ocean” nature of these clouds, similar to oceanic clouds in low efficiency and updraft velocities. This study also suggest cloud seeding method to increase rainfall and recommended to improve climate model simulations.

R.S. Maheskumar et al., (2021) analysed the role of aerosols and topography in rainfall patterns over the Western Ghats. This research analyses cloud aerosol interactions and their effects on precipitation processes. This study includes aircraft measurements and satellite data applications. This study deals with the impacts of aerosol in cloud microphysics. This research revealed that maritime clouds over the Western Ghats provides rainfall at lower altitudes. Inland clouds needed to grow taller due to the concertation of aerosols from pollution. This study also revealed the amount of aerosols play a major role in rainfall variability.

Jayesh A. Phadtare et al., (2022) studied rainfall differences in the Western Ghats. This study applied Froude number-based classification to analyse onshore and offshore rainfall patterns. This study tries to link monsoonal westerly flow dynamics to rainfall variability. With the help of radiosonde data, satellite observations, and reanalysis products, this research shows the flow stratification effects on rainfall. From this research, we can understand that low Froude numbers strengthened offshore rainfall and high values increased orographic rainfall in the Western Ghats. This Froude number-based classification helps to analyse orographic effects and support rainfall predictions study.

S. Halder et al., (2022) studied the monsoon rainfall variation over the Western Ghats. This study mainly concentrates on dynamical and moist thermodynamical processes. This study analyses rainfall variability using longtime datasets, spectral analysis, and regression techniques. The important finding of this research is sea surface temperature variations in Indian and Pacific Ocean influence the rainfall variations in the past decades. The other findings show a rainfall pattern changed from dynamical drivers in the early 20th century to moist thermodynamical processes in the late 20th century as dominant factors.

2.4 Land Use - Land Cover Changes and Climate

At present, various studies extensively analysed the relationship between land use changes and its impact on environment. All research reveals that there is a significant connection between human activities, land transformation, and various environmental consequences.

Turner II B. L. et al. (1992) studied the growth of the human population and its effects on global land use and land cover changes. This study provides a detailed understanding of transformations in cultivated land, forests, grasslands, wetlands, and settlements. The authors also analysed the environmental consequences of these changes, including trace gas emissions, hydrological shifts, and climatic impacts. He noted that land use change has received considerable international attention. Understanding the mechanisms behind land use change and its adverse environmental impacts is essential for comprehending the relationships among population, resources, environment, and sustainable economic development at global, national, and regional scales. According to him, though changes in land use patterns offer many social and economic benefits, they also negatively affect the natural environment. With the rapid rise in the human population, human-induced changes in land use have become a significant component of regional environmental change. He pointed out that the pace of transformation accelerated particularly with industrialization and spread of European exploitative technologies worldwide. As a result, the built-up landscape increasingly replaced natural landscapes through processes of land conversion. These human-induced conversions and transformations of land use have had significant impacts on the structure and functioning of the Earth's ecosystems.

Dale V. H. (1997) attempted to model the interactions between land use change and climate change. The study demonstrates that land use changes influence the climate, while human-induced climate change, in turn, affects land use patterns. It highlights that current land use activities contribute to climate change, and that changes in land use are also a way in which the effects of climate change are manifested. The study reviewed current practices for assessing and modelling the relationship between land use change and climate change, focusing on two main aspects: the effects of land use on climate, and the effects of climate change on land use. It concluded that humans are likely to modify land use in response to climate change, and these adaptations will have ecological consequences.

Agus F et al., (2004) studied the role of different land use pattern helps to reduce floods and control erosion in Java. They used water retention capacity as an indicator to measure this effect. This research shows that changes in land use have weakened the land’s natural protective functions. From the study, it is understood that deforestation, especially in highlands, increases the frequency and severity of flooding downstream. The study reveals that the land degradation such as flood, soil erosion, and sedimentation is due to the conversion of forest. How much additional forest and other land needs to be converted to agriculture will depend to some extent on how well the productivity of existing arable land is maintained or even enhanced. Pressure to produce enough food and fiber to meet the ever-increasing demands, as caused by rapid population growth, has caused inevitable land conversion

Sangeetha P V (2004) investigated the impacts of land use and land cover changes on the biophysical environment of Kerala's Chalakkudi River Basin. Using both primary and secondary data, the study found that alterations in land use significantly affected water quality and soil erodibility in the region.

Foley et al. (2005) examined the global impacts of land use change, highlighting a complex balance between human development and environmental sustainability. On one hand, land transformation has allowed societies to access and utilize more of the planet’s natural resources. On the other hand, these shifts have compromised the ability of ecosystems to support essential services such as food production, climate regulation, water and air purification, and disease control. He addressed that, while modern agriculture has significantly boosted food supply, it has also contributed to environmental degradation. For example, farming practices often lead to water pollution through nutrient runoff and the use of agricultural chemicals, which contaminate groundwater, streams, and rivers. Land use change also accelerates erosion and increases sedimentation in water bodies, further affecting water quality. He also stressed that, historically seen as a local concern, land use change is now recognized as a driver of environmental change on a global scale. Although its intended goal is often to enhance the productivity and utility of land for human benefit, many practices end up diminishing that very capacity. As a result, ecosystems are increasingly strained, with reduced ability to maintain vital resources such as clean water, fertile soil, and healthy forests, all of which are crucial for long-term human well-being.

Wu J (2005) discussed the long-standing human impact on landscapes, emphasizing that humans have transformed landscapes since ancient times to optimize ecosystem goods. The study concluded that these alterations have restructured and redefined landscape functions and their ecological balance.

Hansen et al. (2005) examined the patterns and impacts of land use change in rural America, drawing attention to the limited availability of detailed data on how fast these changes occur, what drives them, and their ecological consequences. Their research brought to light growing concerns about the rise of rural residential development and its potential to disrupt native ecosystems. Rather than offering definitive answers, the study raised important questions that remain largely unresolved. For example, how extensively is rural residential development spreading across different regions of the country? Is it possible to build theoretical models to anticipate patterns of land use change, much like those developed for vegetation succession? And what are the ecological implications of scattered rural homes or increasing housing density for native wildlife species? These questions envisage the need for a deeper understanding of the relationship between human settlement patterns and ecological health. Hansen and his colleagues emphasized that while these issues are of significant concern, more comprehensive theoretical frameworks and empirical research are necessary to grasp the full scope of rural land use transformations and their environmental consequences.

Wu J. (2008) explored how changes in land use have far-reaching environmental impacts, emphasising their role as an important driver of ecological transformation. This study pointed out that activities such as deforestation, the spread of urban areas, and the expansion of agriculture have significantly reshaped the natural landscape. These changes are not recent developments; rather, they reflect a long history of human interaction with the land. People have continuously modified their surroundings to meet growing needs, often without fully understanding the consequences. Wu highlighted that by altering the physical structure and ecological functions of landscapes, societies aim to secure access to natural resources and ecosystem benefits. This ongoing transformation depicts the deep connection between human development and environmental change.

Dianwei et al. (2009) conducted a detailed analysis of land use and land cover changes in the Songnen Plain of Northeast China over a fourteen-year period, from 1986 to 2000. By using a combination of Landsat Thematic Mapper imagery and topographical maps, the study was able to trace shifts in the landscape and identify the underlying causes. The findings revealed that changes in climate-particularly temperature fluctuations-alongside national policies and rapid population growth, were central drivers of these transformations. As a result, the region experienced a range of environmental challenges. The important identification of the study is, the spread of sand desertification and salinization altered the soil structure, while grasslands, once vital for local livelihoods and biodiversity, began to degrade. Additionally, the alteration of land surfaces contributed to increased vulnerability to flooding. This study highlights the complex interplay between human activity, policy decisions, and environmental processes, showing how even gradual changes in land use can trigger significant ecological consequences over time.

Jyothirmayi P. et al. (2011) analysed land use changes and its impact on the environment in the Valapattanam river basin, in Kannur District. This study adopts thematic maps for understanding the distribution of cultivators and agricultural labourers for the years 1981, 1991, and 2001. This data support to analyse the human influence on this region. From the analysis of these socio-economic indicators, this research highlighted the shifts in land use patterns. The study identified the major driven forces are population pressure, changing livelihoods, and human interventions. These have accelerated environmental decline in the basin. From this study, the important consequences were the loss of forest cover and the degradation of mangrove ecosystems. The findings from the research portrait that changes in land use, particularly those linked to agricultural dynamics and settlement expansion, can disrupt delicate ecosystems and accelerate environmental degradation.

Aighewi I T et al., (2013) assessed the impact of historical land use and sewage discharge on surface water quality in Maryland, USA, using Remote Sensing and GIS. Their findings showed that reductions in agricultural land and increases in urban land use contributed to declining phosphorus levels and dissolved oxygen in water bodies due to runoff.

Brilla B J et al., (2015) examined the impact of land use changes on water quality in Kalady Panchayat, Ernakulam District, Kerala. By analysing water samples from surface and underground sources during pre-monsoon, monsoon, and post-monsoon periods, the study revealed excessive turbidity, total hardness, iron content, and microbial levels exceeding BIS standards for drinking water.

Parth Sarathi Roy et al. (2022) studied the environmental and climate effect on land use and land cover change. This research mainly focused on historical evolution, ecological impacts, and interactions with the existing climate system. The main aim was to synthesise the previous research on the changes in human landscape and its influence in ecosystem functions, atmospheric processes, and biodiversity. This study applied a review methodology, illustration on remote sensing data, climate models, and empirical studies to highlight shifts in land use. From this study, it is understood that deforestation, agricultural expansion, and urbanisation have disrupted hydrological cycles, increased heat stress, reduced biodiversity, and increased greenhouse gas emissions. This study also revealed the need for integrated monitoring and land use policies using satellite programs, machine learning, and biodiversity variables.

Zainab Tahir et al. (2025) studied land use and land cover changes in Lahore District to support better land planning and environmental care. The aim was to understand the land pattern change between 1994 and 2024 and to predict future changes for 2034 and 2044. This study adopted satellite images and mapping tools to classify land types such as built up areas, vegetation, barren land, and water bodies. This study found that built up areas increased by 359.8 km^2, and vegetation and barren lands decreased by 198.7 km^2 and 158.5 km^2. Water bodies remained mostly stable. These changes shows that fast urban growth and the loss of green and open spaces. This study also noted that a lack of long-term local research and its value in such analysis in planning ahead. This study suggests the need for better land management protecting farmland, improving greenery, and planning cities is the best way that balances development with nature.

2.5 Rain Shadow and Land Degradation

The study by Yanni Gunnell (1997) investigates the impact of the Western Ghats on the climatic patterns of peninsular India, focusing on the interaction between orography and the southwest monsoon. The primary aim is to analyse the Western Ghats as a climatic "gatekeeper" influencing rainfall distribution and agroclimatic diversity. Using statistical classification and mapping techniques, the research highlights steep environmental gradients, particularly in rainfall, soil, and vegetation patterns. A notable empirical gap is the limited exploration of the historical uplift’s influence on climate. The study emphasizes the region's unique bioclimatic diversity but acknowledges variability in rainfall patterns and agricultural challenges.

The World Meteorological Organization's (2005) report of “Climate and Land Degradation” examined the impact of climatic factors on dry land degradation. The main objective of the study is understanding the influence of climate on land degradation. This report also provide solution for sustainable land use practices. This report used global datasets, case studies, and climate modelling, to identify a spatial and temporal gap in detailed assessments of degradation risks. The major findings from the report are rainfall variability, temperature shifts, and extreme weather events are increasing land degradation. This report also suggests including better climate data for better management practices.

Mannava V.K. Sivakumar and Ndegwa Ndiang’ui's (2007) studied “Climate and Land Degradation”. This study tries to analyse the relationship between climatic variations and land degradation. This research aims to understand the influence of climate in land degradation. The methodology adopted in this study are analysing various case studies, historical data, and stakeholder consultations during an international workshop. The main research gap identified in the study are the role of climatic factors in triggering land degradation. From this research, we can understand that carbon sequestration methods are effective one for reducing degradation impacts.

Mannava V.K. Sivakumar and Robert Stefanski (2007) analysed the interaction between climate change and land degradation. This study helps to analyse the influence of climate variations in land degradation. This study also proposed sustainable ways to manage land degradation. The major findings of the research revealed the role of precipitation, temperature, and extreme climate events in increasing degradation. This study also envisaged the necessity for regional climate monitoring networks to reduce land degradation effects.

Reynolds et al., (2007) explored the natural and human dimensions of land degradation in drylands, emphasizing its causes and consequences. The study aimed to integrate biophysical and socio-economic factors influencing desertification. Employing the Dahlem Desertification Paradigm (DDP) as a framework, the research highlighted gaps in understanding how human-environment interactions drive degradation. Theoretical and conceptual gaps were addressed, offering a holistic perspective on desertification dynamics. Major findings underscored the need for policy frameworks addressing local and global scales. Despite its comprehensive insights, the study called for better integration of socio-economic variables into environmental management strategies. This work remains pivotal for combating desertification.

Pierre Brabant's (2010) work, "A Land Degradation Assessment and Mapping Method," addresses the critical need for standardized guidelines in assessing land degradation globally. The study aims to propose a composite index-based methodology that integrates field observations, GIS tools, and degradation indicators like type, extent, and severity. The methodology emphasizes the importance of indicators and uses case studies from Togo and Vietnam to validate its applicability. It identifies methodological gaps in global uniformity and consistency. This study shows that the method is useful for land degradation studies. It also helps in sustainable land use practices.

P.G. Gore, B.A. Roy, and H.R. Hatwar (2011) analyse the impact of climate change on land degradation in India, focusing on moisture status using the P/PE ratio (Precipitation/Potential Evapotranspiration). The study examines arid, semi-arid, and dry sub-humid zones over two periods: 1901-1950 and 1941-1990. Employing meteorological data, the study identifies significant spatial gaps in degradation assessments. Key findings reveal 18 districts with notable land degradation, particularly in semi-arid and dry sub-humid zones, and 35 districts with improved soil moisture. The study emphasizes targeted action to mitigate degradation, underscoring the role of moisture balance in combating climate-induced land challenges.

Sally Bunning, John McDonagh, and Janie Rioux (2011) studied land degradation as part of Drylands (LADA) project. This study mainly focused on creating a standardised approach to assess land degradation and sustainable land management at local levels. The main aim of the study is to integrate people participation in land degradation analysis and sustainable land management practices. With the help of DPSIR framework, field surveys, and stakeholder consultations, this study identified a methodological gap in participatory data scheduling. The findings from the research advocates the value of people engagement and ecosystem services in degradation management.

Abu Hammad and Tumeizi (2012) explored socioeconomic and environmental drivers of land degradation in the Eastern Mediterranean, focusing on urbanization, poverty, and overgrazing. Using remote sensing, field surveys, and statistical analysis, the study highlighted urban sprawl's 51-fold growth in 80 years, correlating with environmental degradation. The research identifies gaps in comprehensive planning and resource conservation strategies, emphasizing inadequate regulations and limited institutional support as critical barriers. The research findings reveals that land misuse and overgrazing are increasing erosion and biodiversity loss.

The study by G.S. Tagore et al., (2012) focuses on mapping degraded lands in Madhya Pradesh using remote sensing and GIS. It aims to classify soil erosion into sheet, gullied, and stony waste categories to inform land reclamation strategies. Employing IRS-P6 LISS-III satellite data and field validation, the study identifies 58,365 hectares of sheet erosion as predominant. For the erosion mapping, this study suggests high resolution data. This study also proposed remote sensing techniques are cost effective for land management studies.

Kosmas et al., (2013) studied the indicators for monitoring land degradation and desertification across diverse global sites. The primary aim of the study is to identify effective indicators to assess various degradation processes of soil erosion, salinization, and water stress. Using field data from 17 study sites, correlation analysis, and expert evaluations, the research addresses methodological and spatial gaps in integrating biophysical and socio-economic factors. Key findings highlight climate, land management, and water use indicators as critical drivers. The study underscores the importance of, context-specific monitoring frameworks for effective land management and desertification mitigation.

Kosmas et al., (2014) attempts to develop methodologies for selecting indicators to monitor land degradation and desertification risks. The main aim of the study is to identify effective tools for evaluating desertification processes. To derive the best tool, this study used 70 indicators from biophysical, socio-economic, and land management domains. For this analysis, this research collects 1672 samples in 17 global regions. The methodology adopted in the study are regression analysis and stakeholder consultations. Findings underscore the importance of rainfall seasonality, slope gradient, and vegetation cover in assessing desertification risk. The research advocates for a simplified, site-specific indicator system to enhance land management practices.

Rajesh Kumar and Amar Jyoti Das (2014) studied the relations between climate change and land degradation. This study investigates the consequences of soil quality and sustainable development. This study also tries to identify the climatic factors of temperature rise and rainfall variability, increase land degradation and the loss of soil properties. This study conducts an extensive review of literature. From the reviews, they found a literature gap existing in climate and soil interactions. The major findings of the research help to understand the role of climate in erosion, acidification, and nutrient depletion in soil degradation.

The study by S. G. Narkhedkar et al., (2014) focuses on understanding the rainfall mechanisms in the rain-shadow region of northern peninsular India. Its main aim is to investigate the dynamic, thermodynamic, and microphysical processes influencing rainfall variability. Using daily rainfall, wind, and thermodynamic data (2009-2011), the study analyses convergence, divergence, and cloud dynamics. The research highlights a spatial gap, addressing an underexplored region. Major findings reveal that congestus clouds dominate due to limited vertical development from aerosol concentration and low convective potential. The study suggests that further exploration of socio-economic impacts is warranted, marking an empirical gap.

Florin Loras, Indrachapa Bandara, and Chris Kemp (2015) analysed the relationship between climate change and land degradation. This study helps to understand the climatic factors behind the land degradation and its feedback effects on global climate systems. With the help of multidisciplinary approach, this study incorporates case studies, climatic data, and modelling. From the study, they revealed a spatial and theoretical gap in assessments of land and atmosphere interactions. The findings derived from the study are changes in temperature, precipitation, and conversion of land use increasing land degradation and affecting soil quality and carbon sequestration. This research advocates the need for sustainable land management to overcome the climate induced challenges.

Li et al., (2015) analysed the impacts of climate and land use changes on land degradation in North China Plain. The study aimed to assess degradation patterns and identify key drivers using NDVI data and binary panel logit regression. While prior studies lacked integration of biophysical and socioeconomic factors, this research addressed the empirical gap. Findings revealed that rainfall and temperature increases improve land quality, while urban expansion and intensive agriculture exacerbate degradation. Grassland and forest conversion mitigated degradation. Methodological limitations included data temporal constraints. The study highlights sustainable land management practices to combat degradation.

Manikandan A.D. and V. Mathew Kurian (2016) analyse the interplay between land degradation and rural livelihoods in the Attappady region of Kerala, India. The study aims to explore how rapid population growth and in-migration impact land use, leading to degradation and socio-economic marginalization of indigenous communities. Using a conceptual framework integrating demographic, economic, and environmental factors, the research identifies a theoretical gap in linking population dynamics with land degradation. Key findings highlight the adverse effects of deforestation, soil erosion, and agricultural extensification, urging participatory eco-restoration and sustainable land management practices to safeguard livelihoods and environmental resilience.

Mfondoum et al., (2016) investigates land degradation in arid and semi-arid regions. This study tries to correlate spectral indices and principal component analysis (PCA) with the help of Landsat-8 satellite imagery. The main objective of the study is to map degradation severity areas using indices such as MSAVI2, NDBSI. From the statistical correlation and weighted sum methods, this study identified six degradation classes. The research findings revealed a strong correlation between degradation land, bare soils and sand encroachment. This study also proposed to adopt different geographical data will help to generate precise land degradation information.

Saowanee Wijitkosum (2016) analyse the impact of land use and spatial changes on desertification risk in the Huay Sai Royal Development Study Centre of Thailand. This study analyses land use changes and desertification risk from 1990 to 2010. To assess the spatial changes of land use, this study includes MEDALUS model, satellite imagery, and GIS techniques. For desertification assessment, this study adopts climate, soil, and human activity factors for desertification assessment. The findings from the research reveals about 74% area was coming under high risk due to the impact of desertification. This research also highlights the risk area increased from 74% in 1990 to 77% in 2010.

Abdelrahim A.M. Salih et al., (2017) analysed land degradation and desertification in Sudan. This study used Spectral Mixture Analysis (SMA) and Change Vector Analysis (CVA). The main aim of the study is to assess and locate degradation through Landsat imagery. These remote sensing techniques reveals methodological gaps by sensing sub pixel changes and material compositions. The research findings show about 41% increase in sand encroachment and increase vegetation due to afforestation efforts.

The study of Temesgen Gashaw, Amare Bantider, and Hagos G/Silassie (2017) examined land degradation in Ethiopia, identifying causes, impacts, and rehabilitation strategies. The study aims to highlight the socioeconomic and ecological consequences of land degradation and propose effective mitigation measures. Methodologically, it integrates literature review and data analysis to outline key degradation factors like population growth, deforestation, and soil erosion. The research identifies a methodological gap, emphasizing the limited use of vegetative conservation techniques. Findings underscore the severe impact on agricultural productivity and biodiversity, advocating for sustainable land management practices to curb degradation.

Hans Nicolai Adam et al., (2018) analysed climate adaptation challenges in Attappady. They mainly focused on local livelihoods. They used semi-structured interviews; questionnaires survey and focus group discussion. From the study, they found structural issues of land marginalization and ineffective interventions. This research identified the lack of sustainable adaptation plans to address socio-political vulnerabilities. This study also reveals income dependence on state schemes. This study also warns maladaptive practices of cash crop farming are unsuitable for the study area.

Naseer Ahmad and Puneeta Pandey (2018) studied the use of geospatial technology to analyse and display land degradation in Bathinda. This study aims to evaluate the severity of land degradation. This study adopts geospatial techniques and soil quality details to understand the land degradation. With the help of Landsat satellite data from 2000 and 2014, this study indicates a methodological gap in correlating soil characteristics with spectral data. The findings from the study revealed irrigation and land use changes affect soil salinity.

AbdelRahman et al., (2019) studied land degradation in Chamarajanagar, Karnataka. This study used geostatistical techniques of GIS and remote sensing. This research assesses land degradation types with the help of spatial analysis. This study applied USLE and RUSLE model to integrate soil, slope, land use, and climatic data. The research findings show severe degradation due to salinization, erosion, and chemical leaching having about 53% of the area. This area was classified as highly degraded area and proposed to adopt sustainable resource management in the affected area.

Damseaux et al., (2019) explored the impact of orographic digital elevation model (DEM) generalization methods on simulating the rain shadow effect in Patagonia using the MAR climate model. The study aimed to improve precipitation and temperature simulation by testing three novel DEM generalization methods (P90, EM, and TC). Using sensitivity experiments and validation against the CRU dataset, the researchers found improved temperature accuracy but persistent precipitation biases. A notable gap exists in addressing precipitation variability over the Patagonian plains. The findings recommend refined DEM techniques for enhanced regional climate modelling, particularly in complex orographic areas.

Felicia O. Akinyemi, Laura T. Tlhalerwa, and Peter N. Eze (2019) focused on land degradation in African drylands. They adopted Composite Land Degradation Index (CLDI). This research tries to assess physical, chemical, and biological degradation in Palapye, Botswana. This research also provides a baseline for Land Degradation Neutrality (LDN). Field data, soil quality values, and GIS mapping are applied in this study. From these data, they identified methodological gaps in degradation assessment. The findings of the study revealed severe degradation near settlements due to human activities and also soil salinity and erosion affect natural ecosystem.

Kawy and Darwish (2019) assessed land degradation in Qalyubia of Egypt. The main aim of the study is to map agricultural degradation areas and identify the factors supporting land degradation. This study used geospatial technologies and field surveys to analyse soil quality characteristics. This research identified salinization, alkalization, compaction, and waterlogging are the major issues due to poor irrigation management and excess use of chemicals. In addition, this study mapped degradation hazard areas and revealed a spatial gap in resource management and called for sustainable solutions.

In the study "Assessment of Potential Land Degradation in Akarsa Watershed, West Bengal, using GIS and Multi-influencing Factor Technique" by Ujjal Senapati and Tapan Kumar Das (2020), the authors explore land degradation in the Akarsa watershed, focusing on gully erosion. The primary aim is to delineate potential land degradation zones (PLDZ) using GIS and remote sensing integrated with the Multi-Influencing Factor (MIF) technique. They employed thematic maps and ROC validation, identifying a spatial gap, as the study is region-specific. Major findings reveal that about 38.15% of the area faces moderate degradation, with the model demonstrating 82% accuracy. However, socioeconomic factors were not included, suggesting room for further comprehensive studies.

Sandeep et al., (2020) examined land degradation vulnerability in the semi-arid Rayalaseema region, India, integrating NDVI, LST, rainfall, and soil parameters using AHP and GIS. The study aimed to model and assessed vulnerability using remote sensing data and GIS-based techniques. Methodologically, MODIS, TRMM, and SRTM datasets were analysed alongside pedological factors. A conceptual gap was noted, as limited focus exists on integrating multi-temporal satellite data for degradation studies in similar ecosystems. The findings revealed 35% of the area is highly vulnerable to degradation due to erratic rainfall and poor vegetation. This study highlights AHP-GIS efficacy in sustainable land management.

Jonathan Reith et al., (2021) analyse land degradation in the semi-arid Kiteto and Kongwa districts of Tanzania. The main objective of the study is to improve Sustainable Development Goal (SDG). This objective has been achieved using high resolution remote sensing datasets. This study also includes Landsat time series data, land use land cover maps and Google Earth Engine for spatial analysis. This research reveals that about 27% of the area experienced degradation from 2000 to 2019. This study also given warning that overgrazing and unsustainable farming are primary factors for land degradation in the study area.

Oliver K. Kirui, Alisher Mirzabaev, and Joachim von Braun (2021) analyse land degradation in Eastern Africa. This study adopts remote sensing techniques and field data for validation. This study aims to analyse the area expansion and patterns of degradation with the help of NDVI and LUCC datasets. These results have been validated through focus group discussion. The findings from this research revealed high degradation identified in Tanzania (51%) and lesser degradation in Malawi (41%), Ethiopia (23%), and Kenya (22%). This study identified degradation hotspots include southern Tanzania and western Ethiopia, showing the need for region specific mitigation strategies to reduce degradation effectively.

Saowanee Wijitkosum (2021) examined land degradation and desertification in Thailand's drought-prone Lam Ta Kong Watershed. The study aimed to evaluate environmental sensitivity using the ESAI model, GIS, and Remote Sensing, complemented by fuzzy analytical hierarchy processes. It identified critical degradation drivers, notably soil and climatic factors.

Addressing a literature gap, the research highlighted soil texture and salinity as predominant risks. Major findings showed 33% of the area facing high degradation risk. While insightful for policymaking, its limitations include reliance on historical climatic data, underscoring the need for future real-time analysis to refine mitigation strategies.

Kumar et al., (2022) studied geoenvironmental monitoring of land degradation in semi-arid regions. The main aim of the study is to analyse land degradation and desertification. This study used Landsat-8 Operational Land Imagery programs. From this data, this study derived Land Surface Temperature (LST) and Normalized Difference Vegetation Index (NDVI). Finally, this study correlate NDVI and LST. The derived result revealed that degraded lands occupy about 50% and decertified areas around 27% in the study area. This study effectively used satellite data for the land degradational analysis. But they proposed microlevel analysis using satellite data is not effective one.

Lal Chand Malav et al., (2022) studied land degradation vulnerability (LDV) in the semi-arid Chanda Kalan Watershed of Rajasthan. The study aimed to analyse spatial vulnerability with the help of geospatial techniques and Analytical Hierarchical Process. This study included NDVI, LULC, soil texture, LST, rainfall, and topography. This research revealed about 24% of the area coming under high to very high vulnerability. This research identified ravines and gullies were the most degradation features in the study area. This research advocates GIS and AHP techniques are highly suitable in analysing land degradation in the semi-arid region.

Gianoli, Weynants, and Cherlet (2023) studied land degradation in European Union. This study applied “Convergence of Evidence” approach to analyse the land degradation. The goal of the study was to identify areas with multiple land change issues. The main problems of the study area are soil erosion, water stress, and population pressure. To analyse this issue, this study incorporates various GIS tools and biophysical and socio-economic variables. The main issue the study faced was limited data including poor resolution satellite images and lack of soil erosion data. The main findings of the study is that the mapped degradation mainly effects croplands and urban areas.

2.6 Land Conversion and Soil Quality

Burton S and colleagues (1989) examined the transformation of forested land into agricultural use and its implications for soil degradation in the Chitawa district. By analysing soil samples across various land use categories, they found that soil fertility, measured through SOC, Total Nitrogen, and Cation Exchange Capacity (CEC), declined significantly when natural forests were converted to agricultural fields.

Hajabbasi M A et al., (1997) carried out a study to evaluate the effects of deforestation on physical and chemical properties of soils under oak (Quercus brontii) forests in Lordegan region of central Zagrous mountain, Iran. Quantification of soil quality changes following deforestation by measurable soil attributes is important to sustainable management of soil and water conservation. Nine profiles which were derived from Bakhtiari conglomerate from three sites were selected for this research. Soil characteristics that were analysed include: bulk density, mean weight diameter, aggregate uniformity coefficient, organic matter, nitrogen, potassium, phosphorous, pH, EC, soluble anions and cations, plasticity index, and tilth index. Deforestation and subsequently tillage practices resulted in almost increase in bulk density, decrease in organic matter and total nitrogen. The tilth index coefficient (average of three depths) of the forest site was significantly higher than the cultivated forest and the deforested sites. Deforestation and clear cutting, of the forests in the central Zagrous mountain resulted in a lower soil quality and thus decreasing the productivity of the natural soil.

Brye K R et al., (2005) studied the influence of agricultural activities in soil quality in Arkansas. Soil physical, chemical and biological properties were evaluated in the top 10 cm at six native grassland sites and compared with adjacent tilled agricultural land. Soil organic matter and total C and N concentrations were significantly lower and soil pH, electrical conductivity and extractable soil P, K, Ca, Mg, Fe were significantly higher under tilled agriculture than under native prairie land use. The introduction and continuance of intense mechanized agriculture and its associated practices have significantly, and for the most part negatively, impacted native soil quality in this region. The derived results indicated a considerable reduction in soil organic matter, total carbon, and total nitrogen. They revealed the main problem of the soil quality deterioration is the conversion of prairie into agricultural fields.

Langley T S J et al., (2005) studied different agricultural practices on soil properties in New Hampshire. They analysed various physical, chemical, and biological soil parameters. Four transects were established on each site, and moisture content, pH, microbial biomass, O horizon thickness, and A horizon organic matter content were measured. O and A horizon pH values increased with increasing intensity of past management, possibly due to past burning and liming associated with agriculture. A horizons were thicker and contained more soil organic matter at the sites that had been used for agriculture and O horizons were thickest at the least disturbed site, indicating that O and A horizons have different responses to past disturbance intensity. The results revealed that historical practices, such as liming and burning increased soil pH value in the study area.

Zhang P et al., (2006) studied a complete assessment of soil quality changes in the Karst region in China. This karst area is impacted by intense cultivation and vegetation degradation. The objectives of this study are to elucidate the changes in overall soil quality by a holistic approach of soil nutritional, biological activity, and soil health indicators. Topsoil samples were collected on selected eco-tesserae in a sequence of land degradation in a karst area. The soil nutrient pools of organic carbon, extractable extracellular carbon, total soil nitrogen, alkali-hydrolyzable nitrogen, total phosphorus, available phosphorus were analysed by wet soil chemistry. The soil biological properties were studied by means of measurements of microbial biomass carbon of respiration and of soil enzyme activities. Soil health status was assessed by simple indices in conjunction with bacterial community structures determined by polymerase chain reaction and denaturing gradient gel electrophoresis. While the nutritional pool parameters basically change the soil life-supporting capacity with cultivation interference and vegetation declined, those parameters of biological activity as well as bacterial community structures measured by molecular method evidenced well the changes in soil functioning for ecosystem health with the land degradation.

Idowu O J et al., (2008) studied the Cornell Soil Health Test to understand the soil quality. This research adopted field-data, laboratory value, and visible near-infrared spectroscopy methods. Over 1,500 samples collected from controlled research experiments and commercial farms were initially analyzed for 39 potential soil quality indicators. Four physical and four biological indicators were selected based on sensitivity to management, relevance to functional soil processes, ease and cost of sampling, and cost of analysis. Seven chemical indicators were also selected as they are part of the standard soil nutrient test. Soil health test reports were developed to allow for an overall assessment, as well as the identification of specific soil constraints. The new soil health test is being offered on a for-fee basis starting in 2007. In addition, visible near infrared reflectance spectroscopy was evaluated as a possible tool for low-cost soil health assessment. From preliminary analyses, the methodology shows promise for some but not all of the soil quality indicators. In conclusion, an inexpensive soil health test was developed for integrative assessment of the physical, biological, and chemical aspects of soils, thereby facilitating better soil management.

Feng Q et al., (2009) monitored soil-water physicochemical properties across the lower Heihe River basin in northwest China, classifying land into four desertification categories. Based on an analysis of the main nutrients, the cumulative percent contribution of total N, total P, organic matter, and available N reached 76.24% of ecosystem needs and basically reflect the level of soil fertility. According to a low-dimensional cluster analysis of principal components and the differentiation of integrated nutrient gradients, the soils in the study region were classified into four types, which coincided spatially with the four desertification land types. With a decrease in the quantity of water exiting the upper and middle reaches of the Heihe River basin, the salinity of surface waters and shallow water table depth in the lower reaches have significantly increased through evaporation. The changes in the hydrological process have caused an imbalance in water distribution across the basin and altered the state of oasis-supporting water resources. The deterioration of soil water and expansion of desertification progress from non-salinized soils in the oasis, to soils slightly salinized through periodic salt accumulation, salinized Chao soils, and salinized forest shrub meadow soils along the riverbanks and on lake shores. These can then evolve into moderately to heavily salinized soils and eventually into alkali lands. All together, these degradative processes constitute the complex dynamics of oasis desertification, whereby the natural oases' surface biotic productivity system is degraded, leading to oasis shrinkage, ecosystem deterioration, and land desertification. This research calls for an urgent need to extend the study of soil and surface water chemistry in the region.

Zeng D H et al., (2009) analysed the effects of land cover changes on soil quality in the sandy lands of Keerqin in northeastern China. This study showed that converting grasslands to plantations is the major issue in soil quality declining such as Soil Organic Carbon, total nitrogen, and phosphorus are significantly affecting soil fertility. This research found that land cover change, sampling season and land cover type sampling season interaction significantly influenced soil enzyme activities. Usually soil enzyme activities were lower in the pine plantations than in grassland and savanna. The results suggest that land cover change markedly influenced soil chemical and biological properties in sandy soils in the semiarid region, and these effects vary with sampling season. Sommer R et al., (2011) quantified soil organic carbon losses in Central Asia by combining literature data with FAO-UNESCO soil maps. They found that converting rangelands and wetlands to agricultural land resulted in reduced SOC levels.

Zhang C et al., (2011) assessed the impact of various vegetation types on soil properties in China's Loess Plateau. This study identified a considerable variation in the physical, chemical, and microbial properties of soils across different vegetation types. Not only the nutritional status and biological activity but also the soil ecological functioning or soil health has been impacted profoundly by land degradation in the karst area of southwest China. The objectives of this study are to elucidate the changes in overall soil quality by a holistic approach of soil nutritional, biological activity, and soil health indicators in the karst area as impacted by intense cultivation and vegetation degradation. Topsoil samples were collected on selected eco-tesserae in a sequence of land degradation in a karst area of southwest Guizhou. The soil biological properties were studied by means of measurements of microbial biomass carbon of respiration and of soil enzyme activities. Soil health status was assessed by simple indices in conjunction with bacterial community structures determined by polymerase chain reaction and denaturing gradient gel electrophoresis. The nutritional pool parameters described basically the changes in soil life-supporting capacity with cultivation interference and vegetation declined, the other parameters of biological activity as well as bacterial community structures measured by molecular method evidenced well the changes in soil functioning for ecosystem health with the land degradation.

Qiu L et al., (2012) studied the effect of land use changes on soil organic carbon in the semi-arid grasslands of Ningxia Hui in China. The objective of the study was to study the effect of land use change on aggregate size distribution, aggregate-associated organic carbon concentrations, and aggregate associated stocks in a semiarid grassland area and to relate changes in the aggregate fractions to changes in soil. This study collected soil samples from adjacent grassland, cropland, and shrubland plots. The result shows that about total soil organic carbon concentrations and stocks decreased significantly after the grassland was converted to cropland or shrubland. The proportion of soil in the macro-aggregate fraction decreased after conversion to cropland or shrubland. Decreases in macroaggregate associated organic carbon stocks accounted for more than half of the organic carbon losses that occurred when grassland was converted to cropland. The decreases in macroaggregate-associated organic carbon stocks were due to declines in both macro aggregation and macro aggregate-associated organic carbon concentrations after conversion to cropland. In contrast, decreases in microaggregate-associated organic carbon stocks accounted for more than half of the organic carbon losses when grassland was converted to shrubland. The declines in micro aggregate associated organic carbon stocks were primarily due to a decrease in microaggregate-associated organic carbon concentrations after conversion to shrubland. This study concluded that land use change caused significant decreases in soil organic carbon stocks. Conversion to cropland soil resulted in large decreases in macro aggregate associated organic carbon stocks whereas conversion to shrubland resulted in large decreases in micro aggregate associated organic carbon stocks. The results revealed a remarkable reduction in soil organic carbon concentration and replacement after grasslands were converted to croplands and shrublands.

Yones K et al., (2012) analysed the land use changes and their effects in soil and water quality in northern Iran. They applied laboratory methods to analyse the soil and water quality parameters. The main goal of the research was to assess shifts from forest to pasture, cultivation, and urban land affected as the important environmental indicators. This study adopts field sampling and laboratory analysis to analyse the physical, chemical, and biological soil properties, along with water quality. A split-plot design and ANOVA were used for statistical evaluation. Soil samples were analysed for factors of organic carbon, bulk density, microbial respiration, and cation exchange capacity. A clear empirical and spatial gap was identified, as the study was limited to one watershed and did not assess long-term ecological monitoring. The findings from the research revealed that soil degradation and declining water quality due to deforestation and urbanization, with forest soils showing good health indicators.

Nosrati K (2013) studied multivariate statistical techniques to analyse soil quality variation in Iran's HIV catchment area. In this study, factor analysis and discriminant analysis were used to identify the most sensitive indicators of soil quality for evaluating land use and soil erosion within the HIV catchment in Iran. This analysis compares soil quality assessment using expert opinion based on soil surface factors form of Bureau of Land Management method. Therefore, soil physical, chemical, and biochemical properties were measured from different sampling sites covering three land use/soil erosion categories. Stepwise linear regression revealed that soil surface indices, soil movement, surface litter, pedestalling, and sum of soil surface factor were also positively related to the dehydrogenase and silt. This suggests that dehydrogenase and silt are most sensitive to land use and soil erosion.

Dawoe E K et al., (2014) studied the forest land conversion and its impact on soil quality in Ghana's lowland humid areas. The main objective was to analyse the changes in soil physical and chemical properties along a chrono sequence of 3, 15, and 30-year-old cocoa farms compared to forest land. This study used field sampling and laboratory analyses to assess soil bulk density, porosity, organic carbon, total nitrogen, nutrient stocks, microbial biomass, and degradation indices across four land-use types. A randomised plot design and statistical tests, including ANOVA, were applied. This research shows an empirical and temporal gap, as long-term soil dynamics under cocoa systems in Ghana remain underexplored. The results of the research revealed an initial soil degradation within three years after forest clearing, especially in topsoil, but gradual improvement in older cocoa systems, due to organic matter return through litter and deep-rooted trees. This study indicates some nutrient stability, phosphorus and microbial biomass declined with time. This study also explained the importance of early-stage soil conservation, use of leguminous shade trees, and organic matter management to maintain long-term productivity in cocoa agroforestry.

Okou F A Y et al., (2014) studied ecological factors influencing soil degradation in the Atacora Mountain region of northern Benin. The main aim of the study was to classify soil degradation levels and identify the important environmental drivers. This research applied field observations to assess erosion indicators and ecological features of canopy cover, slope, and ground cover. This study included cluster, discriminant, and multivariate analysis. From this research, the study identified four degradation classes of light, moderate, high, and extreme. This research found that degradation was more severe in low-lying, accessible areas and less in steep, elevated zones. Canopy and ground cover emerged as the most significant factors controlling soil degradation. This study identified that plant litter and stone cover were the important factors reducing soil degradation. This study shows the need for better land management practices, including maintaining vegetation cover and promoting sustainable land use in mountainous ecosystems.

Ferrara C et al., (2015) studied the relationship between urban expansion and soil landscapes in Italy. The present study assesses the spatial distribution of socio-economic indicators compared with indexes of land vulnerability to natural/human-induced soil compaction in municipalities in Italy using an exploratory data analysis. The aim is to ascertain if local municipalities classified at high soil vulnerability are also characterized by a specific territorial profile. More than 30 indicators correlated with soil vulnerability to compaction reflecting the long-established interactions between rural communities and the landscape in turn shaped by latest socio-economic changes. The present study has showed that factors discriminating vulnerable from non-vulnerable areas include demographic and socio-spatial processes, economic factors, environmental variables and landscape attributes. Land-use intensity, crop fragmentation, population density in rural areas and, more generally, human pressure variables are the factors mostly associated with high levels of soil vulnerability to compaction. Assessing latent relations between socio-economic factors and soil vulnerability to compaction provides an in depth understanding of the overall risk for soil compaction. Soil conservation strategies may benefit from improved knowledge of socio-ecological systems informing a more sustainable land management against soil degradation.

Adugna A et al., (2016) analysed land use changes and their effects on soil dynamics in Ethiopia. Land use change can have negative or positive effects on soil quality. The objective was to assess the effects of land uses changes on the dynamics of selected soil physical and chemical properties. Soil samples were collected from three adjacent land uses, namely forestland, grazing land and cultivated land. Soil quality was tested in National Soil Testing Center, Ministry of Agriculture of Ethiopia. Percentage changes of soil properties on cultivated and grazing land were computed and compared to forestland. The statistical techniques of Analysis of variance were used to test the significance of the changes. The results indicate that sand, silt, SOM, N, pH, CEC and Ca were the highest in forestlands. Mg was the highest in grazing land while clay, P and K were the highest in cultivated land. The percentage changes in sand, clay, SOM, pH, CEC, Ca and Mg were higher in cultivated land than the change in grazing land compared to forestland, except P. In terms of relationship between soil properties, SOM, N, CEC and Ca were strongly positively correlated with most of soil properties while P and silt have no significant relationship with any of other considered soil properties. Clay has negative correlation with all of soil properties. Generally, cultivated land has the least concentration of soil physical and chemical properties except clay and AP which suggest increasing degradation rate in soils of cultivated land. To increase SOM and other nutrients in the soil of cultivated land, integrated implementation of land management through compost, cover crops, manures, minimum tillage and crop rotation; and liming to increase soil pH are suggested.

Teferi E et al., (2016) analysed the impact of land use land cover and its impact on soil quality in the Blue Nile Basin of Ethiopia. This study reported that soils under grasslands showing higher bulk density. This study also suggesting that deforestation and grassland conversion are mainly contributed to soil compaction. Diana Che Lata et al. (2024) analysed soil conditions in the Pasir Gudang industrial zone. The main aim of the study is to understand the level of contamination in different types of land use. This study focused on industrial, residential, riverside, and educational areas. This research also examined soil properties such as pH, organic matter, phosphorus, potassium, and electrical conductivity. Topsoil samples were collected from 20 sites and tested using recognized laboratory methods. Heavy metal levels, including zinc, nickel, and lead, were compared with international standards to evaluate pollution levels. From this research, it is noted that most locations showed moderate to good soil quality. The area near Sg Kim Kim showed poor results. Certain sites in the study area had metal concentrations that crossed global average limits. The research gap of this research is that soil data was only collected from selected zones and is not enough to understand the full regional impact.

2.7 Rain Shadow and Livelihood Dynamics

Daniel Maxwell et al., (1998) studied the impact of urban expansion in land rights and livelihoods in peri-urban Accra, Ghana. This study aimed to analyse the rapid urbanization and its effect on land use, property rights, and agricultural livelihoods. From the interviews and community mapping methods, this research identified the socio-economic consequences of urban sprawl. The other findings of the research revealed that land use change displaced traditional farmers and forced them to change their livelihood from farming to casual labour, and petty traders.

Simon Batterbury (2001) analysed livelihood and landscape changes in south-western Niger. This study tries to explore rural communities' adaptation towards environmental and economic challenges. This study tries to understand the relationship between social, economic, and ecological factors which support the livelihood and landscapes. With the help of political ecology approach, field surveys and case studies, this research identified conceptual and spatial gaps in microlevel livelihood practices. The findings underscore a better adaptation mechanism, revealing diverse practices such as migration and non-agricultural activities.

Gina Ziervogel and Rebecca Calder (2003) analysed the role of seasonal climate forecasts in improving rural livelihoods in Lesotho. This study aimed to assess the forecasting improvement in measuring adaptive capacities. This study applied a livelihoods approach combined with participatory methods, and field surveys. This study identified research gaps to integrate climate forecasts and decision making by the local. The findings showed that vulnerable farmers get less forecasting information due to the accessibility barrier and socio-economic constraints.

Roger Calow et al., (2006) analysed the relationship between drought, water security, and rural livelihoods in Ethiopia. This study focused on groundwater management in drought prone regions. To improve drought preparedness and protect livelihoods are the main aim of the study. To achieve this aim, this study adopts groundwater mapping and analysing local water security. This study employed surveys, mapping, and stakeholder knowledge to analyse the water availability in drought. The findings of the report revealed that variability in groundwater reliability across the regions. This result indicated that the importance of integrated water security assessments to reduce the risk of drought.

Selvaraju R. et al., (2006) analysed climate variability and livelihood adaptation in drought-prone areas of Bangladesh. This study advocates plan for sustainable agriculture. This study identified adaptive practices to overcome climate risks with the help of participatory methods, field surveys, and climate modelling. This study tries to integrate local knowledge with scientific knowledge. For sustainability, this study found that drought tolerant crops, rainwater harvesting, and diverse livelihoods. This study also noted that poor institutional support and lack of resource access slowdown the adaptation. This study also underscores the need of participatory approaches and policies to improve adaptive values in vulnerable communities.

Shuichi Miyagawa (2006) analysed the importance of rainfed lowland rice varieties in northeast Thailand. This study focused on the adoption of improved rice varieties of RD6 and KDML. This study aimed to analyse changes in rice cultivation practices and their impact on agroecosystems. This study used long term monitoring, surveys, and agroecological analysis. This study identified the agricultural transition from traditional to improved varieties. The findings revealed that RD6 and KDML required more investment and labour, and this crop is dominated due to their higher yields, grain quality, and adaptability. This study suggests the need of sustainable practices in production increase and to maintain ecological health.

Joseph K. Assan et al., (2009) analysed the impacts of environmental variability on rural livelihoods in Northeastern Ghana. This study mainly focused on climate adaptation and poverty reduction. This study aimed to analyse the impact of temperatures rising and erratic rainfall patterns in livelihood security. To analyse the relationship between climatic factors with livelihood. This study used household surveys, focus groups, and secondary data to understand climate and agriculture relations. From this research, it identified empirical and spatial gaps in understanding localized adaptation. The other findings of the research revealed that diversification into non-agricultural activities and migration improved livelihoods. But these approaches are not enough to reduce deep rooted problems. Therefore, this study invites problem specific policies to enhance livelihood options and reduce rural poverty.

Manoranjan Mishra et al., (2011) studied the vulnerability of highland communities in South Sikkim, India. This study tries to analyse the adaptive capacities of a community in the climate-induced risks. This study also tries to develop the practical adaptation strategies for managing climate change impacts. The study including household surveys and participatory vulnerability assessments and identified the importance of local perceptions in policy frameworks. This study revealed that climate variability's impact on agriculture, water resources, and livelihoods. This study also proposed adaptive methods of crop diversification and traditional water harvesting.

Anne Ulrich et al., (2012) studied small scale farming livelihood dynamics in Laikipia, Kenya. This research mainly focused on socio-ecological adaptability and development. This study aimed to assess livelihood changes. For this analysis, this study included bi-temporal surveys. Based on the resource-based wellbeing indices, this research found a gap in understanding rural communities' adaptation and changing socio-environmental conditions. The findings of the research revealed poverty despite diversified strategies such as off-farm activities. This research also underlined resource scarcity, structural inequalities and the need for improving skill development, and sustainable resource use.

Koko Warner et al., (2012) tries to integrate the rainfall variability, food and livelihood security, and human mobility across eight countries in Asia, Africa, and Latin America. This study aimed to analyse the household migration in a risk management strategy. This study used multidisciplinary approach, including surveys, participatory research, and modelling. From the collected data, the study identified conceptual and empirical gaps in migration drivers. The derived findings from the research revealed that migration decisions are decided by rainfall variability, food insecurity, and livelihood options. The more vulnerable households are forced to migration. This report also suggest immediate attention is essential for resilience building.

Narcisa G. Pricope et al., (2013) analysed the relations between climate and population in the East Africa. This research focused on rangeland degradation and pastoral livelihoods as the research area. The main aim of the study is to analyse vegetation and livelihood dynamics in climatic variability and population pressures. With the help of MODIS and AVHRR satellite data, this research tries to identify spatial gaps in regional degradation assessments. The research findings revealed major loss of green cover and deficit rainfall. This research tries to connect with increased population densities and resource exploitation. This study also suggests the need of integrated methods to overcome the climate impacts and also proposed to improve the food security and ecosystem health in vulnerable dryland regions.

Rusinga et al., (2014) studied smallholder farmers view and their ways to adapt climate change in Mhakwe, Zimbabwe through climate change perceptions and adaptation strategies among smallholder farmers. This study aimed to analyse the farmers opinion on microclimate changes and their impact on agricultural practices. This study used integrated approach combining surveys, interviews, and observations. This research identified a literature gap to adopt indigenous knowledge integration in climate adaptation. The findings from the research revealed farmers adopt zero tillage, mulching, and mixed cropping. This study addressed the need of local knowledge and climate data access for better adaptation planning.

Debela et al., (2015) examined the "perception of climate change and its impact by smallholders in pastoral / agropastoral systems of Borana, South Ethiopia" with the main objective of understanding local perceptions and the factors influencing climate change awareness. This study adopts integrated approach, including household surveys, climate data and applied multinomial logistic regression to analyse the perception data. This study represents the under representation of pastoral systems in climate change perception literature. The results show that about 96% of respondents perceived climatic change mainly as declining rainfall and rising temperatures. The respondent feel that climate change reduced agricultural productivity. The important factors such as age, education, livestock holdings, and access to extension services influenced local people's perception. This study also envisaged that the importance of communication and engagement strategies in climate adaptation planning in marginalized rural communities.

Gopal D. Bhatta et al., (2015) studied the people adapt their livelihoods to climate change in the Indo-Gangetic Plains. This study focused rainfall patterns and its impact on food security. This study analysed survey data from 2660 households across India, Bangladesh, and Nepal using statistical regression. This study identified the interrelations of climatic and non-climatic factors. The research results revealed that medium rainfall areas mainly depend on off-farm income and high rainfall zones get benefit from on farm diversification. At present, irrigation plays a dominant role in supporting livelihoods. This study underlined the need for techniques to manage resource disparities across the study area.

Baatuuwie et al., (2017) studied community's perceptions of land degradation in the Savanna Belt of the White Volta Basin. The aim of the study is to analyse local land user's perceptions on degradational indicators, its drivers, and mitigation strategies. The study applied qualitative methods such as group discussions among communities. The collected data is analysed in SPSS based statistical analysis and Relative Importance Index (RII). This study identified major degradation indicators of rills, gullies and soil colour change. This study found the difference between scientific assessments and local knowledge systems in land degradation research. The findings represent that poor soil management, deforestation, and population act as primary drivers. At the same time-controlled burning and stone bunds were viewed as the main mitigation measures. This research support participatory land management and suggest including indigenous knowledge of local people.

Saguye T.S (2017) conducted a study on farmer's perception on the impact of land degradation hazard on agricultural land productivity in Jeldu District, Ethiopia. The primary aim of the study is to examine the smallholder farmers perception on land degradation and its impact on productivity. This research included household surveys, focus group discussion, and field observations in different ecological zones. Both descriptive and econometric analyses were adopted which includes ordered probit and linear regression models. This study revealed that the importance of local people's opinion is denied. The findings from the research showed that opinion of about 72% of farmers on land degradation was severe one. This study also linked land degradation with soil erosion, fertility loss, and reduced yields. This perception was highly influenced by education, age, extension services, and slope of the land. This research suggests the importance of local knowledge in sustainable land management practices.

Tesfahunegn (2017) studied farmers perception on land degradation in Northern Ethiopia. This study focused to understand local views in the Dura catchment. The main aim was to analyse the causes, indicators, and determinants of farmer's perception of land degradation. Using a mixed methods approach transect-walks, group discussions, semi-structured interviews, and statistical analysis including binary logistic regression the study identified how socioeconomic, biophysical, and institutional factors shape perceptions. Addressing a conceptual and methodological gap, the research integrates participatory tools with quantitative models to uncover local knowledge often overlooked in degradation studies. Major findings reveal that farmers perceive deforestation, overgrazing, and poor soil management as key degradation causes, while soil depth, erosion, and fertility loss are common indicators. The study stresses tailoring land management strategies to farmers' as related to sustainable intervention.

Asrat and Simane (2018) studied farmers perception of climate change and adaptation strategies in the Dabus Watershed of Ethiopia. This study helps to understand perceptions of the local people and the factors favouring climate change adaptation. This study employed a household survey of farmers, focus group discussion, and applied the Heckman sample selection model. This study analysed the perception and decision-making processes behind adaptation. This research analysed location-based drivers for adaptation in the different agro-ecological zones. This research findings revealed that education, access to information, and experience considerably influenced perception. This study represented the importance of site-specific interventions to develop the smallholder's adaptive capacity.

Phool Kumari et al., (2018) studied the role of poultry backyard rearing in enhancing livelihood security of poor families in Auraiya District, Uttar Pradesh. This study analyses the socio-economic impact of poultry farming on rural households. With the help of structured survey and participatory methods, this study identified the adoption and sustainability of backyard poultry practices. The findings from the research revealed that backyard poultry improved household income, nutrition, and empowering rural women. Disease management and lack of market access were the problems faced by poultry farmers.

Sanogo (2018) studied farmer's perception on land degradation and local strategies for land restoration and livelihood improvement in Mopti Region, Mali. The main aim of the study is to support sustainable land restoration through people's participation. This study tries to identify land use and land cover changes as degradational drivers. With the help of satellite imagery, household surveys, focus group discussions, and statistical tools, this research identified spatio-temporal changes. The results from the study revealed rapid land cover changes mainly from vegetation to cropland, increase population pressure, climate variability, and inadequate soil conservation. From the perception of farmers, identified erosion and deforestation as the major threats. This study suggests promoting local methods of contour bunding, agroforestry, and planting grasses.

Elizabeth Edison and Rugmini Devi (2019) conduct a study in Attappady to understand the tribal land alienation, agricultural changes and food culture transition. This study analysed the impact of land alienation on Adivasi communities in Kerala's Attappady hills. This study tries to understand tribal agricultural transformations, food habits, and cultural identity. This study adopted ethnographic fieldwork, interview, and participant observation in Paloor and Cheerakkadavu hamlets. With the help of the data, this research revealed the experiences of scarcity. This research identified the in-migration people not only changed land use, but the entire socio-cultural fabric of indigenous people. The findings from the study also reveal that traditional shifting cultivation and food systems were replaced by cash cropping and forced people to depend on ration systems. This resulted in biodiversity loss, nutritional decline, and weaker community bonds.

Shalander Kumar et al., (2020) analysed climate risk, vulnerability, and resilience among smallholders in semiarid India. This study mainly focused on drought impacts. This study aimed to develop a framework for measuring vulnerability and resilience using panel data from household survey. This study adopted survey data and statistical indices such as crop productivity and income. This research identified empirical gaps in climate-oriented research. The authors strongly criticized that marginalized farmers are not included in vulnerability analysis and noted that structural inequalities remain a barrier to reasonable climatic adaptation. The findings from the research revealed that diversification in farming and income sources increased stability.

Marcus Taylor and Suhas Bhasme (2021) studied the political ecology of climate stability in a South Indian village. This study helps to evaluate the socio-economic and ecological impacts of building stability projects in watershed development and agroforestry. This study adopts interviews and field data. This study also showed methodological and conceptual weaknesses in demonstrating power relations and inequality. This study also noted that infrastructure and crop innovations benefited only for the wealthier farmers. The weaker farmer sections faced disparities in various level. This study represent that standard frameworks does not properly address inequities in rural development.

Onja H. Razafindratsima et al., (2021) analysed the roles of forests and tree-based systems in poverty dynamics. This study mainly focused on poverty alleviation as given in the UN Sustainable Development Goals. The study collected evidence from literature review and workshops. This study mainly focused to livelihood diversification, subsistence, risk mitigation, and ecosystem services. This study identified gender differences and analyse the impact of forest systems in reducing poverty. From the findings, we can understand that when forests contribute significantly to wellbeing and risk management, their potential remains limited to uplift people from the poverty.

Benson Turyasingura et al., (2022) analysed the effects of land degradation in the livelihoods of farmers of Kanungu District in Uganda. This study analysed the causes and impacts of land degradation. This study also proposed solutions to improve sustainability. To identify degradational impacts, this study adopted integrated approach, including surveys and interviews. From the research, they showed that deforestation, population pressure, and poor agricultural practices reduced productivity and biodiversity. This study also advocates agroforestry, crop rotation, and education to eradicate degradation and improve livelihoods.

Nguyen Mau Dung and Nguyen Thi Hai Ninh (2023) studied a comprehensive study on "Farmers' perceptions on land degradation in Vietnam". The main aim of the study is to analyse regional differences in perception and adoption of sustainable land management. This study employed stratified sampling and interview in three provinces. To analyse the data, the study applied descriptive and comparative analyses. The survey result revealed that about 85% of farmers observed the signs of degradation of declining soil fertility and crop yields. The study identified better adoption in mountainous and coastal regions than in the Mekong Delta.

2.8 Conclusion

This chapter has reviewed some of existing literature about the relationship between topography and rain shadow formation and how topography creates topo-climate by its influence. It also reviewed the role of Western Ghats in influencing the climate of peninsular India, especially, in Kerala. This review also covered the literatures relate to impacts of rain shadow effects and land use and land cover changes on land degradation. In addition, this review chapter provided the reviews of the existing literature on Attappady with special attention of rain shadow effect on land degradation and livelihood dynamics of the people of Attappady. This review of literature provided some pertinent research issues especially, the impact of rain shadow effect on agriculture and land degradation in Attappady which has not received proper attention in the research studies. The link between rain shadow effect, land degradation and the livelihoods dynamics of the people of Attappady have not received proper importance in the recent research works. An issue faced during this review was that lack of literature references on rain shadow effect and their impact on land and livelihood dynamics of the people. However, this review chapter helped to understand the conceptual and theoretical framework, methodology and material sources of the research.

CHAPTER 3

GEOGRAPHICAL PROFILE OF ATTAPPADY HILLY REGION

CHAPTER 3

GEOGRAPHICAL PROFILE OF ATTAPPADY HILLY REGION

3.1 Introduction

Geography is a multifaceted discipline that has evolved over thousands of years, playing a crucial role in understanding the Earth's lands, features, inhabitants, and phenomena (Mousa et al., 2022). Through the study of geography, individuals gain insights into different societies, cultures, and environments, fostering a sense of interconnectedness. Regional geography is a branch of geography that plays a crucial role in understanding the socio-economic development and cultural complexities of a region (Xiangzheng et al., 2022). Regional study mainly emphasize on uniqueness of the earth is the core of regional geography. Many scholars including Hartshorne and Hettner argued, geography’s purpose was synthesis. The principal purpose of geographical scholarship is thus synthesis, the integration of relevant characteristics to provide a total description of a place (Johnston R J, 2000). Thus, it is inevitable to discuss the geographical personality of the present study area, Attappady taluk. This chapter discusses the bio-physical characteristics of Attappady taluk.

3.2 Location

The high range mountain landscape of Attappady Taluk is located on the eastern slope of the Western Ghats, Palakkad district of the state of Kerala (Fig: 3.1). This study area has a favourable geographical location with Western Ghats on the west and the Coimbatore plain on the east. The taluk is located in the western part of Palakkad district with the Nilgiris district on the north, Palakkad plain is on the East. The taluk extends from north latitudes 10^{0} 55’ 36.16‘‘N to 11^{o} 14’13.27’’N and east longitudes from 76^{0}23’13.96’’E and 78^{0}48’8.57’’E.

covers an area of 829.45 Km^2 and is inhabited by 64318 persons (Census 2011). Attappady taluk consists of seven villages, three panchayats and one block.

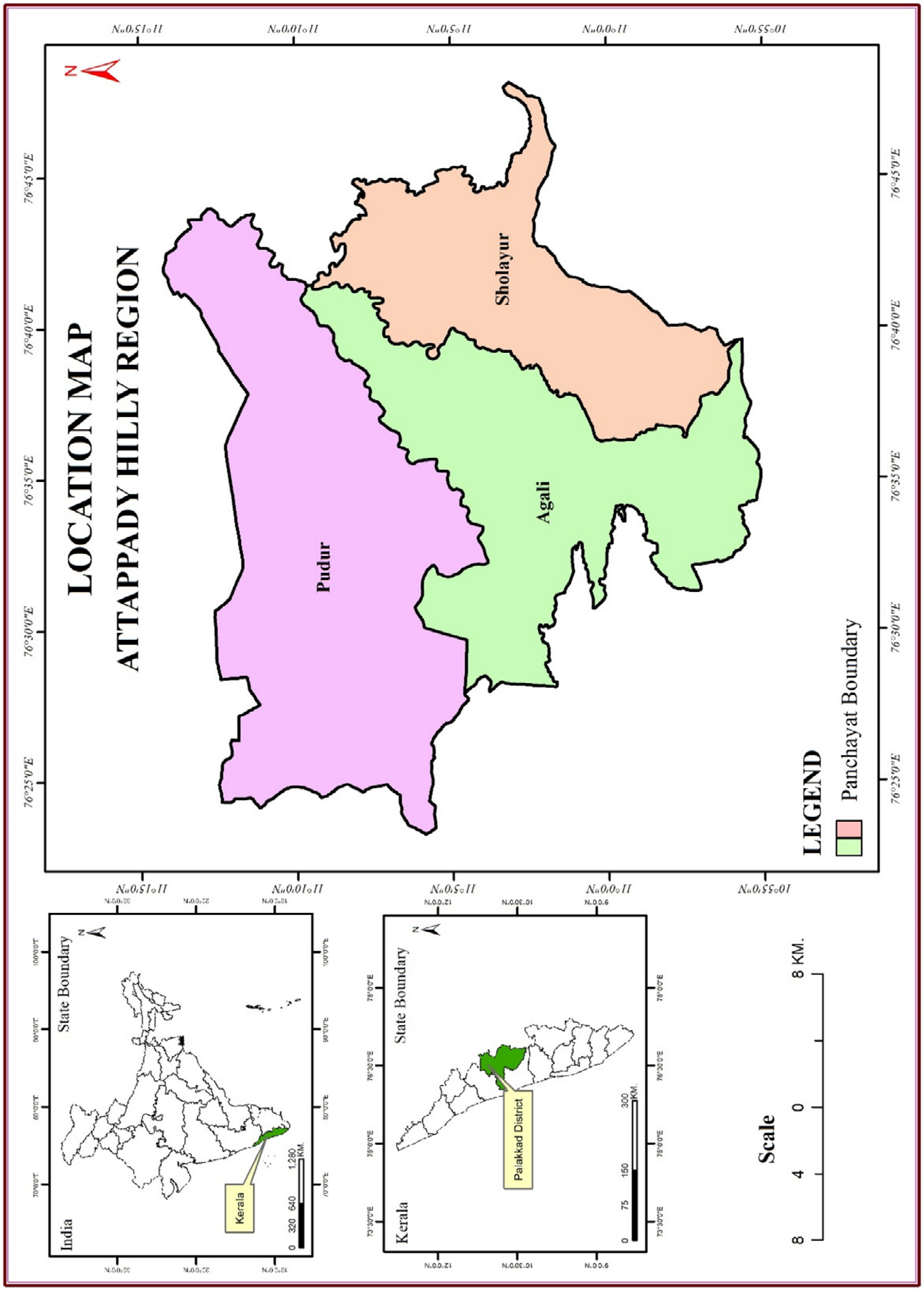
3.3 Relief

Study of landforms becomes an interesting venture not only for the common man but also for the geographers and geologists. Relief is the difference in elevation between the highest and the lowest points in an area; the vertical variation from mountain tops to valley bottom (Hess D et al., 2011). It is a measure of the average elevation difference between adjacent high and low points in a land surface (Strahler et al. 2006). Relief plays a crucial role in geographical studies by providing a foundational understanding of landscapes and their formation, influencing various natural aspects like soil, climate, vegetation, and hydrography (Bruna et al., 2022). Relief of an area plays an important role in determining the population concentration, their lifestyle and activities. Moreover, relief is essential in landscape classification, as it helps determine landscape types based on terrain morphometry and genesis, highlighting the local specific nature of the terrain (Piotr et al., 2020). The Attappady area falls within the pre-Cambrian metamorphic terrain (P.K. Thampi et.al, 1979). Structural landforms in the study area are created by massive earth movements due to plate tectonics (Soman. K, 2002). The study area displays varied relief which ranges from 500 meter to 2300 m above MSL (Fig 3.2). The low-lying areas are formed in the western part of the taluk from where the height of the areas increases towards the east.

Table 3.1: Relief Category (in meter)

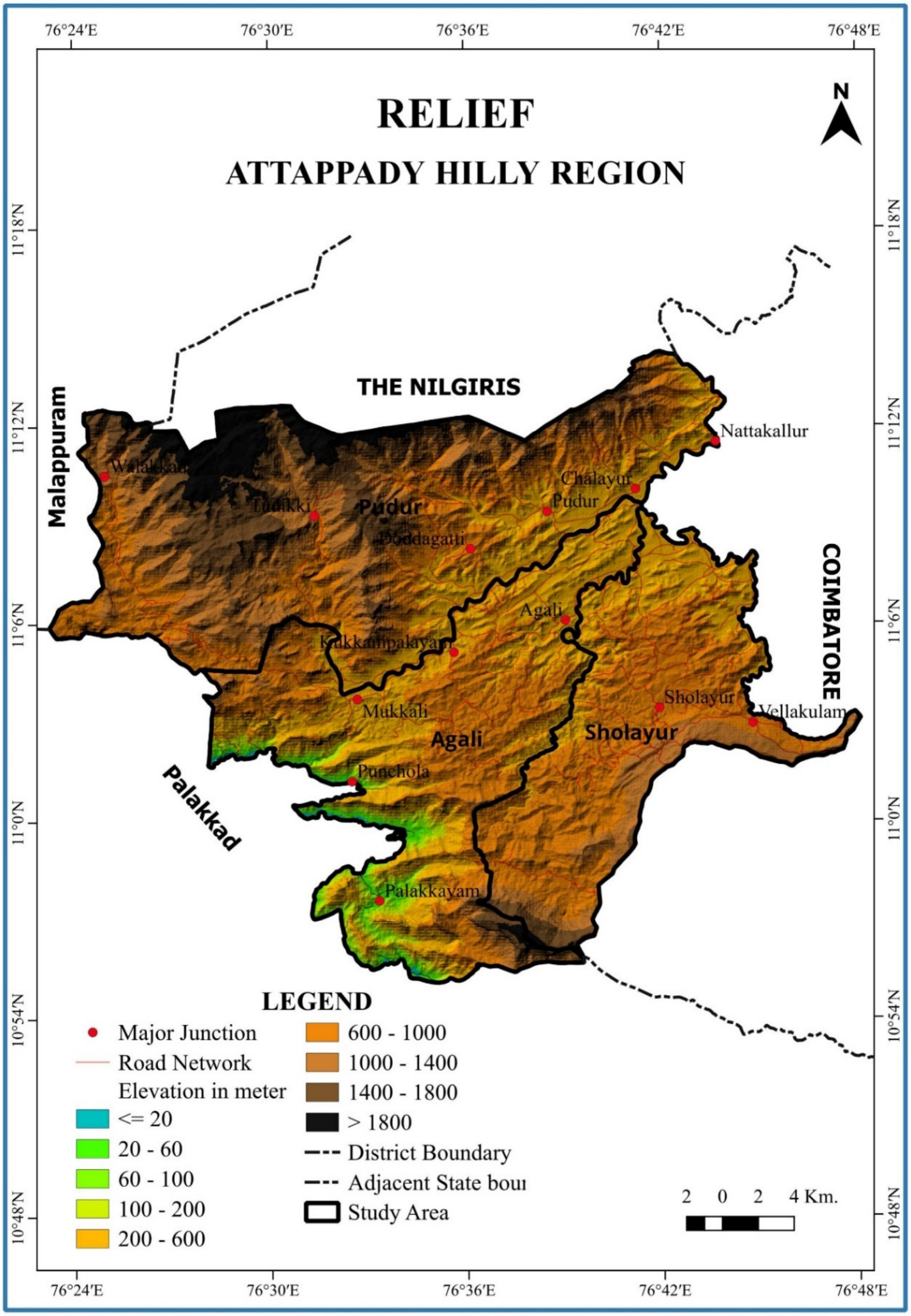
Sl. No	Elevation in meter	Area in km^2	Area in %
1	<100	2.55	0.31
2	100 – 500	79.52	9.59
3	500 - 1000	451.16	54.41
4	1000 – 1500	189.72	22.88
5	1500 -2356	106.27	12.82
	Total	829	100

Source: ASTER DEM, (30 Meter resolution)



Source: Prepared by Researcher

Fig. 3.1: Study Area Map



Source: Prepared by Researcher

Fig. 3.2: Relief Map

It is clear from table 3.1 that less than 2.5% of the total area in the taluk falls in the altitude zone 20-100m which is followed by 30% in 100-600 m, and 38.41% in 600- 1000 m. The taluk is mostly a high land region because 97% of the total area of the district falls above 100 m altitude. Further, 2.5% of the taluk area falls in an altitude of less than 100 m. The proportion of area above 1000 m above MSL accounts for about 29%. These highlands are found in the north and southern part of the study area and form a part of the Western Ghats Mountains. From the above discussion, it is well known that most of the areas of the taluk are of high elevation and thus are less suitable for human inhabitation. Due to this, population density is low in the study area because the land is unsuitable for urban development, settlement, transportation development and industrial expansion. The western high land topography intercepts the rain bearing westerly monsoon winds that help to receive high rainfall in the western part and rainfall gradient is decreasing from west to east.

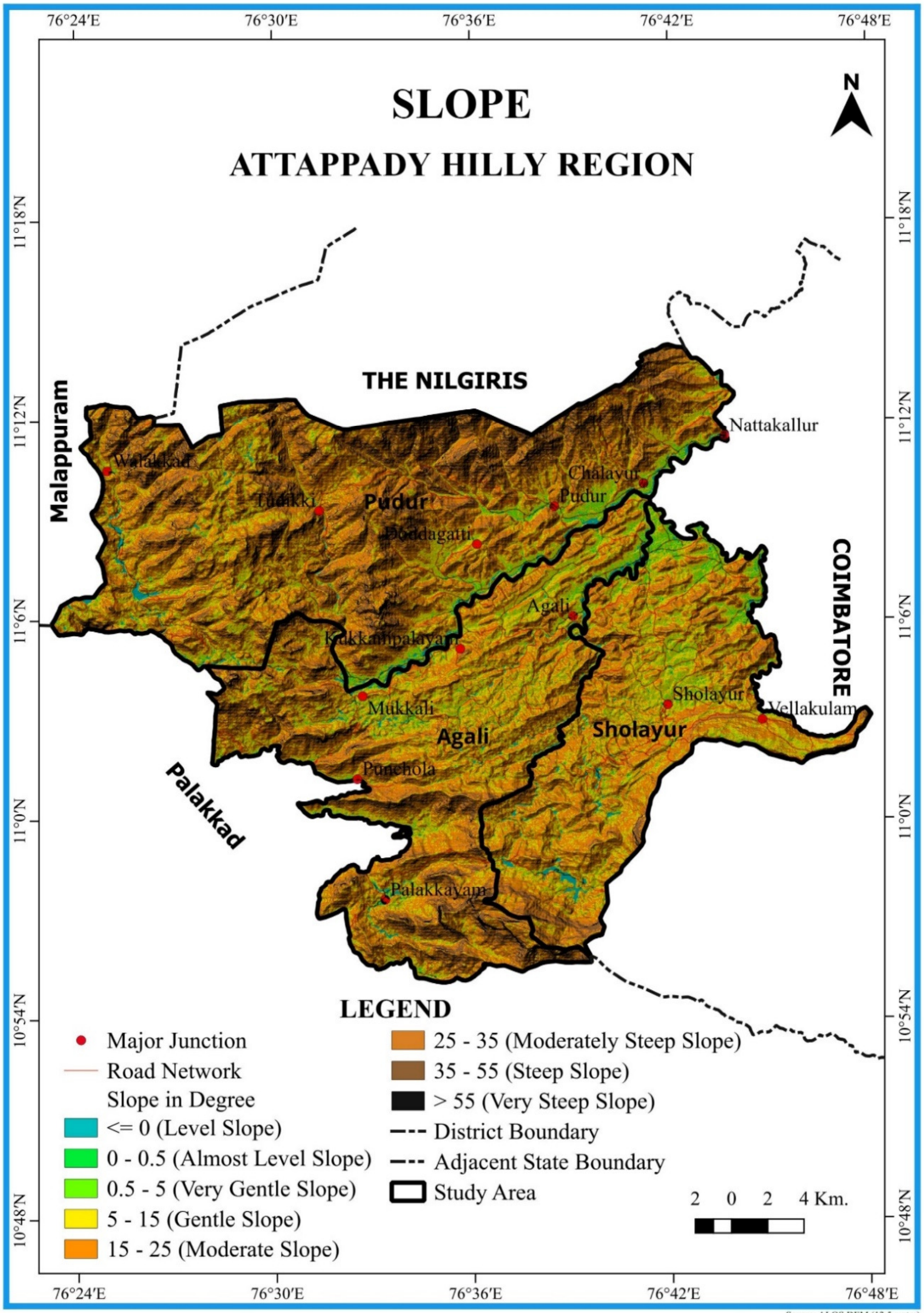
3.4 Slope

Slope refers simply to the inclination of the land surface at a particular spot (Trewartha G T et al., 1967). Slope is the upward or downward inclination of surface between hills and valleys and forms the most significant aspect of landscape assemblages (Prasannakumar. V, 2007).

Table 3.2: Slope Category

Sl.No	Slope in Degree	Area in km^2	Area in %
1	Level Slope	14.1	1.7
2	Very Gentle Slope	44.98	5.42
3	Gentle Slope	225.53	27.22
4	Moderate Slope	292.83	35.32
5	Moderately Steep Slope	179.83	21.69
6	Steep Slope	68.09	8.21
7	Very Steep Slope	3.64	0.44
	Total	829	100

Source: ASTER DEM, (30 Meter resolution



Source: Prepared by Researcher

Fig. 3.3: Slope Map

Slopes are always perceptible and are more significant in the rain shadow region of Attappady. It plays a crucial role in rain shadow regions by influencing precipitation patterns and the formation of arid climates. Terrain morphological characteristics are mainly determined by the slopes of that region because it introduces variation and complexity in the landscape of an area. The development of landscape is also decided by the slope. Geological condition, climatic factors and geographic factors play a major role in the development of slope. Understanding slope dynamics in rain shadow regions is crucial for predicting and mitigating geological disasters and managing the delicate balance of water resources in these arid environments.

The study area displays a gentle to steep slope. About 63% of the area falls in a slope of less than 25 degrees (Fig 3.3). In Attappady about 30% of the area has an inclination of above 25 degrees from horizontal. These steep slope areas are formed as a part of the Western Ghats Mountains in the northern and southern part of the study area. In contrast to this, the very gentle sloping areas are developed in the east and central parts. This means that the study area is sloping from west to east. It is clear from table 3.2 that most of the areas of Attappady are moderate steep sloping (above 35 degree) which is combined with the high relief of the taluk and low population concentration. The density of population in the Taluk governed by the relief and slope i.e., higher the relief and slope, lower the density of population and vice versa. Thus, the density of population is low in the west and increases towards the east. Thus, the processes of land use change and land conversion is accelerated in the unexploited east as compared to the steep slope areas in the north and southern part.

3.5 Geomorphology

The study of geomorphology provides an orderly and accurate description of various landforms and land forming processes (Parthasarathy et.al, 2010). In order to understand the physical setting knowing geomorphic processes and their work is much essential. Designation of the study of land forms as geomorphology has come about as a result of dissatisfaction with the term physiography, which was formerly applied to this subject (Thornbury W D, 2008). The land forms of an area are mainly influenced by structure, process and time. Geomorphology plays a crucial role in understanding the relationship between landforms and rain shadows. Research in various regions highlighted how climate changes related to orographic barrier uplift can lead to the development of rain shadows (Joaquin et al., 2020; Christopher et al., 2002). The presence of evaporates in arid regions indicates the impact of rain shadows on water resources and desertification, emphasizing the connection between geomorphology and climate (Tara et al., 2017).

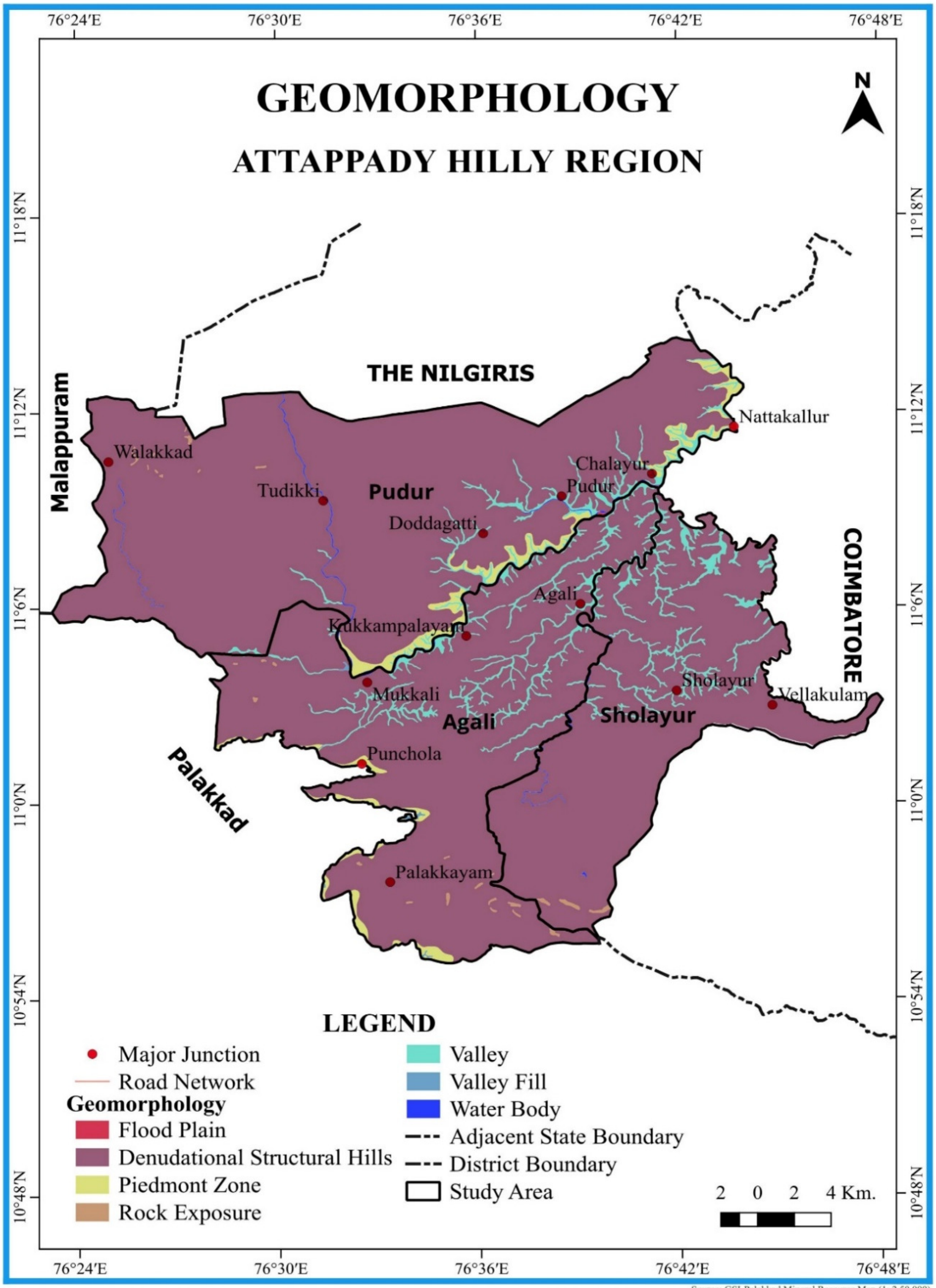
Table 3.3: Geomorphology

Sl.No	Landforms	Area in km^2	Area in %
1	Flood Plain	0.32	0.03
2	Denudational Structural Hills	765.4	92.51
3	Piedmont Zone	17.38	2.10
4	Rock Exposure	1.7	0.20
5	Valley	36.63	4.42
6	Valley Fill	0.55	0.06
7	Waterbody	5.34	0.64
	Total	829	100

Source: Landsat Imagery (30-meter Resolution)

The landforms of Attappady ranges from Denudational Structural Hills to Valley and piedmont Zone in the middle. From west to east the study area traverses through seven distinctive types of landscapes (table 3.3). Among them the flat and gentle features are formed along the major river course and the ruggedness of the landscape seen towards the east. The major landscape features of the area and their respective areas are shown in figure 3.4.

Denudational Structural Hills is the dominant landform of the area covering 93% of the area. It covers the entire study area between the Western Ghats in the west and Coimbatore plain in the east. It is followed by the valley formed along the river course towards east. It occupies 5% of the total area. All other landforms viz., valley fill, flood plain, and piedmont zone together occupy 3% area of the taluk. Rock Exposure is scattered in the western part of the area. The population concentration is determined by the relief and slope which in turn is determined by



Source: Prepared by Researcher

Fig. 3.4: Geomorphology Map

geomorphology. A valley fill, piedmont zone and denudational structural hills with gentle slope and low elevation will have more density of population than that of an elevated hill or mountain with steep slopes. This in turn affects human activities and land use change. Land use change and land conversion in Attappady is in par with the distribution of landforms.

3.6 Geology

Geology is the science that examines Earth, its forms and composition and the changes that it has undergone and is undergoing (Tarbuck E J et al., 2016). Geological records show that orographic barrier uplift can lead to the formation of rain shadows, affecting precipitation levels on the leeward side of mountain ranges (Joaquin et al., 2020; Christopher et al., 2002). The materials composing a particular area is an important focus of geology.

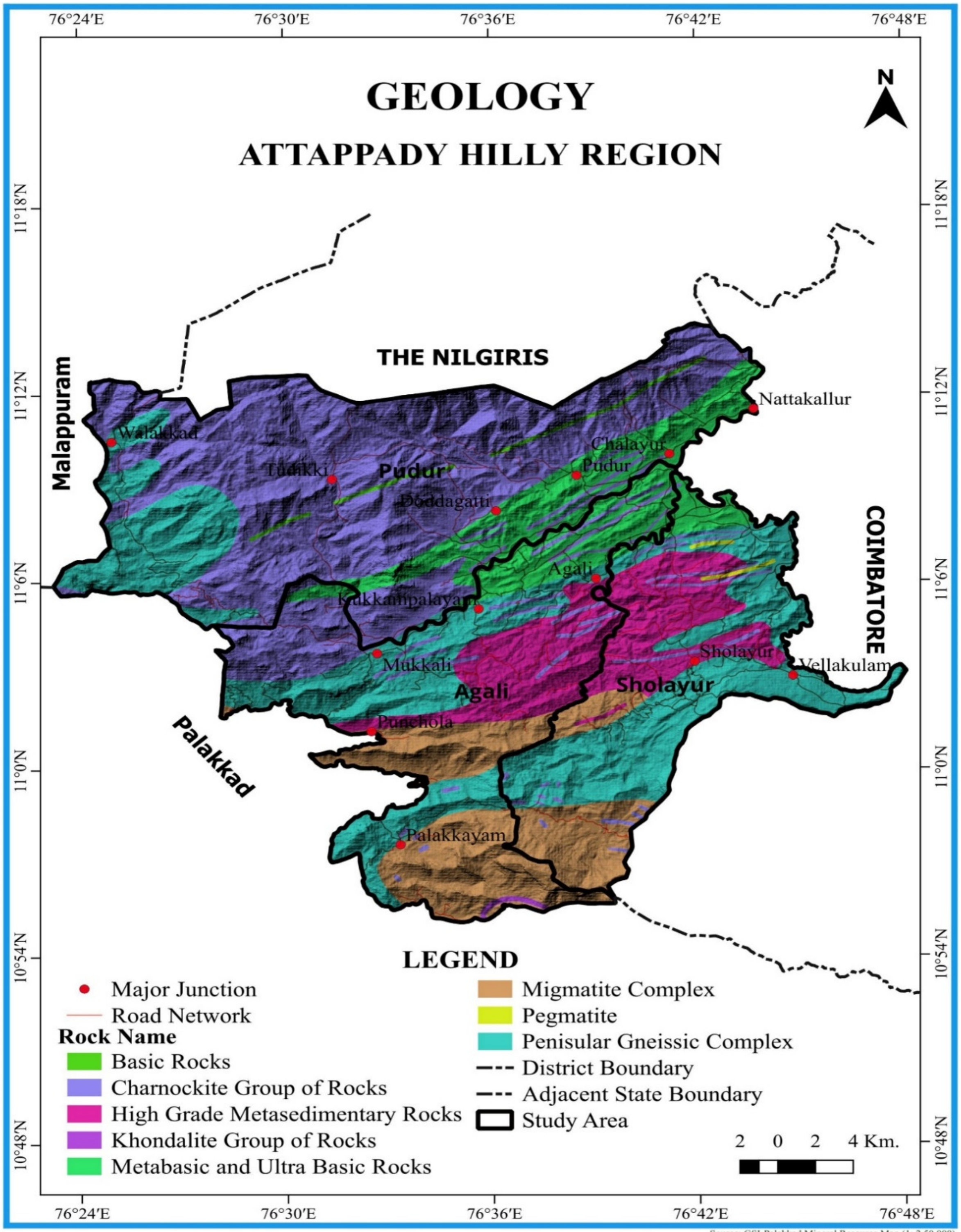
Table 3.4: Geology

Sl.No	Rock Types	Area in km^2	Area in %
1	Basic rocks	5.15	0.03
2	Charnockite group of rocks	313.34	37.67
3	High grade metasedimentary rocks	92.3	11.16
4	Khondalite group of rocks	1.36	0.16
5	Metabasic and ultra basic rocks	88.28	10.67
6	Migmatite complex	107.3	12.97
7	Pegmatite	1.43	0.17
8	Peninsular gneissic complex	219.84	26.57
	Total	829	100

Source: Palakkad District Mineral Resource (1:2,50,000)

Geologically the study area can be divided into four divisions viz., (1) the northern part represented by the Charnockite group of rocks and (2) High grade meta sedimentary rocks in the centre, (3) Peninsular gneissic complex rocks extend from centre to southern part, and meta-basic and ultra basic rocks in the eastern part. Figure 3.5 depicts the geological divisions of the study area.

The Archaean crystalline rocks comprise Khondalite group, Charnockite group and Migmatite group. From table 3.4, the charnockite group of rocks covers 38% area of the taluk and that of Migmatite complex is 13%, High grade metasedimentary rocks and Metabasic and ultra basic



Source: Prepared by Researcher

Fig. 3.5: Geology map

rocks comprises about 22%. The charnockite group of rocks is formed in the entire northern part. Charnockite group of rocks, characterized by hypersthene-quartz-feldspar assemblages with or without garnet, have significant implications in tropical areas based on various studies. Research in the Gneissic Complex in India reveals metamorphic to magmatic charnockites derived from varied protoliths, including garnet-bearing amphibolites, indicating high-temperature conditions during post-collisional East Gondwana assembly (Borah et al., 2023). Additionally, investigations in the Kerala Khondalite Belt in southern India highlight the role of carbonic fluid infiltration and CO_2-rich fluids in the formation of charnockites, with evidence of post-peak metamorphic carbonic fluid infiltration events (Madhusoodhan et al., 1998; H.M 2011). Furthermore, the conversion of garnet-biotite paragneiss to charnockite in the Precambrian Khondalite belt of southern Kerala underscores the presence of CO^2-rich inclusions in charnockites, emphasizing the influence of carbonic fluids in tropical regions (Srikantappa et al., 1987).

3.7 Drainage System

Drainage refers to the naturally occurring channeled flow formed by streams and rivers (Mayhew S, 2015). Owing to the undulating nature of the land and its graduated altitude, Attappady has a well ordered system of natural drainage (Fig: 3.6). As many as 12 major tributaries of both Bhavani (East Flowing River) and Bharathapuzha River (West Flowing River) emerged from this location, and flow over an aggregate length of 3080 km. Kundanchola puzha, Karinga todu, Madrimaram todu, Vallepare todu, Kummattan todu, and Vachakayan todu are the major tributaries of Kunti Puzha and Yemmavi Puzha, Kokkiveri pallam, West Varaha pallam, East Varaha pallam, and Seruvani River are the tributaries of east flowing Bhavani river carrying fertile soils to the Palakkad and Coimbatore plains. Scanty rainfall on a high land area creates a non-perennial flow and most of the large rivers carry down considerable volume of water. During the wet season, many of the streams overflow their banks

Source: Prepared by Researcher

Fig. 3.6: Drainage System Map

and inundate the adjoining lands, particularly in Karaiyur and Ranghanathapuram where the rainfall is heavy and sometimes affected by flood.

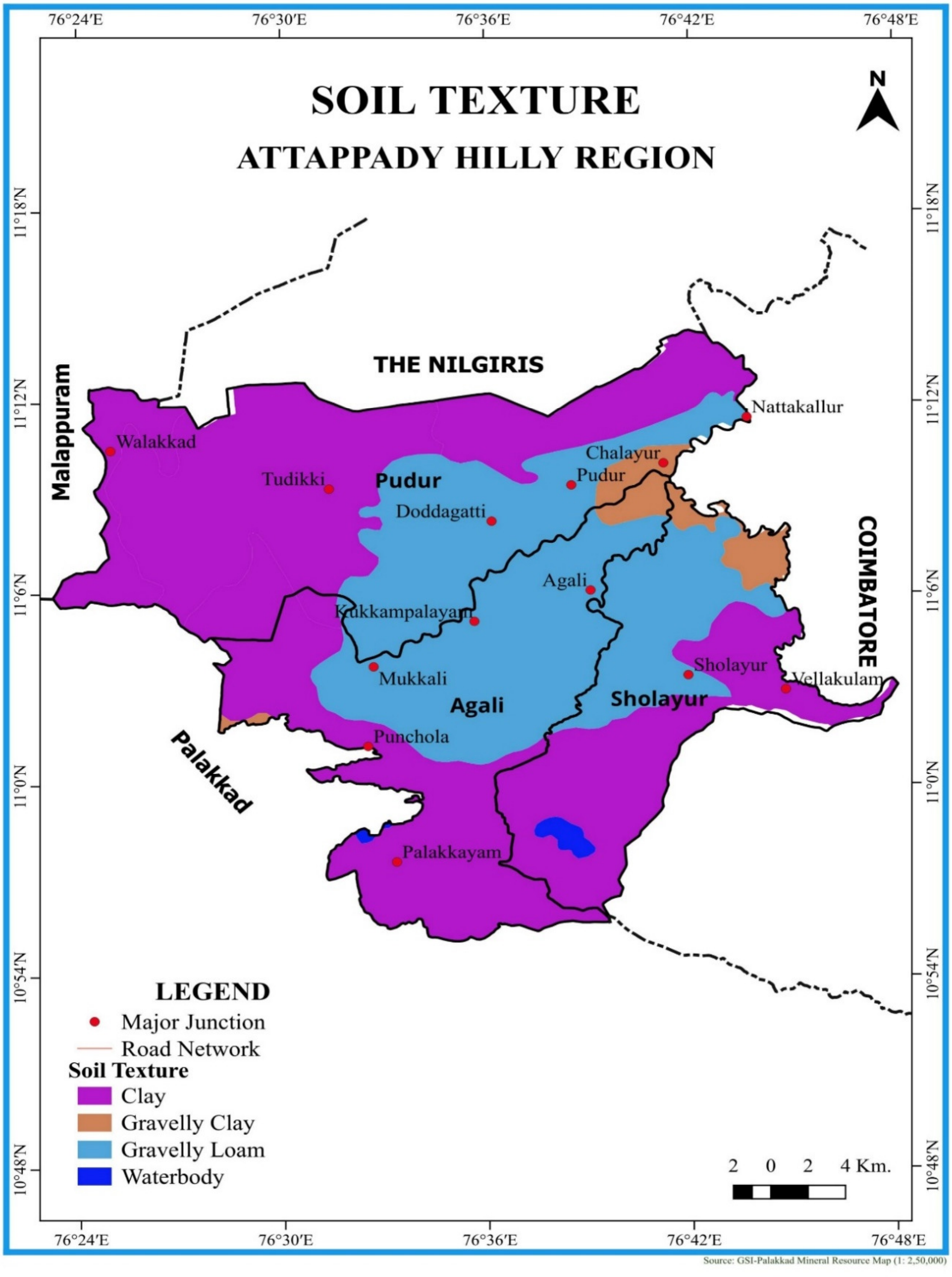
3.8 Soil Texture

Soil may be defined as the thin surface layer of the earth, formed by the break-down of the rocks in various ways and by various processes (Monkhouse F J, 1954). Soils are, next to water, man"s most vital natural resource (Thornbury W D, 2008). Soils in rain shadow regions exhibit unique properties shaped by a combination of geological, climatic, and anthropogenic influences. Studies in the rain shadow region reveal diverse soil types like brown hill, mountain meadow, and desert soils, with vulnerability to climate change and anthropogenic factors leading to hazards like landslides and floods (Joaquin et al., 2020). Similarly, the uplift of the rain shadow effect, leading to a decrease in mean annual precipitation and the development of Alfisol-like, Andisol-like, and Aridisol-like paleosols over time (Juanita, L., Beytell.,2023). Furthermore, investigations in rain-shadow regions highlight the significant impact of mesoscale convections and sub-cloud processes on water isotopes, emphasizing the importance of understanding these processes for interpreting soil characteristics in such areas (M.J.M et al., 1995). The soil texture of Attappady display very much difference in their properties and spatial distribution. The soil survey Organization, Agriculture Department, Government of Kerala has identified the following types of soil texture in the study area (Fig 3.7).

Table 3.5: Soil Texture

Sl.No	Soil Texture	Area in km^2	Area in %
1	Clay	488.88	59.26
2	Gravelly Clay	29.85	3.61
3	Gravelly Loam	301.33	36.52
4	Waterbody	4.84	0.58
	Total	824.91	100

Source: Benchmark of Soils, Palakkad District (1:2,50,000)



Source: Prepared by Researcher

Fig. 3.7: Soil Texture Map

In Attappady, clay soil covering about 60% of the study area spread in the west, north and southern portion of the study area. The next soil texture is gravelly loam (37%) lying in the middle part of the study area. Gravelly clay soil accounts for only 4% of the area situated in the eastern part of the study area (table 3.5).

3.9 Climate and Ecology

Climate is an aggregate of environmental conditions involving heat, moisture and motion (Critchfield H J, 2009). Climate is an active factor in the physical environment of all living things. Attappady is home to a diverse climate and ecology. Geographically, the panchayats are located as follows: Pudur to the north-east, Agali on the central western side of the plateau, and Sholayur on the south-western flank. Rainfall patterns are diverse and vary sharply, with the dichotomy lying between the western and eastern areas of the block. Rainfall patterns are closely connected to topographical diversity and locations on the plateau. Annual precipitation ranges from 700 to more than 3000 mm. The western part receives the bulk of precipitation from both the south-west monsoon and north-east monsoon. Consequently, this part of Attappady is wet, moist and humid for most of the year. Majority of the agricultural lands are located in the central valley and western flanks. The eastern parts on the other hand, receive the bulk of precipitation from the retreat monsoon and are drier and hotter throughout the year (Adma H.N et al., 2018). The dry season in the eastern section lasts between five and seven months and this is where most of the degraded forest land is located. Temperature average around $17^{o}{}_{C}$ and differ seasonally, with a hot and dry summer between March and May, and a cooler winter in November to December. A forest cover of 83% in 1957 reduced to 20% by 1996; this was accompanied by a change in micro-climatic patterns combined with land resource degradation (Kunhaman, 1981; Radhakrishnan, 2012). Apart from general land quality degradation and attendant impacts on agrarian practices, changes in precipitation have been from the 1970s onwards with droughts, especially in its eastern parts, occurring more frequently (Sathis, 1989). The two most important rivers are the eastward flowing Bhvani and Siruvani that are fed by a number of smaller tributaries. The detailed climate description has been given in chapter 5.

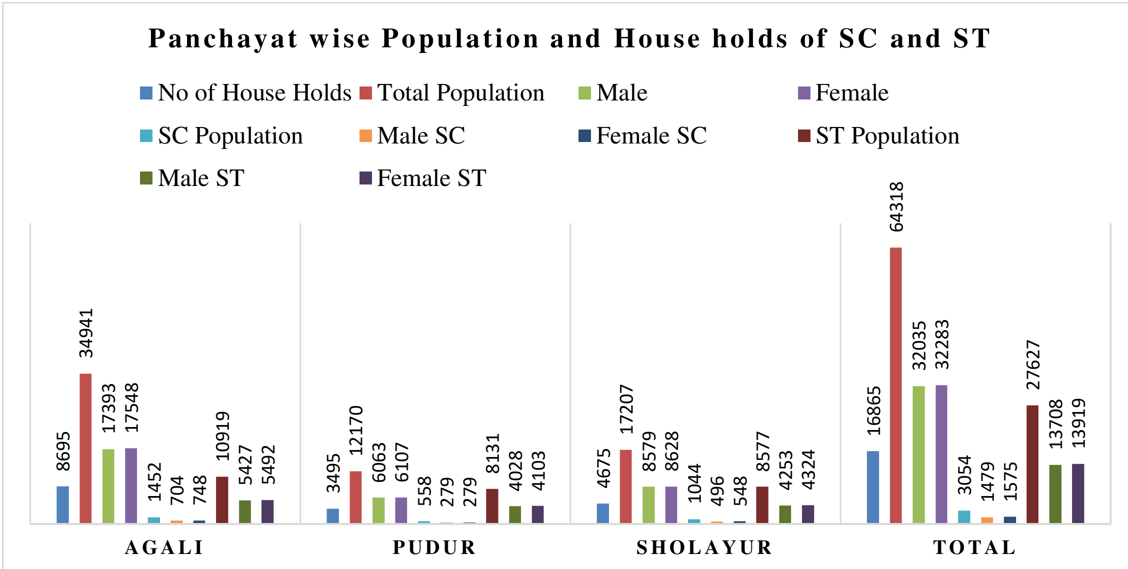
3.10 Population profile

As of the 2011 census report (table 3.6), Attappady taluk has a total population of 64,318 where 32,035 are males and 32,283 are females. This taluk has scheduled tribe population of 27,627 (43% of total population) where 13,708 were males and 13,919 were females. The tribal population of the valley mostly consists of, Irula, Kurumba tribal people. A section of settlers from other Districts of Kerala and Tamil Nadu are also settled in Attappady. The total SC population is 3054(4.75%), and other settlers are 33637 (52.29%). The population of children in the age group of 0-6 is 7,009 (10.9%) among which 3,551 are boys and 3,458 are girls. The total number of literates in Attappady is 43,021 with an overall literacy rate of 75% which is lower than the state average of 94%. Male literacy stands at 80.2% and Female literacy at 70%. The total number of households in Attappay was 16,865 as per 2011census.

Table 3.6: Population and Households of SC &ST

Panchayats	No of House Holds	Total Population	Male	Female	SC Population	Male SC	Female SC	ST Population	Male ST	Female ST
Agali	8695	34941	17393	17548	1452	704	748	10919	5427	5492
Pudur	3495	12170	6063	6107	558	279	279	8131	4028	4103
Sholayur	4675	17207	8579	8628	1044	496	548	8577	4253	4324
Total	**16865**	**64318**	**32035**	**32283**	**3054**	**1479**	**1575**	**27627**	**13708**	**13919**

Source: Panchayat Department, Govt. of Kerala Census 2011



Source: 2011 census

Fig. 3.8: Panchayat wise Population

3.11 Economic Activities

The economic activities are an indicator of nature and prospects of the level of the economy of a region. It also reflects the socio- economic-cultural characteristic and standard of living of the people. The main economic activities in Attappady are agriculture, cattle rearing, and collection of minor forest produce. Agriculture is the primary source of income for the population in Attappady. Though there is a scarcity of water, the people follow traditional style of cultivation. Cultivation of plantain, coconut, cereals, ragi are noticeable. Along with agricultural activities, cattle rearing is also the main source of income. The main crops grown are plantain, coconut, cereals, and ragi. Millets are a significant part of the agriculture in Attappady, and the region is a leader in millet cultivation in Kerala. Another main source of income in Attappady is cattle rearing. Other economic activities in Attappady include minor forest produce, processing and marketing and dairy cooperatives. Some tribal communities are practicing shifting cultivation in remote areas (Richard Scaria et al., 2013).

3.12 Natural Vegetation

Natural vegetation is that part of the earth's plant cover which is not cultivated or domesticated (Trewartha G T et al., 1967). Farm crops and planted pastures are not a part of it. The relevance of floral diversity is that the vegetation structure, species diversity, and ecosystem processes, as these were identified as essential components for a long-term persistence of an ecosystem (Sonalkar S., 2016).

Attappady is a broad mountain valley located at the origin of the Bhavani River, nestled beneath the Nilgiri hills of the Western Ghats. The western part of Attappady is rich in thick evergreen forests, but as one moves eastward, the vegetation gradually shifts to a mix of evergreen and deciduous forests. Beyond that, the Coimbatore plateau features dry deciduous forests. Today, Attappady is one of the driest regions in Kerala, with its eastern slopes lying in the rain shadow area, receiving less than 1000 mm of rain annually. In contrast, the western part gets nearly 3000 mm of rainfall.

Hot, dry winds during the summer and irregular rainfall patterns, combined with poor soil moisture retention, have led to land degradation and signs of desertification in many parts. Over time, the soil and vegetation of the region have also changed significantly. As the forest type shifts from evergreen to dry deciduous, soil acidity tends to decrease while the amount of exchangeable nutrients increases (Alexander et al., 1986).

According to a report by AHADS (2010), there's a clear transition from moist tropical forests in the west to dry, thorny scrublands in the east. The widespread deforestation in the past has reduced the land's ability to absorb and retain water, which in turn has impacted soil fertility. Eastern Attappady now shows a mix of dry deciduous forests and scattered moist deciduous tree species. Much of the land is being transformed into euphorbiaceous scrub jungles.

Agroforestry can play a key role in restoring this landscape by helping to store carbon, conserve resources, and reduce dependency on forests. As documented by Sonalkar (2016), key vegetative zones in Attappady include the plantations and biomass areas of Agali, Kottathara, Melle Chavadiyur, Palliyara, Pattimalam, Sambarkode, and Vellamari.

3.13 Conclusion

Attappady is the largest tribal taluk, located in the Western Ghats of Palakkad district of Kerala. The terrain of Attappady is marked by hills and valleys. The altitude varies between 200 and 2400 meters above MSL. This region is situated between the two ranges of Western Ghats, and its slope is towards north-east. Attapady taluk consists of three panchayats namely, Agali, Pudur and Sholayur and six villages. This study area has a favorable geographical location with Western Ghats that obstruct the moisture laden wind from the Arabian sea and causes poor rainfall towards east causing 'rain shadow' on the eastern part of Attappady. This taluk straddling the ecological divide between the region of orographic precipitation to the west and the rain shadow to the east. In the western part of the study area experiences wet climate and evergreen forest, but the eastern part has dry and arid type climate with grass and scrubs due to rain shadow effects. The combined effects of both the physiography and rain shadow induced climate exerted more impact on land, soil, vegetation and livelihood dynamics of the people.

CHAPTER 4

DEMARCATION AND MAPPING OF RAIN SHADOW AFFECTED AREAS AT ATTAPPADY HILLY REGION

CHAPTER 4

DEMARCATION AND MAPPING OF RAIN SHADOW AFFECTED AREAS AT ATTAPPADY HILLY REGION

4.1 Introduction

Mountains and other land barriers are likely to cause orographic precipitation (Davie, 2008) and forming rain shadow regions (Smith 1979; Roe 2005). Rain shadow refers to a climatic phenomenon where one side of a mountain range receives significantly more precipitation than the other, leading to a dry area on the leeward side. This occurs due to orographic lift by the topography of a region, where moist air ascends, cools, and condenses into rain on the windward side, while descending air warms and dries, creating arid conditions in the rain shadow region. Generally, therefore, a region of low precipitation in the lee of topography is "rain-shadow". Orographic rain shadows are a primary feature of earth's surface climatology (Galewsky, 2009). The rain shadow development is the function of both topography and atmospheric state (Sobel et al., 2003 and Abdulrazak et al., 1995) and found that the amount of rainfall on the windward slopes is higher than the leeward slopes of the mountains due to the blocking of winds carrying moisture from nearby water bodies. Therefore, rain shadow is a well-known phenomenon by topographic obstacle with maximum orographic precipitation on the upwind side and falls beyond the summits (Barry and Chorley 1987).

Mountains affect the distribution of clouds and precipitation (Houze 2012, Stockham et.al 2017) and is found across the Andes, Himalayas, Cascade Mountains of Washington State, Sierra Nevada of California, and the Rocky Mountains as a whole. The most unique feature of mountain climates is the rain shadow effect i.e., the sharp decline in precipitation on the lee side of mountain ranges (Siler et al, 2012). Orographic effects brings not only the initiation and intensification of precipitation on the windward side of mountains and hills but also the relative deficit of precipitation on the lee side (Atkinson, 1983; Smith, 1979). With increasing height, the air pressure decreases, enabling the moist air to expand and cool and water can condense, resulting in precipitation (Schumann, 1998; Davie, 2008). After passing through the topographic barrier's highest points, the chilly air reaches the leeward, the air warms up again, causing increasing the dryness (Nicholson, 1994; Schumann, 1998; Siler et al., 2013). As moist air ascends the windward slope, it cools, leading to condensation and precipitation. This process can enhance rainfall on the windward side compared to the leeward side (Hende et al., 2021). The basic mechanism of the rain-shadow effect is that on windward slopes, ascending air expands, cools and condense, and enhances precipitation, but on the leeward slope, precipitation is suppressed as the descending air warms and liquid water evaporates, forming as rain shadow region (Smith 1979; Roe 2005). This disparity in moisture availability creates distinct habitats, influencing the types of vegetation and animal species that can thrive in each area (Farias et al., 2021). The interplay between rainfall and biotic interactions is crucial in arid ecosystems, where species dynamics are closely tied to precipitation patterns (Farias et al., 2021). Reduced rainfall can lead to lower crop yields, forcing communities to rely on government assistance or humanitarian aid (Fitriani et al., 2023). Weather anomalies, including droughts, can result in significant income loss for farmers, leading to increased social distress and economic instability (Papaioannou & Haas, 2017). The vulnerability shadow from weather events can severely affect access to markets, impacting local economies and employment opportunities (winter, 2015). Communities may experience heightened food insecurity due to declining agricultural outputs, exacerbating poverty and marginalization (Minkley, 2012). In tropical rain shadow areas, complex interactions between meteorological processes and water isotopes can influence hydrological cycles, impacting water availability (Beytell, 2023). High concentrations of aerosols in the rain shadow area suppress warm rain formation, affecting cloud dynamics and precipitation efficiency (Konwar et al., 2010), (Varghese et al., 2021).

The rain shadow effect of the Western Ghats significantly influences the regional climate, particularly affecting rainfall distribution. This phenomenon occurs due to the orographic lifting of moist air from the Arabian Sea, leading to heavy precipitation on the windward side while creating drier conditions in the leeward rain shadow region. The rain shadow effect in the Western Ghats also significantly influences monsoonal rainfall patterns, creating distinct climatic zones on either side of the mountain range.

The present research tries to investigate the variations of weather of Attappady hilly region under the grip of rain shadow mechanism and where and how rain shadow mechanism is affected. Low rainfall in the eastern side of Attappady significantly influences the region's ecology and socio-economic conditions. This phenomenon, caused by the Western Ghats' topography, leads to reduced rainfall on the leeward side, impacting agriculture and water availability. There are no previous studies that address the reason for the mechanism of less rainfall in Attappady region. The majority of households in Attappady rely on agriculture as their primary source of income, and the majority of them are unable to harvest as a result of the drought (The Hindu 2016). This region has already been severely hit by a heat wave, which has hampered the cultivation of pulses and millets, as well as sunburn incidents. During the summer, communities experience severe drinking water shortages as well as agricultural water shortages. Most wells in eastern Attappady had also dried up, according to hydrologists (The Hindu 2016) and wildfire destroyed almost large tracts of forests and grasslands in the rain shadow region of Attappady (The Hindu 2024). All these issues lead to poverty, the loss of livelihood activities, and malnutrition among tribal populations. To address these problems, identifying and demarcating the rain shadow region of Attappady is crucial and unavoidable. Hence the following description tries to answer the question of why the eastern part of Attappady is experiencing less rainfall and how much area is affected by aridity.

4.2 Scope of Geospatial Technology in Micro-Climate Study

Recently, application of Geospatial Technology in the micro climatic study, especially in assessing climate change impacts, and identifying vulnerable regions particularly in drought - prone areas is high .Geo-informatics encompassing spatial data, satellite imagery, remote sensing, Geographical Information System (GIS), Global Positioning System (GPS), emerges as an indispensable tool for acquiring, analyzing, interpreting, distributing, and utilizing geographic information for monitoring temperature changes, sea level rise, land cover alterations, and greenhouse gas emissions (Ossai and Anyadiegwu, 2014). The integration of geospatial technologies not only provides a comprehensive view of climate change dynamics but also facilitates informed decision-making, effective adaptation strategies, and global collaboration. These technologies allow for the downscaling of climatic data to smaller political units, enhancing local climate understanding and management (Mayomi et al., 2024). This technology also plays a crucial role in assessing impacts on climate change, particularly in disaster-prone areas. It aids in identifying vulnerable regions and planning for resilience against extreme weather events (II, 2022). Moreover, geo-informatic techniques are essential for analyzing urban microclimates, helping urban planners mitigate adverse effects of urbanization on local climates (Shimod, 2023). The generation of thematic maps provides visual insights into climatic variables, facilitating better communication of climate data to stakeholders (Mayomi et al., 2024) (Ikusemoran & Bello, 2023). The present study is proposed at Attappady hill areas have a geographical extension of 829.45 Km^2. Hence, the researcher considered this region as a microclimate division and employed the methodology of micro climatic studies for this purpose. GIS is an ideal tool for the demarcation of the rain shadow mechanism as applied in this study and the details are given in the following paragraphs.

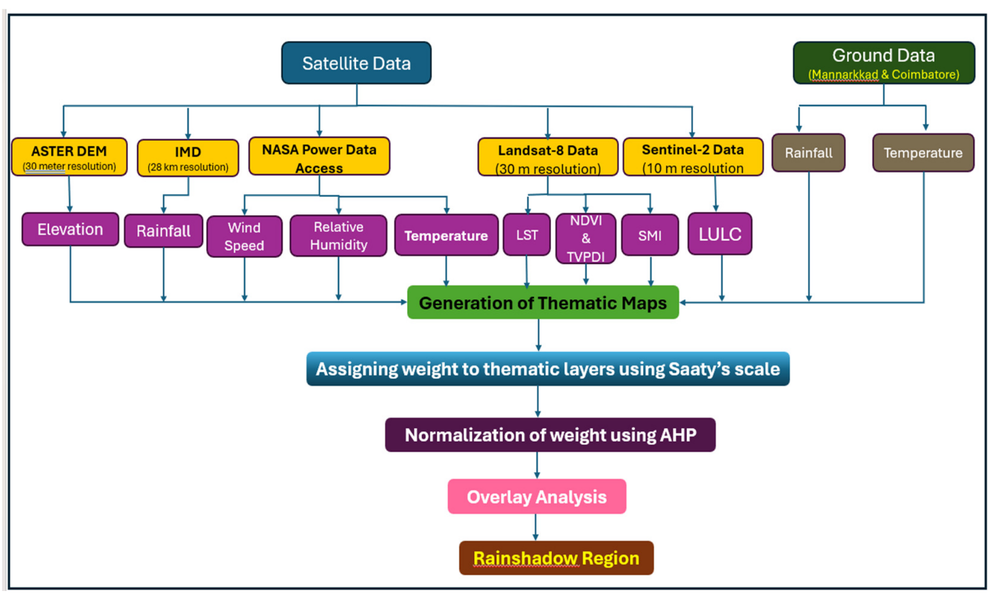
4.3 Materials and Methods for Rain Shadow Demarcation

Demarcation or delineation of the rain shadow region is a complex and more process involved one. To delineate the rain shadow zone effectively, detailed climatic data gathered from ground-based weather stations at Mannarkkad and Coimbatore played a pivotal role. These stations provided essential, localized measurements of temperature, precipitation, and other meteorological parameters, forming the backbone of the analysis. To bolster the accuracy of this ground-derived data and to ensure its alignment with broader regional patterns, additional support was drawn from a variety of weather-related satellite sources. These included data from the Indian Meteorological Department (IMD), which offers comprehensive insights into India's weather systems, and the Tropical Rainfall Measuring Mission (TRMM), renowned for its precise rainfall estimates across tropical regions. By integrating these diverse datasets, sourced from reputable online platforms, the study achieved a robust validation of the rain shadow demarcation, with the ground station data serving as the critical foundation for understanding the local climatic dynamics. This combined approach ensured that the delineation was both grounded in real-world observations and enriched by satellite-based perspectives, enhancing the reliability and relevance of the findings. Table 4.1 shows various parameters used for the study and their data sources. Ten thematic layers were mainly prepared for this study, viz. rainfall, elevation, land use land cover, relative humidity, temperature, wind speed, Land Surface Temperature (LST), Normalized Difference Vegetation Index (NDVI), Soil Moisture Index (SMI), and Temperature Vegetation Precipitation Dryness Index (TVPDI) as the effective factors. All of these factors have a direct impact on a region's ability to become a rain shadow. The thematic layers were mapped by digitizing and the data has been processed by using various GIS tools. The methodology adopted for this study is illustrated in Fig.4.1 through a schematic diagram.

Table 4.1: Data sources used for delineation of Rain Shadow region

Sl No	Parameter	Data source
1	Rainfall	https://disc.gsfc.nasa.gov/earthdata
2	Elevation	ALOS DEM (12.5 Meter Resolution)
3	Wind Speed	NASA POWER I Data Access Viewer
4	Relative Humidity	NASA POWER I Data Access Viewer
5	Temperature	NASA POWER I Data Access Viewer
6	LST	https://earthexplorer.usgs.gov/r-Landsat 8 OLI/TIRS C1 Level-1, Path 144, Row: 052, Dated on 27-January, 2024.
7	NDVI	Google Earth Engine.
8	Land use land cover	https://earthexplorer.usgs.gov/r-Landsat 8 OLI/TIRS C1 Level-1, Path 144, Row: 052, Dated on 14- January, 2024
9	SMI	https://earthexplorer.usgs.gov/r-Landsat 8 OLI/TIRS C1 Level-1, Path 144, Row: 052, Dated on 27-March, 2024.
10	TVPDI	https://earthexplorer.usgs.gov/r-Landsat 8 OLI/TIRS C1 Level-1, Path 144, Row: 052, Dated on 27-March, 2024.

Source: Prepared by Researcher



Source: Prepared by Researcher

Fig. 4.1: Scheme shows the methodology for delineation of Rain Shadow region

4.3.1 Analytical Hierarchy Process

The Analytical Hierarchy Process (AHP) method was used in this study for spatial demarcation of the micro climatic region especially in the context of rain shadow mechanism. AHP method was developed by Saaty (1980) and this is a very stretchy and well-structured method for analysing and solving complex decision problems by decomposition, comparative judgments, and synthesis of priorities. This method allows to focus judgment on each of several properties separately which are essential for making a strong decision (Saaty, 1990) and is the most common and well-known GIS based method for delineating the zone and this method helps in integrating all thematic layers (Arulbalaji et al., 2019). The AHP model applied in this study to determine weights and ranks of different parameters for the rain shadow index model. In this method, each factor assigned rank on a scale of one to nine by assessing each element based on Saaty's scale (Table 4.2). Weightage assigned to the themes of deciding rain shadow regions are high towards leeward side and to windward side are assigned low values.

Table 4.2: Saaty's scale (1980) for pairwise comparison of parameters

Intensity of Importance	Scaling
Extreme importance	9
Very to extremely strong importance	8
Very strong importance	7
Strong to very strong importance	6
Strong importance	5
Moderate to strong importance	4
Moderate importance	3
Equal to moderate importance	2
Equal importance	1

Source: Saaty, T. L. (2012)

4.4 Preparation of Thematic Layers

Mapping rain shadow regions requires an in-depth understanding of climatic and topographic variations, and spatial data combined with advanced spatial technologies provides the tools to Achieve this. In the context of rain shadow mapping, combining climate factors such as rainfall, temperature, wind speed, and relative humidity with ecological indicators such as NDVI and

TVPDI, along with topographic data like elevation and land use land cover, offers a complete perspective. These ten datasets were carefully chosen because they complement each other: climate variables reflect atmospheric conditions, ecological data highlights vegetation and land degradation, and land use details illustrate the influence of human activity. Together, we can generate a detailed and accurate analysis of the rain shadow region in Attappady, which gives accurate information supporting better planning and sustainable resource management. The description and its relevance of the selected thematic layers and its generated methods are explained in detailed manner in the following paragraphs.

4.4.1 Climatic Variable

Since rainfall is a complex phenomenon influenced by various atmospheric and topographic factors, it is one of the important variables used for rain shadow demarcation. The amount rainfall is an important component in determining whether or not a location is in the rain shadow. Rainfall intensity is significantly influenced by orographic effects, where mountain block moist air, leading to increased precipitation on the windward side and reduced rainfall in the rain shadow region. In Attappady, the windward side of western part receives 5218 mm of rainfall, but the leeward side of eastern part receives a minimum of 1000 mm of rainfall. The significant difference in rainfall between the two sides is typical of areas influenced by orographic lift. Rainfall data from the Tropical Rainfall Measuring Mission (TRMM) was used for this study. According to Tarek et al. (2016), TRMM data are more reliable in estimating the average rainfall of a region. Rainfall is measured in millimeters in TRMM data. The downloaded data includes information from both inside and outside the research region. The mean was computed by downloading the annual average rainfall data from 1994 to 2024 (30 years). With the help of a conversion tool, the mean raster data of the rainfall was transformed into point data (Raster to Point). For the study area, the transformed point data was interpolated using the spatial analysis IDW tool. Chen and Liu (2012) found that IDW is a suitable method of spatial interpolation to predict the probable rainfall. The Natural Breaking Method was used to classify the final interpolated rainfall data.

Microclimate datasets such as temperature, wind speed and relative humidity provide a great role in the rain shadow region demarcation. The interplay between rain shadow effects, wind speed and relative humidity is complex and significantly influenced by atmospheric dynamics. In Attappady, minimum temperature is 21.26°C, maximum is 22.84°C, and some time, it rises above 25°C. The temperature variation can be attributed to the rain shadow effect. As air rises on the windward side, it cools, leading to lower temperatures. Conversely, as air descends on the leeward side, it warms, resulting in higher temperatures above 25°C. Wind speed varies between 3.43 and 3.46 m/s, with a mean of 3.45 m/s. Wind speed variations may result from the complex interactions of local topography and regional wind patterns. Windward sides often experience stronger winds due to the interaction of onshore breezes and the orographic lifting of air. Leeward sides, on the other hand, may be sheltered from strong winds, which can explain the lower mean wind speed. Relative humidity ranges from 77.27% to 78.54%, with a mean of 77.86%. The higher relative humidity on the windward side can be attributed to the cooling effect of the increased rainfall and reduced temperatures. On the leeward side, where temperatures are slightly higher and rainfall is less, the air may be drier on average. The threshold for wind erosion is influenced by relative humidity, with a maximum threshold observed at approximately 35% humidity, indicating a significant relationship between wind speed and humidity levels (Ravi & D'Odorico, 2005). Rain shadow regions typically experience reduced precipitation on the leeward side of mountain ranges, which can correlate with temperature variations. When mean monthly temperature decrease of 1 degree correlates with an increase of 13mm in monthly precipitation, suggesting that temperature inversely affects rainfall (Striem, 1979). The development of rain shadows is affected by atmospheric dynamics, including wind speed and terrain relief. Temperature (in degrees Celsius), wind speed (m/s), and relative humidity (in percent) were all acquired from NASA Power Data Access website.

Sample points/areas of interest were randomly selected from both inside and outside the study area. The mean figure for all these parameters were computed from downloaded data and a conversion tool was used to convert the mean raster data to raster to point data and, the transformed point data was interpolated using the spatial analysis IDW tool.

4.4.2 Physiographic Variable

Relief or topography has an important role in the distribution of climatic elements, especially in rainfall. Topography itself has a strong effect on spatial patterns of precipitation both globally and regionally (Smith, 1979) and characteristics of the topography, including the length, width, and height of the mountain range determine how the atmosphere interacts with the mountains (Houze, 1993). Orographic effect brings not only the initiation and intensification of precipitation on the windward side of mountains and hills but also the relative deficit of precipitation on the lee side. The rain shadow effect influencing regional climates and ecosystems of the uplifted area (Takeuchi & Larson, 2005). Rain shadows occur when moist air ascends over a mountain range, leading to precipitation on the windward side and aridity on the leeward side. This phenomenon is intricately linked to the elevation of the terrain, which affects atmospheric dynamics and precipitation patterns. As air rises over mountains, it cools and loses moisture, resulting in precipitation on the windward side. The height of the mountain (relief) significantly influences the extent of the rain shadow; higher elevations typically lead to more pronounced rain shadows (Galewsky, 2009). The elevation of mountain ranges can dictate the distribution of precipitation, with higher peaks often receiving more rainfall (Zavala et al., 2020). Studies show that as mountain uplift, the associated rain shadow can evolve, impacting sediment transport and erosion rates in the surrounding areas (Zavala et al., 2020). The relief image was generated from the Advanced Land Observation Satellite (ALOS) data (12.5 meter) using the classified method in ArcGIS platform.

The Attappady area is flanked by mountain ranges, the Nilgiris in the north and extensions of the Western Ghats in south and in the west. The terrain of Attappady area is marked by hills and valleys, particularly high mountains and narrow valley in the western half. Attappady lies between the two ranges of Western Ghats and the general slope of the area is towards north-east. From the south-west the elevation increases from 90 m to 550 m at Mukkali. From Mukkali to Anakkatty towards east, the elevation is between 500 m and 575 m. The northern boundary of Attappady block lies at an elevation of around 2300 m in the Nilgiris peak. From there it decreases along the south-west and later climbs up to 2000 m at Muthikulam. Around 51 % of Attappady has an elevation between 600m to 1000m and 71.6% of the area has a slope between 15 to 30 degrees, showing the environmentally sensitive nature of the region (Velluva 1999).

4.4.3 Soil Moisture Index (SMI)

The relationship between rain shadow effects and SMI is significant, particularly in mountainous regions were topography influences moisture availability. Rain shadow areas, characterized by reduced precipitation on the leeward side of mountains, can lead to lower soil moisture levels, which in turn affects vegetation and agricultural productivity. The SMI integrates moisture data to predict crop yields, demonstrating that lower soil moisture in rain shadow areas can lead to reduced agricultural productivity (Isard et al., 1995). SMI is a direct indicator of dryness of the land surface. The soil moisture index is based on empirical parameterization of the relationship between land surface temperature (LST) and normalizeddifference vegetation index (NDVI). The SMI has been retrieved directly according to (Moawad, 2012) using LST as follow (Equation 1);

$$SMI = \frac{(LSTmax - LST)}{(LSTmax - LSTmin)} \quad \text{..............................Eq.1}$$

Where SMI is the Soil Moisture Index, LSTmax, LSTmin are the maximum, minimum and value of the retrieved LST respectively. LST and the NDVI were calculated from Landsat-8 Operational Land Imagery (OLI) data.

4.4.4 Land Surface Temperature (LST)

Land Surface Temperature, the skin temperature of the ground, is identified as a significant variable of microclimate and radiation transfer within the atmosphere (Suresh et al, 2016). The relationship between rain shadow and LST is complex, influenced by precipitation patterns and local climatic conditions. Rain shadow regions, characterized by reduced rainfall on the leeward side of mountains, can lead to significant variations in LST due to changes in moisture availability and surface heating (Wei et al., 2014). The negative correlation between precipitation and temperature is evident, where lower rainfall results in higher LST due to enhanced surface heating from solar radiation (Berg et al., 2015). Vegetation plays a crucial role in moderating LST; areas with less vegetation, typical of rain shadow regions, exhibit higher temperatures due to lower evapotranspiration rates (Liu et al., 2018). Landsat-8 OLI data having Thermal Infrared Sensor (TIRS) with two bands (band 10 and band 11 with 100 m resolution) which is useful in providing more accurate surface temperatures. Single Window Algorithm (Suresh et al, 2016) has been adopted (Equation-2) to generate LST from Landsat-8 OLI data for the study area.

LST= BT/1+W*(BT/p)*In(e))Eq.2

Where, BT is the at satellite temperature, W is the wavelength of emitted radiance (11.5µm) p is*C/S (1.438*10∧ -2mk) h = Planck's Constant (6.626*10 ∧ -34JS) s = Boltzmann Constant (1.38*10 ∧ -23J/K) C = Velocity of light (2.998 *10 ∧ 8 m/s) p = 14380

4.4.5 Normalized Difference Vegetation Index (NDVI)

Normalized difference vegetation index is one of the most prominent vegetation indices used in image processing to investigate the green cover of photosynthetic plants. The relationship between rain shadow effects and the NDVI is significant, as rainfall patterns directly influence vegetation health and distribution. Rain shadow areas, characterized by reduced precipitation on the leeward side of mountains, can lead to lower NDVI values, indicating less vegetation cover. NDVI often lags behind rainfall by one to two months, suggesting that vegetation response to precipitation is not immediate, particularly in regions affected by rain shadow effects (Chandrasekar et al., 2016). The impact of rain shadow on NDVI varies by vegetation type, with forests showing a stronger correlation to precipitation than grasslands or scrublands) Nightingale & Phinn, 2003). As climate change alters rainfall patterns, monitoring NDVI can provide insights into how ecosystems in rain shadow areas may respond, informing conservation strategies (Chamaille-Jammes et al., 2006).

The following is the mathematical formula (Equation 4) for calculating NDVI:

$NDVI = (NIR - RED) / (NIR + RED)$ …… Eq.3

NDVI values are unit less and vary on a scale with an upper limit of +1 and a lower limit of -1, with the higher the value on the NDVI scale, the more photosynthetically active the surface vegetation is. Negative NDVI values are used to represent non-vegetated environments such as ice, lake bodies, and rocks (i.e., values less than 0). Low vegetation is defined as having NDVI values between 0 and 0.2; medium vegetation is defined as having NDVI values between 0.2 and 0.4; and mature vegetation is defined as having NDVI values greater than 0.4. (Kumar et al., 2013). In general, a region's NDVI reaches its maximum at the height of the growth season, which in Kerala is from June to December. The NDVI-derived values are frequently employed as a geographical and temporal measure of vegetation health (Mingjun, 2007). Whether natural or farmed, the growth pattern of vegetation is constantly impacted by climatic elements such as precipitation, temperature, and so on (Schmidt et al., 2000) making it critical to investigate the impact of precipitation on vegetation pattern. Natural Breaks were used to further categorise the data after these factors were calculated.

4.4.6 Temperature Vegetation Precipitation Dryness Index (TVPDI)

TVPDI is the remote Sensing data-based dryness methods are widely used in dryness assessments due to the large coverage range and high temporal resolution. TVPDI is a simple, operational and efficient dryness index through constructing a 3D space (P, NDVI and LST) according to the Euclidean distance method. It is used to represent the surface dryness-wetness status (Wei et al., 2020). Hence, it is used to delineate the rain shadow region. TVPDI has been calculated by applying Wei et al., (2020) proposed method. Normalized LST (NLST) =

$$\frac{LST - LSTmin}{LSTmax - LSTmin} \quad \text{Eq.4}$$

$$\text{Normalized NDVI (NNDVI)} = \frac{NDVI - NDVImin}{NDVImax - NDVImin} \quad \ldots\ldots\ldots\ldots\text{Eq.5}$$

$$\text{Normalized P(NP)} = \frac{P - Pmin}{Pmax - Pmin} \quad \ldots\ldots\ldots\ldots\text{Eq.6}$$

$$\text{TVPDI} = \sqrt{(NLSTmax - NLST)^2 + (NNDVI - NNDVImin)^2 + (NP - NPmin)^2} \ldots\ldots\ldots \text{Eq.7}$$

Where, NLST, NNDVI, and NP represent the normalized LST, NDVI, and P represent the annual mean values, and NLSTmax, NNDVImin, and NPmin represent the driest status.

4.4.7 Land Use Land Cover (LULC)

Land use practices such as agriculture and deforestation exacerbate the effects of rain shadow conditions. In drought-prone areas, improper land management can lead to vegetation degradation and increased soil exposure (Suma and Srinivasa, 2021). In rain shadow regions, variations in rainfall and land use significantly affect vegetation cover. Higher rainfall years correlates with increased closed vegetation, while drier years lead to more exposed soil and sparse vegetation (Araujo et al., 2023). Land use land cover (LULC) data for the year 2015 was also created using Landsat-8 OLI data. The seven-fold classification approach of the National Remote Sensing Centre (NRSC)-Level-1 was used. Before the creation of land use data, data was pre-processed, such as preparing multispectral data (24 meters) with the band composite tool and converting the multispectral data to 15-meter resolution data using the ERDAS Imagine platform's resolution merge analysis. Here, 15 PAN data and 24 metre multispectral data were combined, and the 24 metre multispectral data was then transformed to 15 metre data with the help of PAN (15 metre resolution) by applying resolution merge. After the data conversion, supervised classification-Parallel Piped-Maximum likelihood classification algorithms were used. Google Earth Web Application and Survey of India (1: 50,000) toposheets were used for Area of Interest selection.

4.5 Rain Shadow Index and Computation of Priority Scores for the Thematic Layers

To demarcate the rain shadow region in the GIS environment, the relative degree of influence of each theme on the rain shadow region was computed as the priority score and AHP was employed to generate the priority score. The AHP model was applied to determine weights and ranks of different parameters for the rain shadow index model. The formula for calculating the rain shadow index is:

$$RS = \sum_{i=1}^{n} Wi * Ri * 100 \ldots \qquad \text{Eq.8}$$

where RS is the Rain Shadow, Wi is the weight of each parameter, and Ri is the rank of rating of the classified values under a parameter.

The probability of rain shadow has been assessed in this study by using RS model where the final map has been categorized into two classes are rain shadow and wet region. The analytical hierarchy process in this paper consists of two major parts. The first section is the main classification scheme of all the parameters where according to the importance of each parameter values are given and weights are calculated. The second section is constructed by categorizing all the parameters into subcategory. A pair wise comparison matrix has been built in which the diagonal elements are equal to 1 (Equation. 10). The relative importance of all these parameters is given based on different criteria and values (1. Equally important; 3. Moderately more important; 5. Strongly more important; 7. Very strong more important; 2, 4, and 6 are intermediate values). Each row of these values describes the relative importance between two parameters. For instance, the first row represents the significance of elevation with compared to other seven parameters positioned in the column. In the pair wise comparison matrix, the rows follow the inverse value of each factor and its significance with other.

$$A=(aij)n*n =\begin{bmatrix} a11 & a12 & a1n \\ a21 & a22 & a2n \\ \\ an1 & an2 & ann \end{bmatrix}, aii=1, aij =1/aji, aij\neq 0 \qquad \text{Eq.9}$$

After that, weighted arithmetic mean methodology has been employed to calculate the weights in the pairwise comparison matrix. The value in the pairwise comparison is normalized to acquire the normalized values in the standard pairwise comparison matrix (Equation. 8). Later, the weights of all the parameters are determined by mean row method in the standard pairwise comparison matrix. The maximum characteristics root can be expressed as follows:

$Aw = \lambda max$……………………Eq.10

The consistency of the following method is done by the following equation (Saaty 1980):

$$CR = \frac{CI}{RI} \quad \text{……….Eq.11}$$

Where CI is consistency index, CR is consistency ratio, and RI is the random index,

$$CI = \frac{\lambda max - n}{n-1} \quad \text{…………..Eq.12}$$

The assigned weights are consistent only when the consistency ratio (CR) remains within 10%, otherwise, the weights should be reconsidered to evacuate irregularity. CR is estimated by the following equations (Saaty, 1980):

$$CI = \frac{\gamma max - n}{n-1} \quad \text{…………………….Eq.13}$$

Where n is the number of conditioning factors, and γ_{max} is the principal Eigen value of the matrix (table 4.3).

Table 4.3: Random Index values for different n values

N	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Source: Saaty, T. L. (2012)

For n=10, the RI value is 1.49. Here, γmax calculated as 11.30, CI as 0.14 and CR as **0.097**. Therefore, the consistency ratio is calculated as **0.097**. Since **0.097**<0.10, weights assigned to the parameters exhibit.

where CR represents the consistency ratio, CI stands for the consistency index, RI indicates the random index, λmax represents the principle eigen value of matrix, and n is the number of components or factors in the matrix. Calculation of RI values is calculated by a large number of components in Saaty's (1980). It is found that RI depends on the number of factors. When the components are eight, the corresponding value of RI is 1.41 according to the Saaty's (1980) work. For this study, the consistency ratio (CR) is accepted if the value is < 0.10, and it indicates a reasonable level for the pairwise comparison matrix. However, in case of consistency ratio (CR) > 0.10, the values of CR have been readjusted according to the Saaty (1977). Detailed information regarding the analytical hierarchy process is provided by Saaty (2012), which has been referred for all the calculations of this research. All the parameters considered in this study have been assessed individually and classified into four subcategories. Different ranks have been provided to each subcategory through relative scoring using AHP method (Table 4.3). High value has been assigned to variable which is closely associated with rain shadow and less value were given to wet region or a region having high rainfall.

4.6 Microclimatic Features of Attappady Hilly Region

The Attappady Hills exhibit a unique microclimate characterized by its diverse topography, vegetation, and climatic conditions. The region, situated at varying altitudes, experiences a mosaic of microclimates that significantly influence local biodiversity, agricultural practices, and the livelihoods of indigenous communities. One prominent feature of the microclimate in Attappady is the pronounced variation in temperature and humidity across different elevations. The lower altitudes, characterized by dense forests and agricultural land, experience higher temperatures and humidity levels, while the cooler, elevated areas present a more temperate climate. This gradient fosters a rich diversity of flora and fauna, with species adapted to specific microclimatic conditions. The interplay between these microclimatic features and human activities is evident in the agricultural practices of the local communities. Traditional farming methods are often adapted to support the specific climatic conditions of different microenvironments, promoting sustainable land use and conservation of biodiversity. The micro climatic understanding of the Attappady hill region is very significant as it is directly connected with life and livelihood dynamics of the people of this region. The result of each parameter of the study gives how these parameters are integrated and influence each other. The results of the study are elaborated as follows.

4.6.1 Variability of Rainfall in Attappady Hilly Region

The distribution and variability of rainfall in Attappady hill region is uneven. The results (table 4.4) indicate that Attappady hill region receives rainfall from both the Northeast (NE) and Southwest (SW) monsoon season. The average rainfall varies from 220 mm in NE season and 309 mm in the SW monsoon season. The average rainfall is 2096 mm for the 30 years data (1994-2024). The rainfall map is classified into four: the very low, low, moderate, and high as presented in Fig. 4.2. Areas of low rainfall (<1000 mm) is recorded at eastern part and high rainfall (3000 mm) is found at western part of the hill region. In the eastern part of the hill region rainfall and wind speed are having a sudden change of magnitude on the leeward side of the mountains.

The west-facing hills and the regions receive a lot of rain. But, on the leeward side of hills rainfall decreases dramatically as one travel east towards the Tamil Nadu border.

As a result, beyond and east of the mountain ranges, a rain-shadow area develops at Walakkad and Agali, the average rainfall is 4798 mm, whereas at Sholayur and Pudur, it is 650 mm. The extremely elevated region in the western regions near the origins of the Siruvani and Bhavani rivers receives much more rainfall, ranging from 654 mm in the eastern half of Sholayur and Pudur-Nattakallur to 2000 mm in the western part of Pudur-Walakkad and southern part of Palakkayam in Agali. According to data, approximately 68 percent of regions in Agali and Sholayur are covered by rain shadow panchayats, with Pudur having the least amount of rain shadow panchayats in Attappady at 49.98 percent.

Table 4.4: Average Rainfall Variations of the Attappady Hilly Region (1994 - 2024)

Sl.No	Rainfall in (mm)	Area in Km^2	Area in %
1	>650	0.54	0.07
2	651-700	1.51	0.18
3	701-800	11.21	1.36
4	801-900	12.18	1.48
5	901-1000	28.68	3.48
6	1001-1250	57.31	6.95
7	1251-1500	69.48	8.42
8	1501-2000	232.88	28.23
9	2001-3000	305.48	37.04
10	3001-4798	105.55	12.80

Source: TRMM data

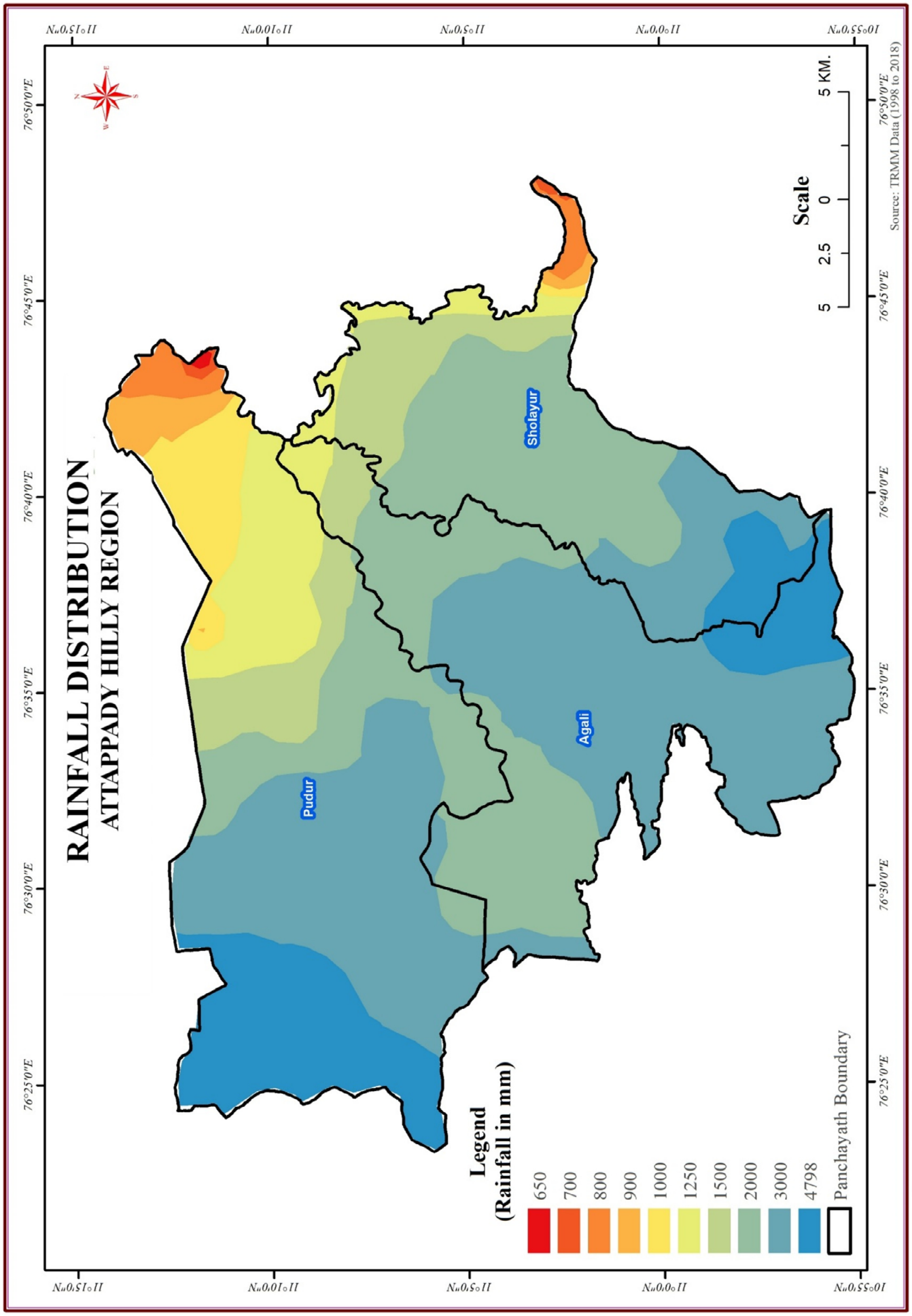
4.6.2 Variability of Temperature of the Attappady Hilly Region

In the study area, temperature varies from 23.08^0 to 24.87^0 (table 4.5). The average temperature is 23.59^0 Celcius temperature (1981-2024). The temperature is higher (>24^0C) in the south and eastern part of the study area whereas low temperature (<23.25^0C) is experienced in the western part of the study area which is shown in Fig 4.3. Due to the strong hot and dry north-easterly winds sweeping in from interior Tamil Nadu, particularly through the Palakkad-Gap in the Western Ghats, high temperature is maintained in Palakkad.

Table 4.5: Average Temperature Variability of the Attappady Hilly Region (1981-2024)

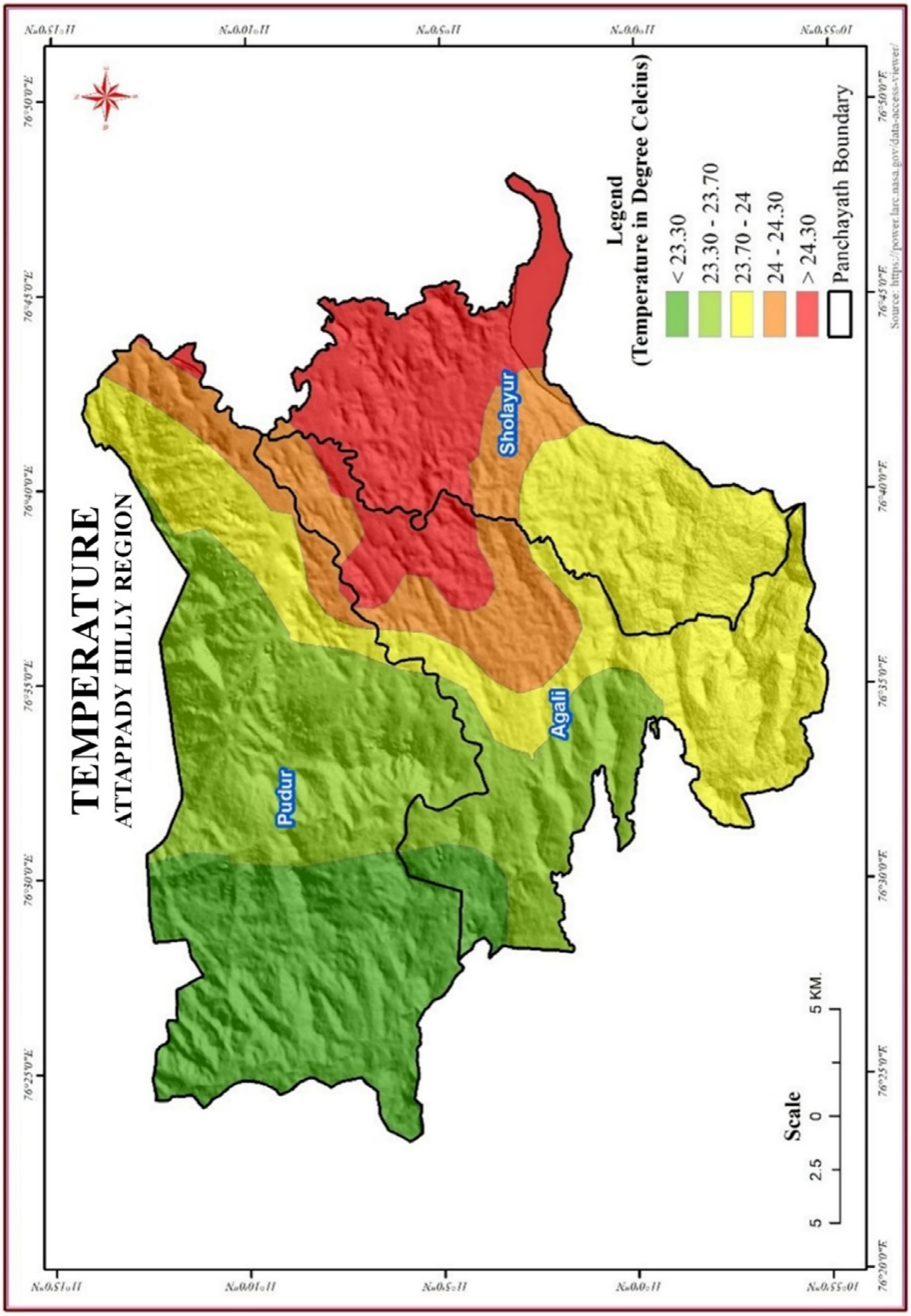
Sl.No	Temperature in (^{0}C)	Area in Km^2	Area in %
1	23-23.25	119.31	14.44
2	23.26-23.50	517.31	62.61
3	23.51-23.75	105.65	12.79
4	23.76-24.00	67.66	8.19
5	>24	16.34	1.98

Source: NASA POWER | Data Access Viewer



Source: Prepared by Researcher

Fig. 4.2: Rainfall Distribution Map of the Attappady Hilly Region



Source: Prepared by Researcher

Fig. 4.3: Temperature Variation Map of the Attappady Hilly Region

4.6.3 Variability of Wind Speed of the Attappady Hilly Region

The maximum wind speed in the research region is 2.71 mph, while the minimum wind speed is 1.88 mph (Fig. 4.4). The average wind speed observed in this region is 2.11 mph (1981– 2024). Because of the mountain barrier, the wind speed has been dispersed in the western margin area and hence the complete eastern portion showing the uniform 2.05 mph wind speed. The southern part has some undulations in the topography which facilitate to increase the wind speed (table 4.6).

Table 4.6: Average Wind Variability of the Attappady Hilly Region (1981– 2024)

Sl.No	Wind Speed	Area in Km^2	Area in %
1	<2.0	526.34	63.64
2	2.0-2.10	194.38	23.50
3	2.11-2.20	32.64	3.95
4	2.21-2.30	27.21	3.29
5	>2.30	46.45	5.62

Source: NASA POWER | Data Access Viewer

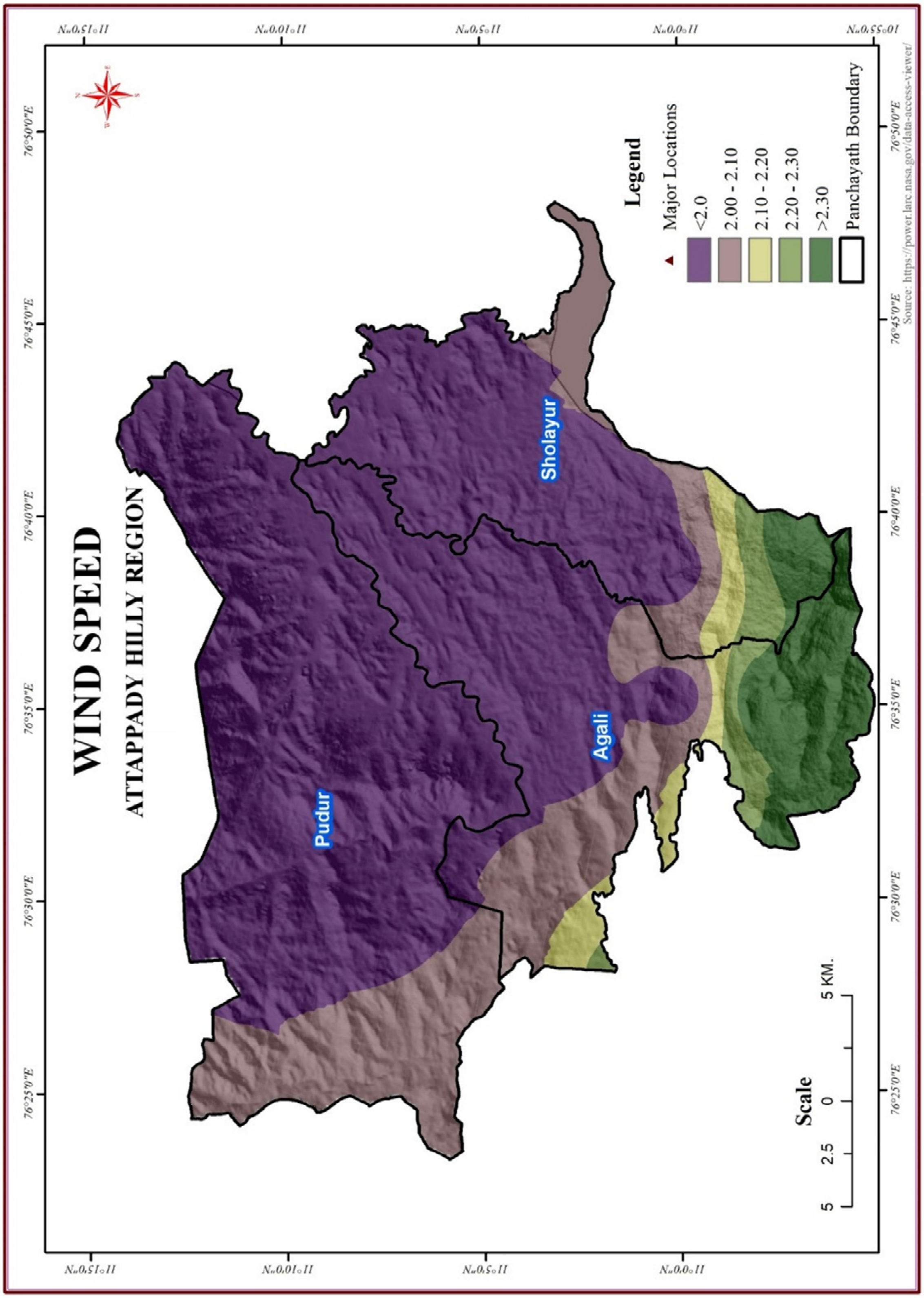
4.6.4 Variability of Relative Humidity of the Attappady Hilly Region

Attappady hill region is situated in between the Nilgiri hill ranges in the North and Vellinkiri hill ranges in the South with an extensive mountain valley. This mountain range location has a major role in influencing relative humidity of the study area. From the study area, it is well evident that the relative humidity gradually decreases from western part (81.17%) to the eastern part (74.91%) shown in Fig 4.5. In the eastern part of the study area, relative humidity is low with 74.91% when compared with western part due to mountain range effect (table 4.7).

Table 4.7- Average Relative Humidity of the Attappady Hilly Region (1981 – 2024)

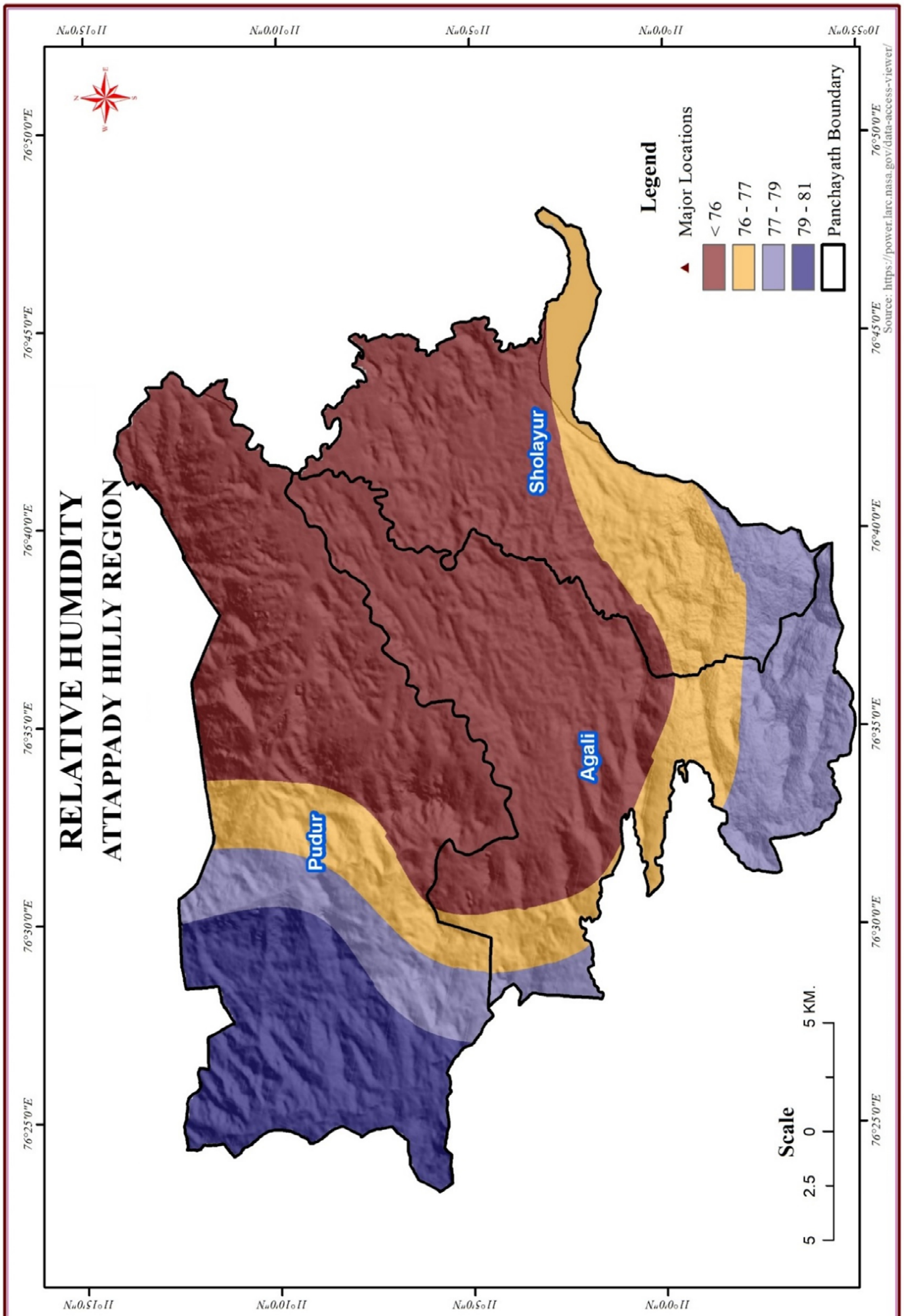
Sl.No	Relative Humidity	Area in Km^2	Area in %
1	<75	7.96	0.96
2	75-76	415.55	50.26
3	76-77	112.18	13.57
4	77-78	73.69	8.91
5	>78	217.35	26.29

Source: NASA POWER | Data Access Viewer



Source: Prepared by Researcher

Fig. 4.4: Wind Speed Map of the Attappady Hilly Region



Source: Prepared by Researcher

Fig. 4.5: Relative Humidity Map of the Attappady Hilly Region

4.6.5 Role of Relief in the Climatic Variability of the Attappady Hilly Region

Relief or topography has an important role in the distribution of climatic elements, especially in rainfall and humidity and wind speed. In the study area the elevation divides the region into two sections: the western side of the windward, which receives a lot of rain, and eastern side of the leeward, which receives less rain. Fig. 4.6 shows that the central and eastern part have relatively low relief features and north and west parts have high relief. These undulating topography affects the rainfall distribution of the study area. The topography of this region is carved out by tectonic, denudational and fluvial agents. The maximum height has been observed in the NW part (Anginda peak 2383 meter) and the lower elevation recorded in the Bhavani's valley and the southeast part of the study area (<500 meter). More than half of the study area, especially the central part of the study area showing medium altitude region of 500-1500 meter and about 10% area having high altitude region with an elevation of more than 1500 meter (table 4.8).

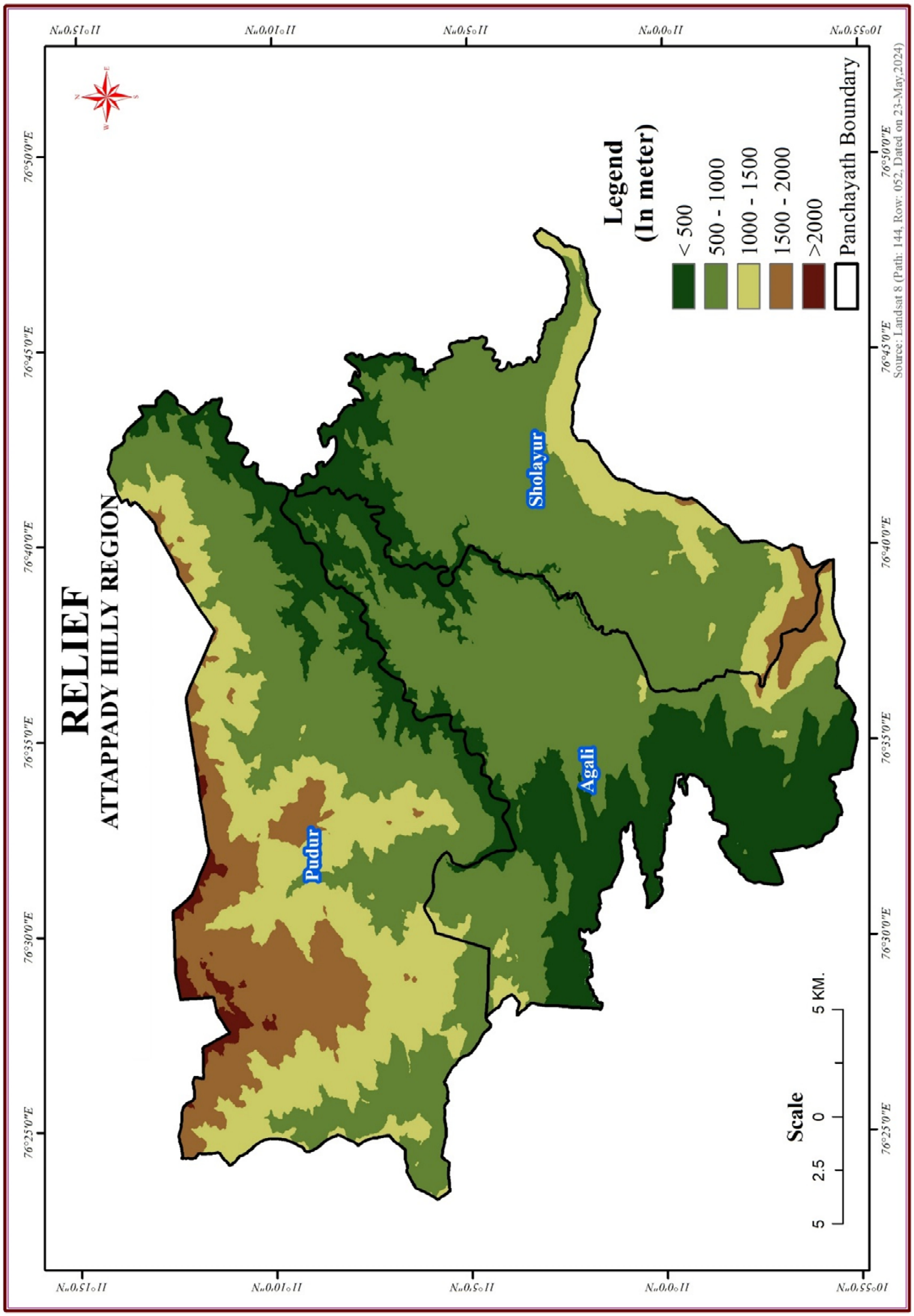
Table 4.8: Relief feature of the Attappady Hilly Region

Sl.No	Relief (in meter)	Area in Km^2	Area in %
1	<500	171.68	20.70
2	500-1000	411.48	49.62
3	1000-1500	160.51	19.36
4	1500-2000	77.84	9.39
5	>2000	7.67	0.01

Source: ALOS DEM (12.5-meter resolution)

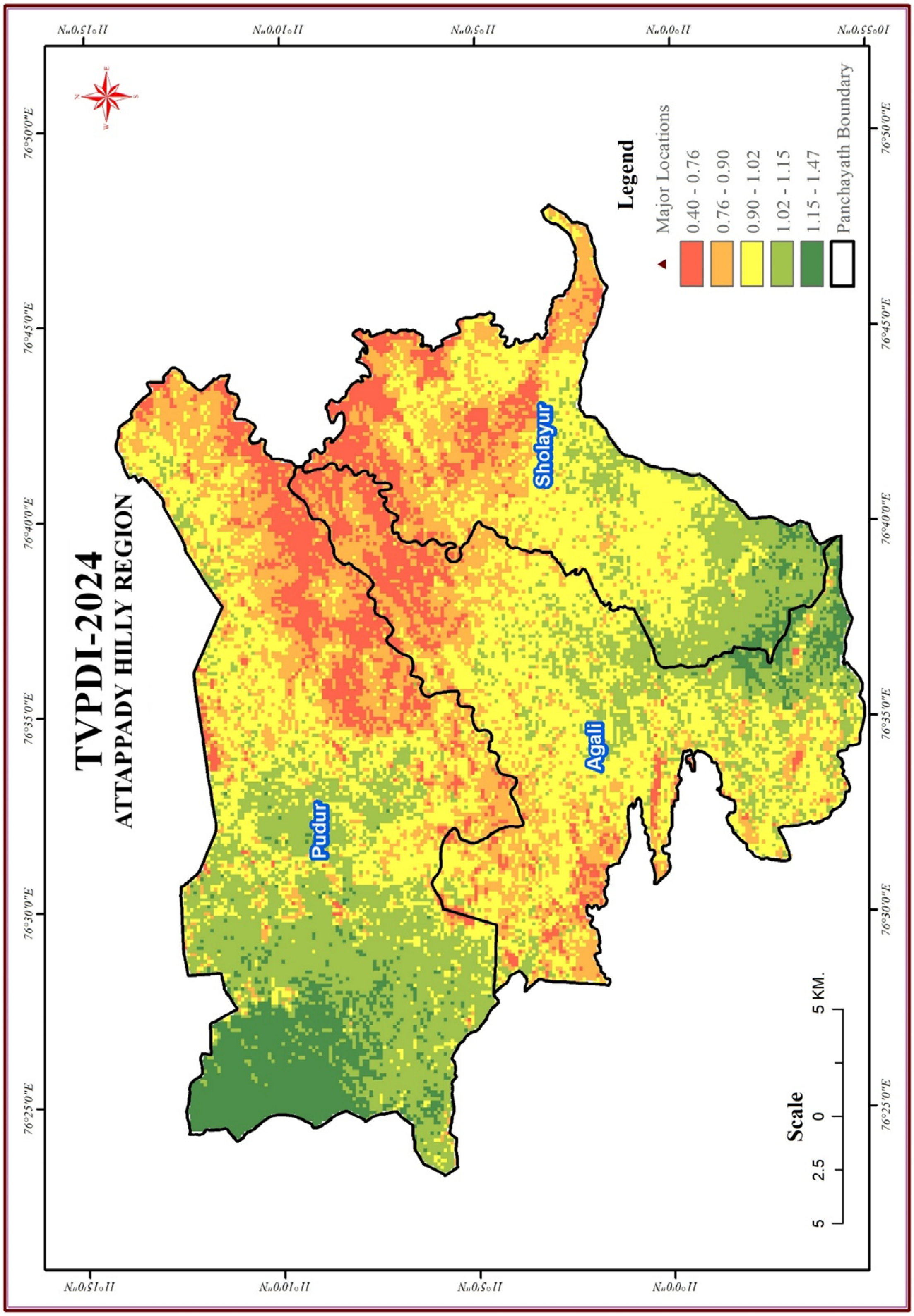
4.6.6 Temperature Vegetation Precipitation Dryness Index (TVPDI) of the Attappady Hilly Region

Temperature Vegetation Precipitation Dryness Index value ranges from 0.40 to 1.47 in this study area (table 4.9). As TVPDI is directly related to rainfall, the resultant value decreases from the western part to eastern part (Fig. 4.7). The western part has thick vegetation with good rainfall and vice versa in the eastern part. The valley is the way for flowing dry wind, therefore the decreased amount of rainfall and the associated features of vegetation and also low TVPDI index value found in this eastern part.



Source: Prepared by Researcher

Fig. 4.6: Relief map of the Attappady Hilly Region



Source: Prepared by Researcher

Fig. 4.7: Temperature Vegetation Precipitation Dryness Index (TVDPI) Map of the Attappady Hilly Region

Table 4.9: Temperature Vegetation Precipitation Dryness Index (TVDPI) of the Attappady Hilly Region

Sl.No	TVPDI Index	Area in Km^2	Area in %
1	0.40-0.76	86.91	10.58
2	0.76-0.90	181.69	22.12
3	0.90-1.02	291.93	35.54
4	1.02-1.15	201.07	24.48
5	1.15-1.47	59.82	7.28

Source: Landsat-8 Data (30-meter resolution)

4.6.7 Soil Moisture Index and its Variation of the Attappady Hilly Region

Soil Moisture (SM) is a direct indicator of dryness of the land surface. NDVI and LST are considered as essential data to obtain SMI calculation. This data was downloaded from Earth Explorer database. Soil Moisture Index was calculated from Landsat-8 Operational Land Imagery (OLI) data dated on February, 2024, Path: 152, Row: 052. SMI value for the study area varies from 0 to 0.99 (table 4.10). Increases value depicting high moisture content in the NW and southern part of the study area which is shown in Fig 4.8.

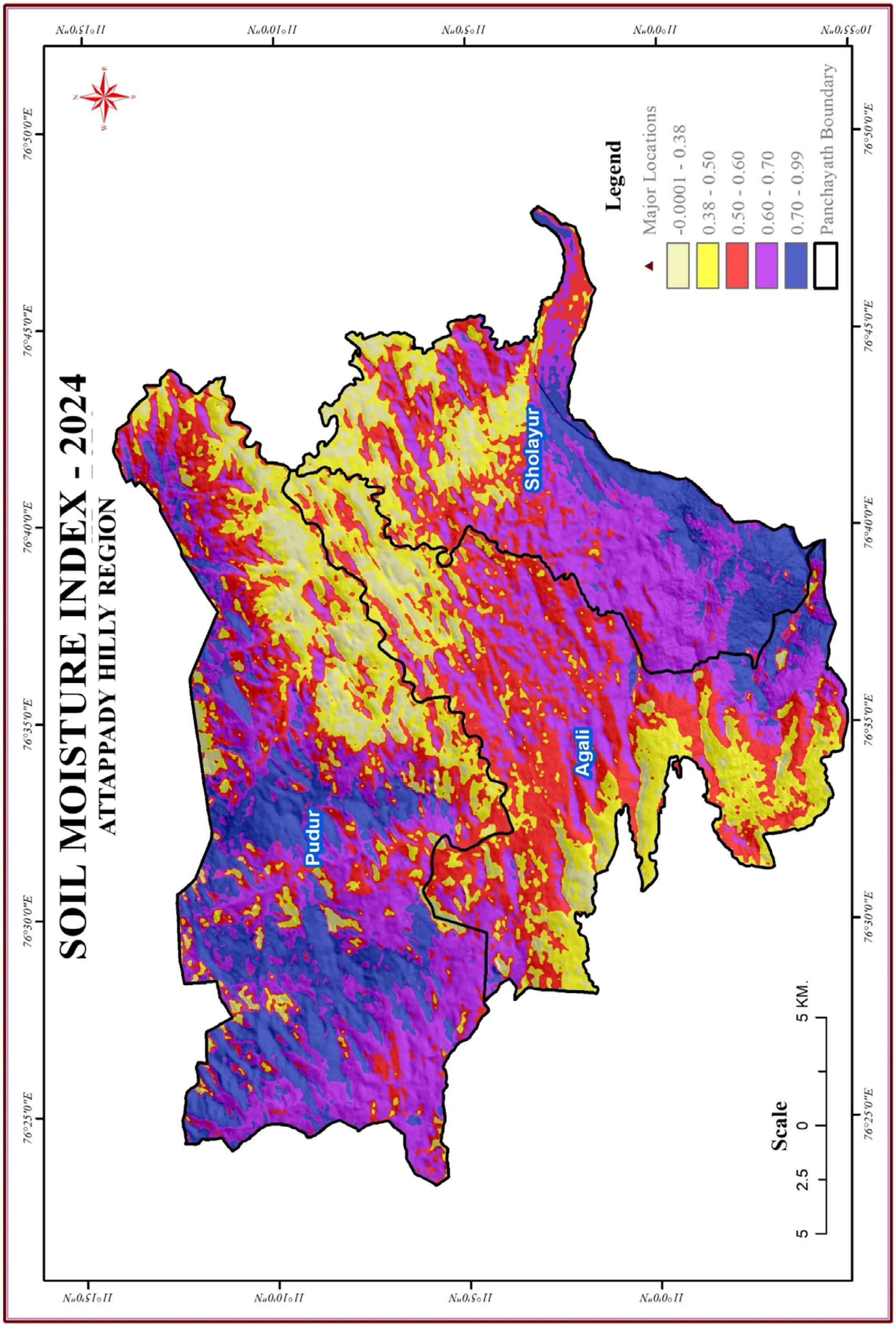
Table 4.10: Soil Moisture Index of the Attappady Hilly Region

Sl.No	SMI Index	Area in Km^2	Area in %
1	0.40-0.76	59.77	7.22
2	0.76-0.90	152.44	18.41
3	0.90-1.02	210.10	25.38
4	1.02-1.15	268.08	32.38
5	1.15-1.47	137.53	16.61

Source: Landsat-8 Data (30-meter resolution)

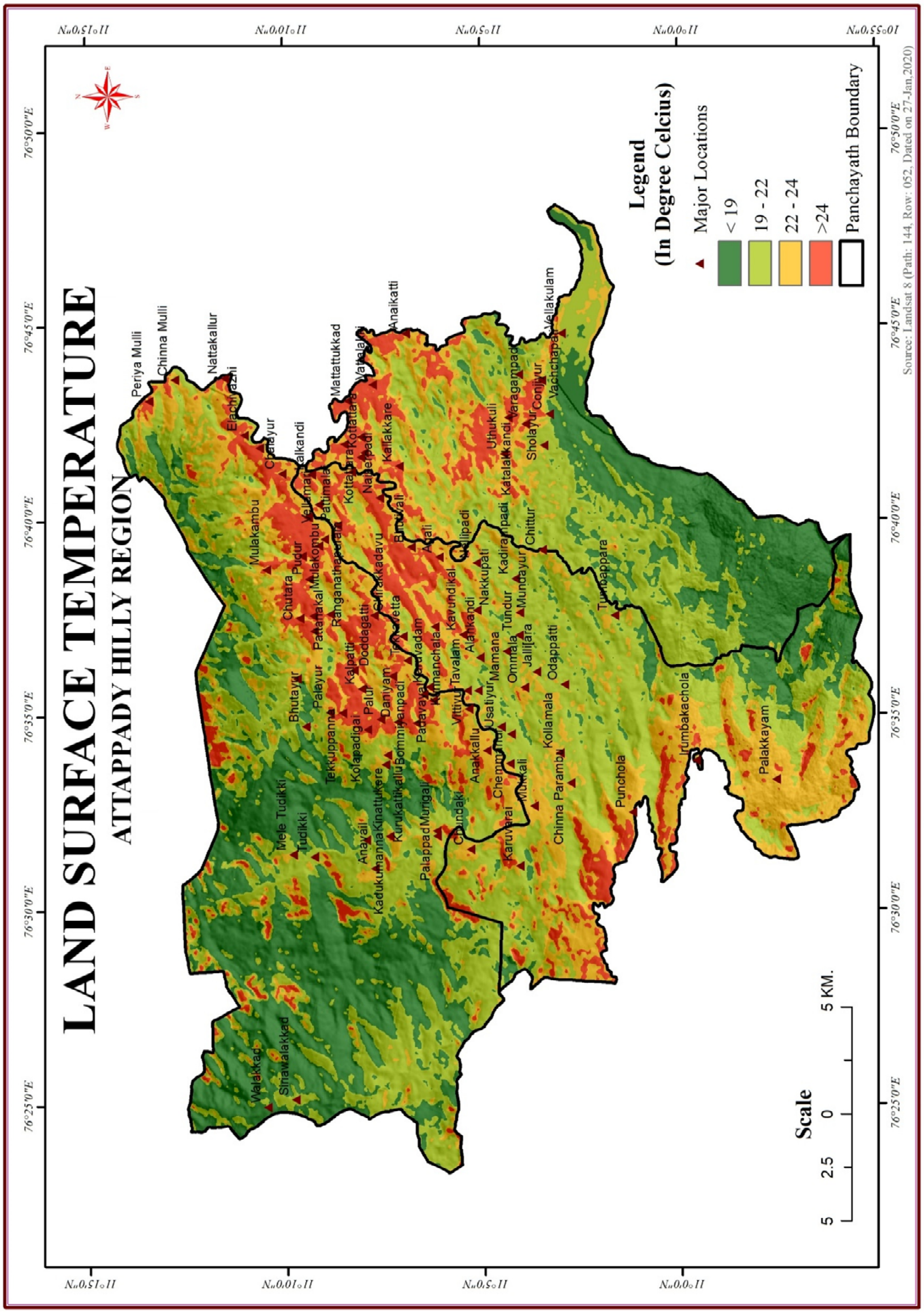
4.6.8 Land Surface Temperature and its Spatial Distribution of the Attappady Hilly Region

LST is identified as a significant variable of micro-climate which is useful in providing more accurate surface temperatures. LST showed a low (14 Degree Celcius) in the vegetative covered area and a high LST value (31 Degree Celcius) in the area with barren land and low vegetative area (table 4.11). For rain shadow region having less rainfall, less vegetation cover and high surface temperature, LST provides a surface temperature variation to demarcate rain shadow region (Fig. 4.9).



Source: Prepared by Researcher

Fig. 4.8: Soil Moisture Index Map of the Attappady Hilly Region



Source: Prepared by Researcher

Fig. 4.9: Land Surface Temperature Map of the Attappady Hilly Region

Table 4.11: Land Surface Temperature (LST) of the Attappady Hilly Region

Sl.No	LST in ^{0}C	Area in Km^2	Area in %
1	<19	87.75	10.59
2	19 -22	197.80	23.89
3	22-24	322.98	39.01
4	>24	219.33	26.49

Source: Landsat-8 Data (30-meter resolution)

4.6.9 Normalized Difference Vegetation Index (NDVI) and its Variation of the Attappady Hilly Region

NDVI is one of the most prominent vegetation indices used in image processing to investigate the green cover of photosynthetic plants. The vegetation index in the study area reveals that the area is mosaiced with scattered vegetation condition (Fig. 4.10). The area with good rainfall and high vegetation shows a high positive value, whereas the negative value was observed in the barren land, and water body mainly in the low elevated wind gap area. From the table 4.12, it is noted that thick vegetation is slightly less (24%) when compared to moderate to thick vegetation (76%). Thick vegetation observed in the forest and the western part of the study area.

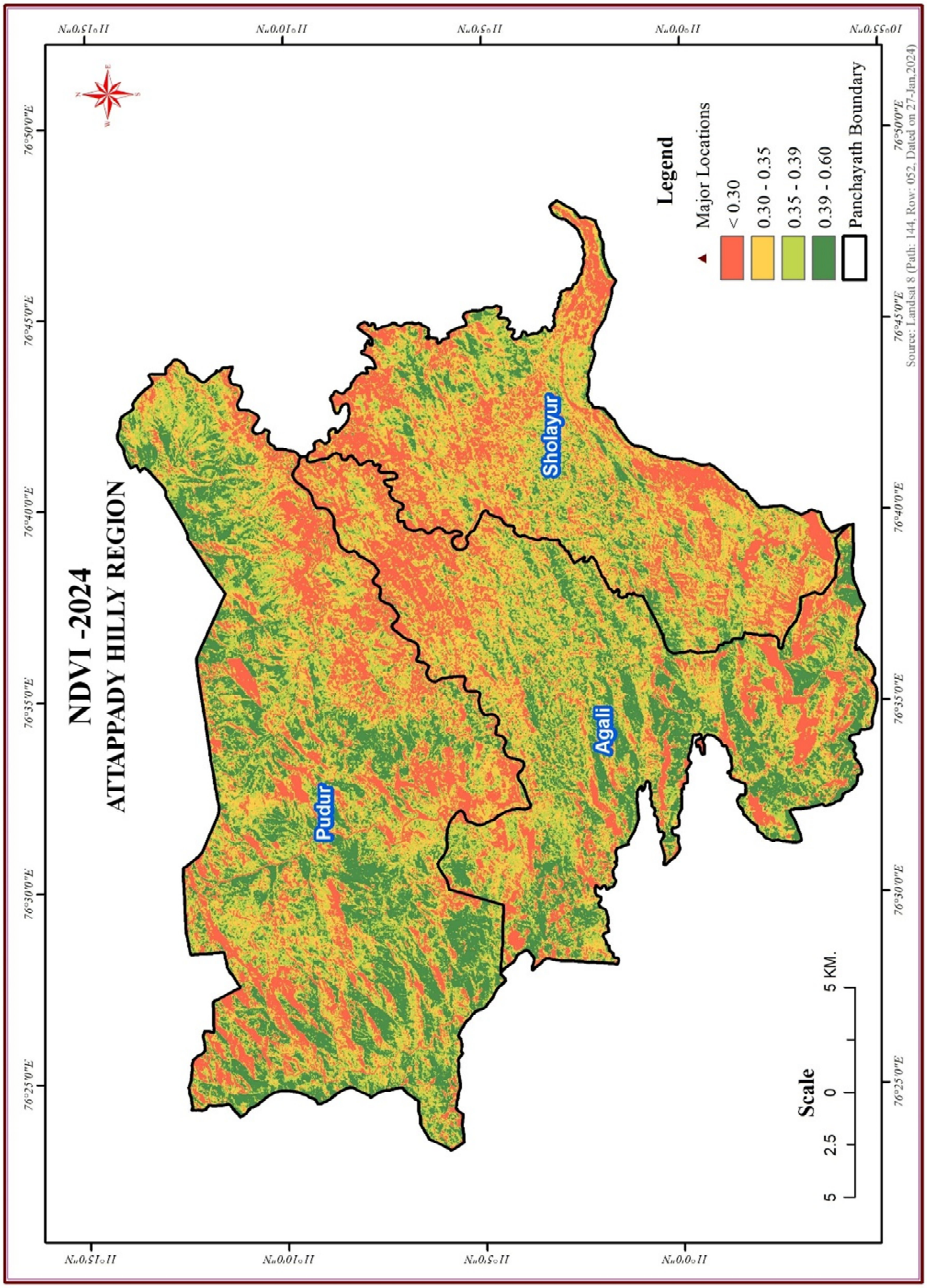
Table 4.12: Normalized Difference Vegetation Index (NDVI) of the Attappady Hilly Region

Sl.No	NDVI	Area in Km^2	Area in %
1	<0.30	208.72	25.21
2	0.30-0.35	220.83	26.67
3	0.35-0.39	200.51	24.22
4	0.39-0.60	197.69	23.88

Source: Landsat-8 Data (30-meter resolution)

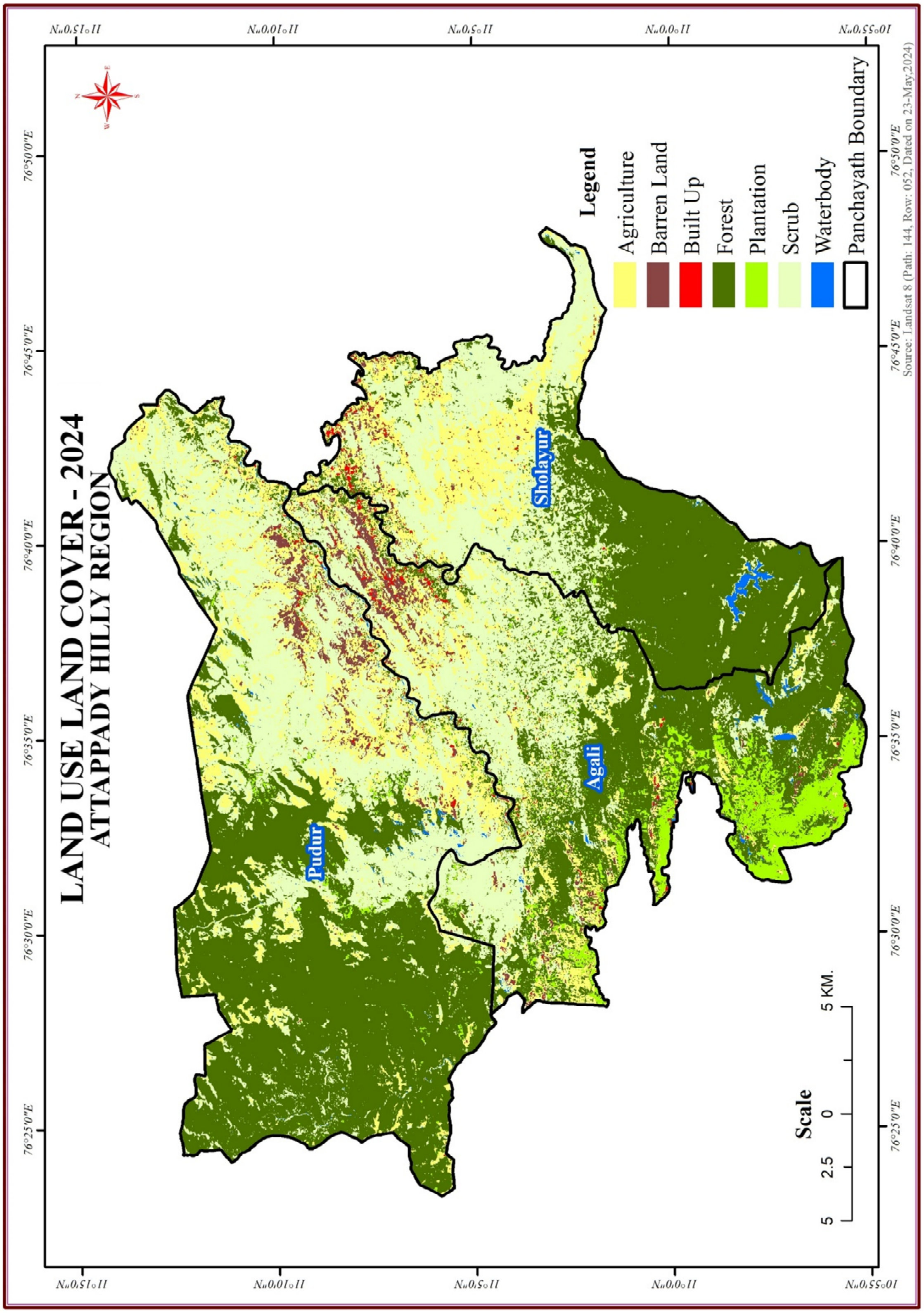
4.7 Land Use Land Cover and its Variation of the Attappady Hilly Region

Most of the study area covered by forest vegetation (61%) followed by agricultural area (29%) and scrub (7%) (table 4.13). Generally, the study area with rural setup depends on seasonal food crop cultivation and plantation crops (Fig. 4.11). Due to the introduction of plantation crops, large original landscape has been modified which tends to decrease soil depth and soil fertility and increase soil erosion.



Source: Prepared by Researcher

Fig. 4.10: Normalized Difference Vegetation Index (NDVI) Map of the Attappady Hilly Region



Source: Prepared by Researcher

Fig. 4.11: Land Use Land Cover Map of the Attappady Hilly Region

Table 4.13: Land Use Land Cover variation of the Attappady Hilly Region

Sl.No	Name	Area in Km^2	Area in %
1	Agriculture	160.79	19.38
2	Barren land	120.39	14.51
3	Built-up	2.90	0.35
4	Forest	352.06	42.44
5	Plantation	44.56	5.37
6	Scrub	147.56	17.79
7	Waterbody	1.28	0.15

Source: Sentinel-2 Data (10-meter resolution)

4.8 Identification and Demarcation of Rain Shadow Region of the Attappady Hilly Region

The rain shadow development is the function of both topography and atmospheric state (Sobel et al., 2003), the most influencing environmental and climatic factors like rainfall, elevation, wind speed, relative humidity, and temperature for rain shadow development have chosen as parameter for the demarcation of rain shadow region in Attappady hill region. Normalised Difference Vegetation Index (NDVI), Land use Land Cover, Soil Moisture Index, Topographic Vegetation Precipitation Dryness Index and Land Surface Temperature were calculated to identify the effect of these factors.

The Analytical Hierarchy Process (AHP) method was applied for spatial demarcation of the rain shadow region. The AHP model determines weights and ranks of different parameters for the rain shadow index model. In this method, each factor was assigned a rank on a scale of one to nine by assessing each element based on Saaty's scale to devise the relative score of each parameter. Normalized Weighted values were calculated using the standardized pairwise comparison matrix and Consistency Ratio (CR) was also derived**.** Consistency ratio (CR) was accepted if the value is < 0.10, and it indicates a reasonable level for the pair wise comparison matrix**.** In the present study CR is 0.097. The same method was used for calculation of pair wise comparison matrix and their weights of sub-criteria for each parameter. Finally, the weightage values of these parameters and sub-criteria of each parameter were used as weightage for weighted overlay analysis in order to decide the rain shadow and wet regions (Appendix.1). The rain shadow region was thus demarcated by weighted overlay techniques in the GIS environment through the analytical hierarchy process.

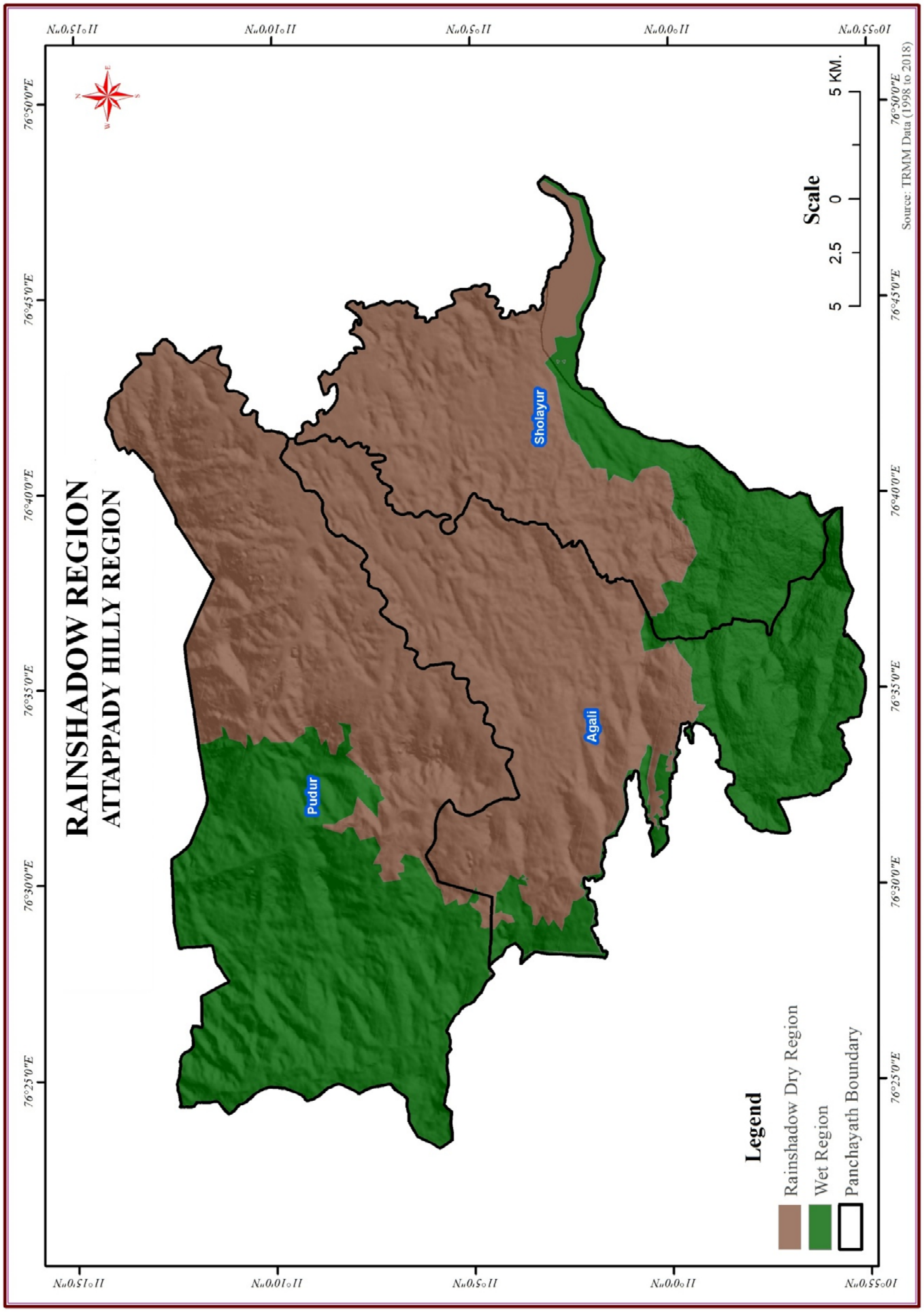
The resultant rain shadow map exhibits values, ranging from 0.47 to 0.11, and are categorized into two classes, using the natural breaking method (Table.4.14). These classes are rain shadow region and wet region, comprising 60.01% and 39.99 % of the total study area respectively (Fig.4.12). The rain shadow regions are situated on the eastern part of the hill region where the rainfall and wind speed are having a sudden change of magnitude in the leeward side of the mountains. Much of the rain-bearing clouds are blocked by the mountain ranges that separate the valley from Mannarkad. As a result, beyond and east of the mountain ranges, a rain-shadow area develops. The west-facing hills and the regions immediately to the east receive a lot of rain. The rainfall decreases dramatically as one travel east towards the Tamil Nadu border. Hence, the leeward side plays a crucial role in controlling the rain shadow of an area. At Walakkad and Agali, the average rainfall is 4798 mm, whereas at Sholayur and Pudur, it is 650 mm. The extremely elevated region in the western regions near the origins of the Siruvani and Bhavani rivers receives much more rainfall. It ranges from 654 mm in the eastern half of Sholayur and Pudur-Nattakallur to 2000 mm in the western part of Pudur-Walakkad and southern part of Palakkayam in Agali.

Table 4.14: Rain Shadow Region of the Attappady Hilly Region

Rain Shadow Region	**Area in Km^2**	**Area in %**
Rain Shadow Region	497.73	60.01
Wet Region	331.80	39.99
Total	**829.53**	**100**

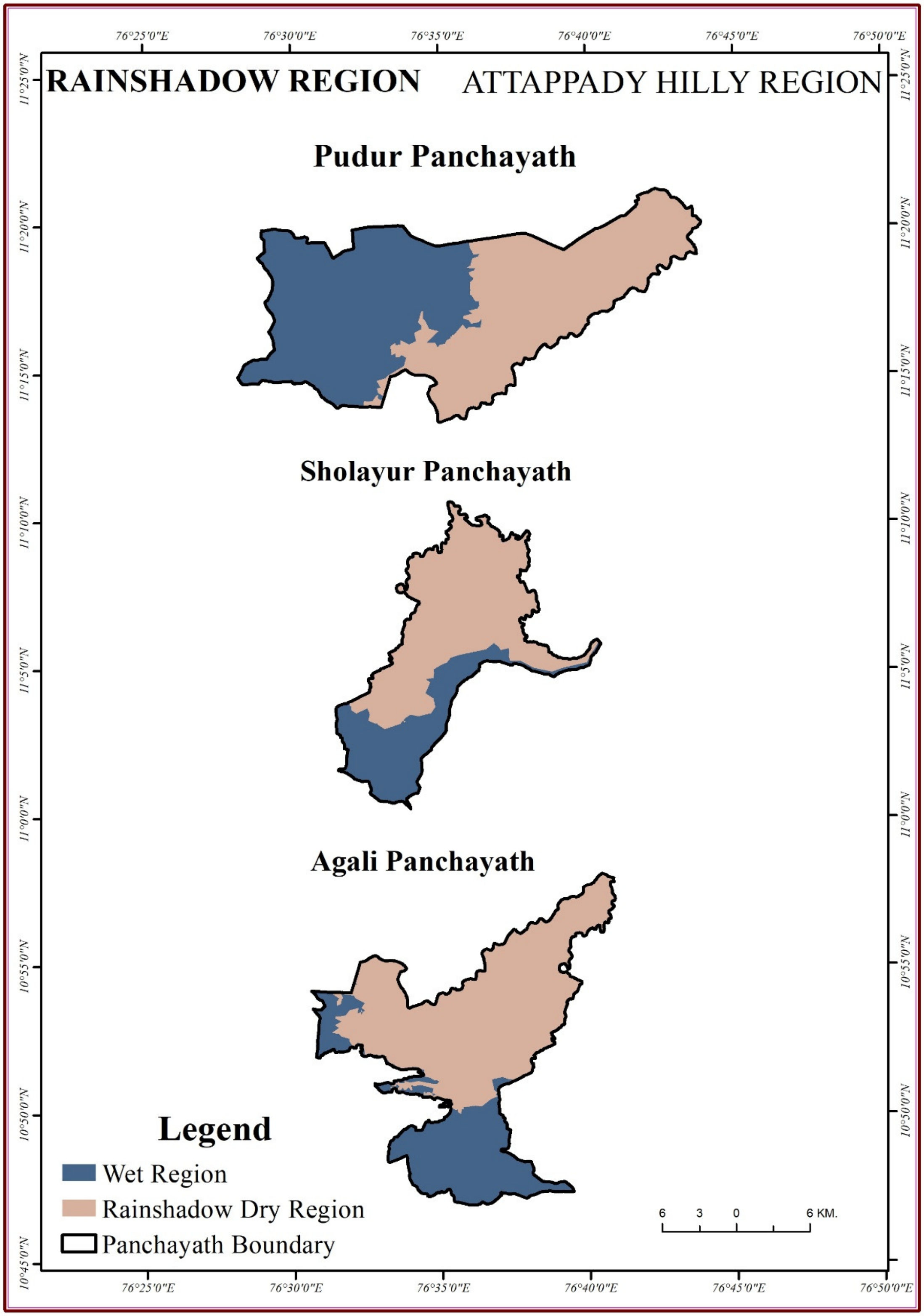
Source: Prepared by Researcher

According to data (table 4.15), approximately 68 percent of regions in Agali and Sholayur are covered by rain shadow areas, with Pudur having the least amount under rain shadow in Attappady at 49.98 percent (Fig 4.13). The major issue behind the decline of rainfall in the study area is rain shadow effect. The high rain shadow regions are located in the eastern and southwestern parts of the plateau, where the eastern edge of the plateau is formed by hills with



Source: Prepared by Researcher

Fig. 4.12: Rain Shadow Region Map of the Attappady Hilly Region



Source: Prepared by Researcher

Fig. 4.13: Panchayath-wise Rain shadow Region Map of the Attappady Hilly Region

many gaps and the risk of heat waves from Tamil Nadu is also significant. The eastern border areas, on the other hand, receive the majority of their rain from the north-east monsoon. The rainfall pattern during the south-west monsoon, on the other hand, steadily decreases from west to east due to the higher and steeper hills on the western side. As a result, elevation and rainfall play a critical part in controlling an area's rain shadow effect. The monsoon winds, which blow from the southwest, usually dump the majority of their moisture on the windward side of the Western Ghats. As a result, when windward places receive a lot of rain during the southwest monsoon, the lee of the Western Ghats, such as Marayur and Attappady, receives less than 100 cm of rain during the same period.

Table 4.15: Panchayath Wise-Rain Shadow Region of the Attappady Hilly Region

Panchayath Name	Rain Shadow Region (Area in Km^2)	Wet Region (Area in Km^2)
Agali	179.96 (68.01%)	84.64 (31.99%)
Pudur	185.08 (49.99%)	185.18 (50.01%)
Sholayur	132.69 (68.17%)	61.97 (46.68%)
Total	**497.73 (60%)**	**331.80 (40%)**

Source: Prepared by Researcher

4.9 Conclusion

One of the most critical climatic phenomena influencing the Attappady hill region is the rain shadow effect, and it has a pivotal role in shaping the region's climate, hydrology, flora diversity and agricultural practices. The implications of the rain shadow effect are profound in the eastern part of this region. The reduced rainfall in the Attappady hill region leads to a semi-arid climate, which poses challenges for agriculture, water availability, and biodiversity. The region's indigenous communities, primarily comprising the Irula, Muduga, and Kurumba tribes, have traditionally relied on agriculture and forest resources for their livelihoods. However, the variability in rainfall patterns, exacerbated by climate change, has significantly impacted their agricultural productivity and food security. This situation necessitates a nuanced understanding of how the rain shadow effect interacts with local agricultural practices and community resilience. As climate change continues to pose unprecedented challenges, it is essential to delineate rain shadow region that will not only contribute to a deeper understanding of the Attappady hill region but also inform policies and practices aimed at promoting sustainable development and resilience among the indigenous communities of this region. This chapter focuses on the delineation of rain shadow zones in Attappady hill region utilizing varying resolution satellite data and AHP approaches with the help of spatial technology. In this study, ten essential determining criteria were selected and analysed along with physical, ecological, and environmental dimensions in the process of defining rain shadow regions.

The rain shadow map of the study area reveals that the values obtained (ranging from 0.47 to 0.11) by Weighted Overlay techniques in the GIS environment through the analytical hierarchy process using the natural breaking method, classified Attappady region into two categories: rain shadow and wet regions, making up 60% and 40% of the area, respectively. The rain shadow regions, found on the eastern side of the hill, experience a significant drop in rainfall due to mountains blocking rain-bearing clouds. As a result, areas east of the mountains, such as Walakkad and Agali, receive much higher rainfall (4798 mm) compared to places like Sholayur and Pudur (650 mm). Rainfall decreases drastically towards the Tamil Nadu border. In Agali and Sholayur, about 68% of regions are in the rain shadow, while Pudur has the least at 49.98%. The rain shadow effect is most pronounced in the eastern and southwestern parts of the plateau, where elevation and monsoon winds significantly influence the rainfall pattern, with the windward side of the Western Ghats receiving more rainfall during the southwest monsoon, while the leeward side (e.g., Marayur and Attappady) receives much less. Thus, this study also proves that the application of Remote sensing data and AHP by Weighted Overlay techniques in the GIS environment are effective methods for rain shadow demarcation.

CHAPTER 5

GENESIS AND PROCESS OF RAIN SHADOW MECHANISM IN THE ATTAPPADY HILLY REGION

CHAPTER 5

GENESIS AND PROCESS OF RAIN SHADOW MECHANISM IN THE ATTAPPADY HILLY REGION

5.1 Introduction

Mountains have a predominant influence on the atmosphere, and they alter the movement of air and disturb the vertical stratification of the atmosphere by acting as physical barriers (Barros and Lettenmaier, 1994). The interactions between mountains and the atmosphere produce precipitation with varying spatial scales, enhanced in some regions and decreased in others. Topography itself has a strong effect on spatial patterns of precipitation both globally and regionally (Smith, 1979) and characteristics of the topography, including the length, width, and height of the mountain range determine how the atmosphere interacts with the mountains (Houze, 1993). Orographic effect brings not only the initiation and intensification of precipitation on the windward side of mountains and hills but also the relative deficit of precipitation on the lee side (Atkinson, 1983; Smith, 1979) giving an explanation on the sophisticated subject of orographic rain. On the windward side, air masses are forced to lift, condensation and cause the release of rainfall and an increase in precipitation with elevation.

Depending on the mountain magnitude and the efficiency of the condensation and release processes, precipitation will decrease on the leeward side. A region of low precipitation in the lee of topography is "rain-shadow". Orographic rain shadows are a primary feature of earth's surface climatology (Galewsky, 2009). Therefore, the rain shadow development is the function of both topography and atmospheric state. (Sobel et al., 2003 and (Abdulrazak et al., 1995) found that the amount of rainfall on the windward slopes is higher than leeward slopes of the mountains due to the blocking of winds carrying moisture from nearby water bodies. Therefore, rain shadow is a well-known phenomenon by topographic obstacle with maximum of orographic precipitation on the upwind side and falls beyond the summits (Barry and Chorley 1987).

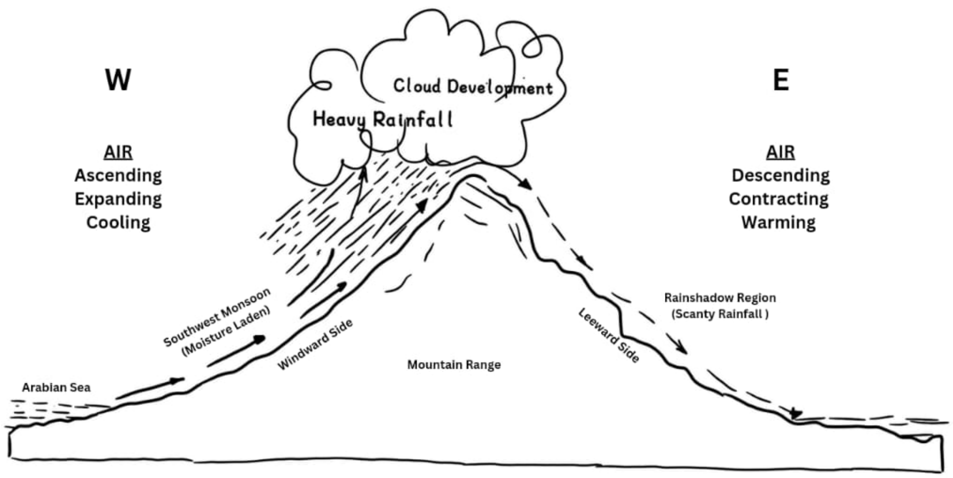
The most unique feature of mountain climates is the rain shadow effect i.e., the sharp decline in precipitation on the lee side of mountain ranges (Siler et al, 2012). Recent studies have shown that the magnitude of the rain-shadow effect varies significantly from storm to storm, location to location, and year to year (Leung et al., 2004; Siler et al., 2013). The frequency and magnitude of the distribution of rainfall amounts varies across the mountain barrier, and bring climatic changes on both sides of the barrier. The mountain barrier affects not only the nature and distribution of precipitation on the windward side of highlands, but also the relative deficit of precipitation on the lee side (Atkinson, 1983). Mountains influence weather and climate in a variety of ways (Smith, 1981, 2003) and also topography has a significant impact on local climate via altering precipitation (Geiger et al., 1995). As a result, precipitation in mountainous places is frequently not uniformly distributed (Geiger et al., 1995).

Mountain elevations and orientation obstruct wind and cloud flow and produce orographic rainfall on windward slopes and creating rain shadow effects on the leeward side and many of the rain producing mountains are not high to intercept clouds (Babu et al 2020.). This uneven distribution of rainfall significantly impacts ecosystems, agriculture, and livelihoods. Therefore, investigating the influence of mountains on rainfall distribution, with a focus on the rain shadow mechanism, is crucial to understanding its environmental and socio-economic implications. Such research can also help in devising strategies to manage water resources, mitigate land degradation, and improve resilience in affected regions.

5.2 Mechanism of Orographic Precipitation

Many mountain ranges exhibit sharp precipitation gradients, often explained by the phenomenon of rain (or precipitation) shadowing. However, non-all-weather events experienced reduced precipitation in the lee of mountains. Sometimes, storm systems show minimal changes in intensity while crossing ridge lines, and in certain situations, precipitation can even increase on the lee side. Studies by Siler et al. (2013) and Mass et al. (2015) demonstrated that heavy rain shadow effects were typically linked to precipitation within the warm sector of storms, whereas weaker rain shadow effects corresponded to storms with warm and occluded fronts. According to Siler and Durran (2016), the weak rain shadows resulted from diminished lee side mountain waves due to stable low-level air preceding the warm front.

As precipitation systems move eastward, they may weaken, not necessarily due to orographic effects, but due to weaker synoptic or mesoscale forcing for ascent. Airflow over mountains isn't always straightforward; on the upwind side, stable low-level flow may be blocked, failing to cross the mountains. On the lee side, descent impacts can be intensified by wave breaking over the terrain and the entrainment of dry air, which extends the rain shadow effect downstream. Different air masses can also bring distinct weather patterns to the western and eastern sides of a mountain range, as noted by Alexander et al. (2017). Accurately predicting weather in mountainous regions has long been challenging for atmospheric scientists. Analyzing how natural mountain barriers statically force air movement and impact precipitation is essential for enhancing future hazard management strategies. Many researchers, including Smith et al. (2012) and Houze (2011), have studied orographic rainfall, given its significance to water resources, flood risks, landslides, regional climates, and the global water budget (Smith, 2012). Orographic precipitation (from the Greek word "Oros," meaning "mountain") forms as air is lifted and cooled over a topographic barrier. When the air cools to below the dew point, clouds form, leading to widespread rain on the windward slopes of a mountain range this is known as orographic rainfall (Fig 5.1). However, as winds descend along the leeward side, they warm up, causing little to no rainfall. This drier area on the leeward side is referred to as a rain shadow region (NIOS Geography).



Source: Prepared by Researcher

Fig. 5.1: Rain Shadow Model

Mountains and other land barriers are likely to cause orographic precipitation (Davie, 2008). This sort of precipitation happens when moisture-bearing air is carried by the wind and collides with a mountain or other obstruction, causing the air to rise up. With increasing height, the air pressure decreases, enabling the moist air to expand and cool. Because chilly air holds less humidity than warm air, the saturation threshold can be achieved and water can condense, resulting in precipitation (Schumann, 1998; Davie, 2008). After passing through the topographic barrier's highest points, the chilly air reaches the leeward side and is allowed to descend down. As air descends, the air warms up again, causing any leftover liquid water to evaporate and therefore increasing the dryness (Nicholson, 1994; Schumann, 1998; Siler et al., 2013). Because the air that has gone through the topographic obstacle has less humidity, the leeward side suffers from a rain deficit, also known as the rain shadow effect (Davie, 2008;

Siler et al., 2013; Barry and Chorley, 1987). The basic mechanism of the rain-shadow effect is that on windward slopes, ascending air expands, cools and condense, and enhances precipitation, but on the leeward slope, precipitation is suppressed as the descending air warms and liquid water evaporates, forming a rain shadow region (Smith 1979; Roe 2005).

Orographic lifting occurs when air is forced to rise due to the topography of a region. Various mechanisms contribute to this orographic lifting, each influencing precipitation patterns in specific ways (Sayli Atul Tawde, 2013). These mechanisms are represented in (Fig.5.2):

C.1. Stable Ascent: This common orographic precipitation mechanism involves deep uplift of moist air along the windward slope of a mountain. When the air is moist and convection is deep enough, precipitation clouds form as the air rises.

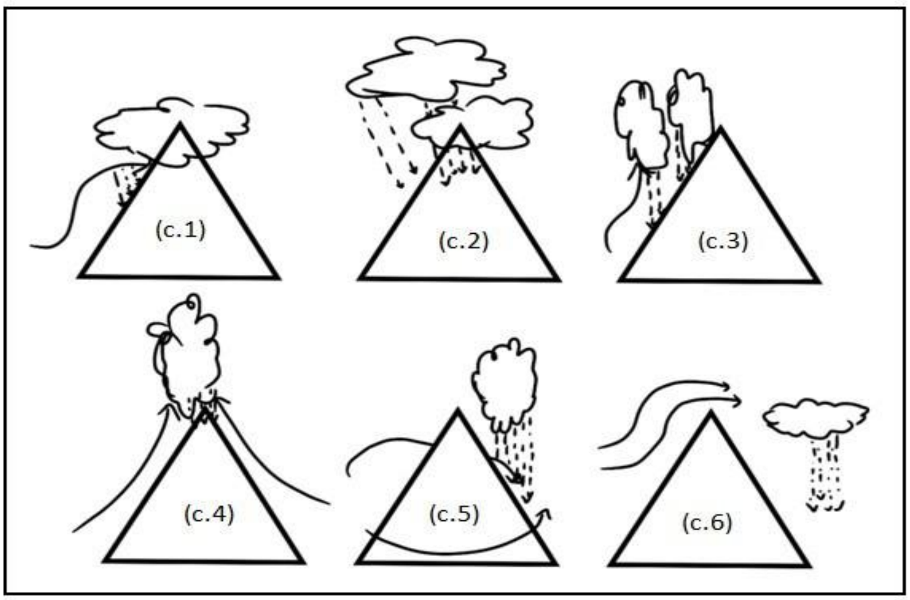
C.2. Seeder-Feeder Mechanism: Precipitation intensifies through the rapid growth of ice crystals descending from upper stratiform clouds into lower-level, orographically induced convective clouds. Falling ice crystals act as condensation nuclei for super cooled water droplets in the lower atmosphere, which then grow through accretion and aggregation.

C.3. Upslope Release of Potential Instability: Shallow layers of potentially unstable air are lifted over a mountain, encouraging convection and potentially leading to precipitation.

C.4. Daytime Convergence: In conditions without strong winds, daytime heating of mountain slopes creates a topographic boundary layer flow. This process causes air to converge at the mountain peak, often enhancing precipitation.

C.5. Triggering of Convergence on the Leeward Side: When stable air (with a Froude number less than 1) moves around the mountain, it may flow down and converge on the leeward side, enhancing precipitation in that area.

C.6. Enhancement of Convergence on the Leeward Side: Lee-side convergence can also lead to warm, low-level convection. Cold upper-level air masses driven over the mountain may become separated from these warmer air masses by a thin stable layer, creating extreme instability and amplifying convective activity.



Source: Prepared by Researcher

Fig. 5.2: Types of Rain Shadow

The stable ascent mechanism of orographic precipitation occurs when large landforms compel moist air to rise along the windward side of mountains, cooling exponentially with increasing altitude. As the moist air rises, it encounters decreasing atmospheric pressure, leading to adiabatic expansion, which cools the air parcel. In an unstable atmosphere, where the surrounding air is cooler than the rising parcel, the air continues its upward path. As it ascends and cools, the relative humidity increases; once it reaches 100%, condensation occurs, leading to precipitation on the windward side. Relative humidity, as described by Wallace and Hobbs

(2006), is defined by the formula:

$$\text{Relative humidity} = \frac{actual\ mixing\ ratio}{saturated\ mixing\ ratio}$$

where the saturated mixing ratio represents the maximum water vapor concentration in a given air volume at a specific temperature. The altitude at which air becomes saturated, causing cloud formation, is known as the lifting condensation level. After precipitation occurs on the windward side, the now dry air descends on the leeward side, where it compresses and warms, reducing its relative humidity and preventing cloud formation. This process creates contrasting climate zones: a moist, cloudy windward side and a dry, clear leeward side, known as the "rain shadow" region (Moran and Morgan, 2007).

Orographic precipitation depends on the static stability of the atmosphere, wind speed, wind direction and on the topography of the mountain. When an incoming air parcel with wind velocity (u) encounters a mountain barrier (height, h) the following mechanisms can occur. Air parcel can pass over a mountain top, or it can rest on the mountain top or unable to cross the mountain top. The phenomenon that the air parcel remains on the windward side of the mountain barrier is known as ‘blocking of the flow’. Blocking due to orography occurs when Froude number is less than one i.e. a stratified atmosphere or weak wind speed. When Froude number is greater than one air flow crosses the mountain top. Froude number (F) is given by following formula:

$$F = \frac{u}{N.h}$$

Where N= Brunt Vaisalla frequency (http://metad.ucar.edu)

Brunt Vaisalla frequency determines the stability of the atmosphere. Stability is the restoring force acting on the uplifted air parcel and it depends on the temperature difference of dry air and ambient air. Higher N indicates high static stability of the atmosphere i.e. air parcel oscillates around its equilibrium position. Heavy downpour due to orography is associated with atmospheric blocking ($F<1$). This blocking is generally initialized by stratification or temperature inversion layer or weak wind speed. When air rises over a mountain slope, it expends energy to counteract gravity, which limits its upward travel. The vertical motion within clouds, essential for droplet growth through collision-coalescence, is influenced by the mountain's physical characteristics. Thus, orographic features significantly affect rainfall intensity, a focus of the present study.

In recent years, there has been an increasing need for forecasted climate data, both on a global and regional scale. The increased climatic fluctuations in rain shadow regions, its influence on population, agriculture and the ecosystem, emphasizes the importance of accurate climate projections (Diro et al., 2011; Chen and Georgakakos, 2015). Furthermore, rain shadow effect in a region strongly reflects on the landform, soil, vegetation and cropping patterns and the stability and diversity of the climatic pattern (Gunnell, 1997). However, the rain shadow effect is frequently researched using rain gauge observational data (Hurni, 1986; Siler et al., 2013; Stockham et al., 2018) rather than model analysis. While the rain shadow effect is mentioned in numerous textbooks, Stockham et al. (2018) discovered that it is rarely discussed in depth in scholarly literature. The major reason for this neglect is most likely the calculation's intricacy and the challenges associated with comprehending the findings. In India, Western Ghats has significant role on spatial patterns of precipitation. They block the southwest monsoon winds and create rain shadow effect on its lee ward side. The detailed investigation helps to understand the role of the Western Ghats on the rain shadow effect mechanism in the Attappady hilly region.

5.3 Rain Shadow Mechanism in the Western Ghats

The Western Ghats significantly influence regional rainfall patterns through the rain shadow mechanism, which affects both the windward and leeward sides of the mountains. This phenomenon is characterized by varying rainfall regimes, driven by orographic effects and atmospheric dynamics. The Western Ghats create a barrier for the southwest monsoon winds, leading to heavy rainfall on the windward side while causing a rain shadow effect on the leeward side Phadtare et al., (2022). This disparity in precipitation results in lush, dense forests on the windward slopes, while the leeward side often experiences drier conditions, impacting local ecosystems and agriculture. Research indicates that the Western Ghats experience significant decadal variability in rainfall, influenced by sea surface temperature changes in the Indian and Pacific Oceans (Halder et al., 2022). This variability underscores the complex interactions between local topography and broader climatic factors, affecting both biodiversity and hydrology in the region (Halder et al., 2022).

There is great influence of geographic location and topographic parameters such as slope, gradient, exposition and elevation on the variability of rainfall. Elevation explains most of the variance in the rainfall. High and more extreme rainfall events are less influenced by elevation, while low and medium rainfall events are significantly influenced by orography, with most of the rainfall appearing on high elevation. In tropical areas, distance to moisture sources, or large circulation patterns over a region weakens the relation of rainfall with elevation. It has been found that precipitation can decrease with elevation. Indian summer monsoon rainfall shows strong spectral variability on daily to seasonal time scale (Shrestha, 2013). The meteorological subdivisions on the windward side of the Western Ghats mountains receive copious rainfall. The coefficient of variability of rainfall is higher over rain shadow subdivisions than the wind ward side. The large-scale convergence at low levels and divergence in the upper levels has been considered favorable condition for rainfall process in the numerical models (Mann R et al, 2023). The seasonal rainfalls are more than 2,300 mm for the windward subdivisions as against 500-600 mm for the leeward side subdivisions. This known feature of steep decrease in the rainfall over the leeside is unique and not found elsewhere in India (Rao 1976).

In general, the windward (west) side of Western Ghats receives a huge amount of rain, whereas the rainfall significantly decreases over the leeward (east) side. Gunnell (1997) examined the climatic impact of Western Ghats on ISM and found that the Western Ghats polarizes the precipitation along the crest of the Ghats and on the immediate scarp foot, along with the formation of a secondary offshore convective cloud band. Patward han and Asnani (2000) analyzed the mesoscale distribution of rainfall during ISM over Western Ghats and identified that the presence of valley modifies airflow thereby controlling the rainfall spatial pattern over this region. Francis and Gadgil (2006) found that heavy rainfall events over the west coast of India are mainly associated with the northward propagation of large-scale systems (i.e. tropical convergence zone, etc.) and are linked to orography. Using 14 years (1998–2011) of Tropical Rainfall Measuring Mission (TRMM) rainfall dataset, Tawde and Singh (2015) also found the prominent orographic influence on the spatial variability of rainfall over the Western Ghats region with enhanced precipitation over the windward side and suppressed rainfall over the leeward side.

The westerly jet at a lower level, blowing almost at a right angle to the Western Ghats brings moisture over the Indian landmass during ISM. Analyzing the X-Band radar data over Western Ghats, during the monsoon (June September) of 2014, Utsav et al. (2017) have also found prominent orographic influence in formation of the clouds over this region. They have reported considerable spatial variability of the storm activity monthly as well as in the diurnal cycle. The convective cells tend to initiate during mid-night to late morning over the coastal region and at noon to late evening over the leeward side. Clustering of these cells occurs along the mountain ridges. Initiation of convection is found to be more scattered during the night compared to daytime. Most of the cells trigger during afternoon time, which also suggests the influence of diurnal heating along with the orographic lifting. A prominent eastward propagation of convective activity is noted in the diurnal cycle over this region. Maheskumar et al. (2014) have investigated the possible mechanism responsible for high rainfall over the west coast of India. They have argued that the high rainfall over this region is the resultant of the heavy rainfall events along with the continuous medium intensity rainfall. The microphysical characteristics of clouds over Western Ghats have been documented in detail by Konwar et al. (2014) with the help of several remote sensing instruments as well as in situ aircraft observations. They have found that in the windward side of Western Ghats, orography induced updraft causes the rapid condensational growth of cloud droplets in shallow precipitation system and helps the formation of bigger droplets which further facilitates collision–coalescence process slightly above the cloud base.

During the heavy precipitation events, collision–coalescence process is seen at higher levels and breakup process is dominant at lower levels, whereas during the light precipitation events the raindrops grow bigger in size by the collision coalescence process during their journey towards the ground. A nocturnal low-level jet (LLJ) was identified by Prabha et al. (2011) during the pre-monsoon conditions on the eastern slope of the Western Ghats Mountain range (rain shadow region) over peninsular Indian region, which is different from the large-scale jet prevailing over this region during monsoon. The temperature gradient between the valley slope and the adjacent atmosphere is a key driver of the nocturnal Low-Level Jet (LLJ), along with factors like slope and valley winds. These LLJs play a role in moisture transport and diurnal water vapor cycles (Wu & Li, 2022) (Braz et al., 2021). LLJs in rain shadow regions exhibit strong diurnal variation, significantly affecting precipitation processes (Wu & Li, 2022). Using high-resolution modeling, a hailstorm in Baramati (Western Ghats rain shadow) was analyzed, showing that outflows from multiple convective cells formed a cold pool and wind discontinuity zone, triggering new convection (Luiz and Fiedler, 2023). However, the study lacks observational data on cloud system characteristics and microphysical evolution.

Most of the studies over this region are confined to the windward side of the Western Ghats but little has been explored over the leeward side of the mountain range, especially the detailed observational and simulated characteristics of cloud systems and associated cloud processes. Extensive rain shadow region in the lee ward side of Western Ghats frequently encounters severe droughts. Hence, the convection initiation and its life cycle are important for understanding precipitation mechanisms and eventually the diurnal cycle of precipitation. Previous studies lack information about the observed features (using various state of the art instruments) of the cloud characteristics over this region as well as the detailed microphysical evolution associated with the systems, which we have addressed in the present study.

The Western Ghats play a crucial role in shaping the climate of Peninsular India by interacting with the southwest monsoon to create varied rainfall patterns (Gunnell, 1997). The windward side of the Western Ghats receives the highest rainfall, while the leeward side experiences significantly lower rainfall due to the depletion of moisture in clouds (Sahu, 2018). Kerala, located on the windward side, gets an average annual rainfall of 282 cm, whereas Tamil Nadu, primarily in the rain shadow zone, receives much less (Sahu, 2018). Rainfall in Kerala decreases from west to east, with the eastern slopes receiving less than 100 cm annually. The Palghat Gap causes a marked reduction in rainfall in the leeward areas, disrupting typical rainfall trends (Rao, 1976). The orographic influence on rainfall is pronounced as moisture-laden air condenses over the hills, causing the foothills to receive maximum rainfall. Kerala's climate is governed by its geographic position, proximity to the ocean, and orography, with the state divided into tropical monsoon and tropical savanna zones (Subramanyam & Murthy, 1982).

Various researchers, such as Sato and Joseph (2005), Ram (2011), and Alexander et al. (2018), have studied different rain shadow zones worldwide. The rain shadow effect creates distinct climate zones, often arid or semi-arid, which shape local ecosystems and influence agricultural practices (Robert, 2012; Andreas, 2006). Rain-shadowed regions like the Sierra Nevada and the Andes host unique plant and animal communities adapted to drier conditions, establishing them as biodiversity hotspots or vulnerable ecosystems (Tamlin, 2012; Mingxing, 2021). Agriculture in these areas often centers on drought-resistant crops and water-conserving practices, crucial for sustainability in such challenging environments (Kanhu, 2022). Understanding the rain shadow effect is vital for managing water resources and preserving biodiversity in these sensitive ecosystems (Mingxing, 2021). This chapter investigates the environmental conditions favouring initiation of the rainfall variation in the Attappady, analysis of specific dynamic and microphysical characteristics of the cloud cluster on both side of the Attappady and prepare a scientific model for the climatic variable in the windward and leeward side of the Attappady.

5.4 Materials and Methods for Modelling of Rain Shadow Region

The relationship between relief and climate is complex, significantly influencing ecological dynamics and climate variability. Research indicates that relief affects temperature, precipitation, and ecological responses, with varying impacts across different altitudinal zones. To identify the microclimate peculiarities of any region there is an assessment on the climate variables, vegetation in spatial and temporal scale. And finally identifying the association between climate and vegetation association in the different elevations. The interplay of rainfall variation, elevation, wind speed, relative humidity, temperature, and NDVI (Normalized

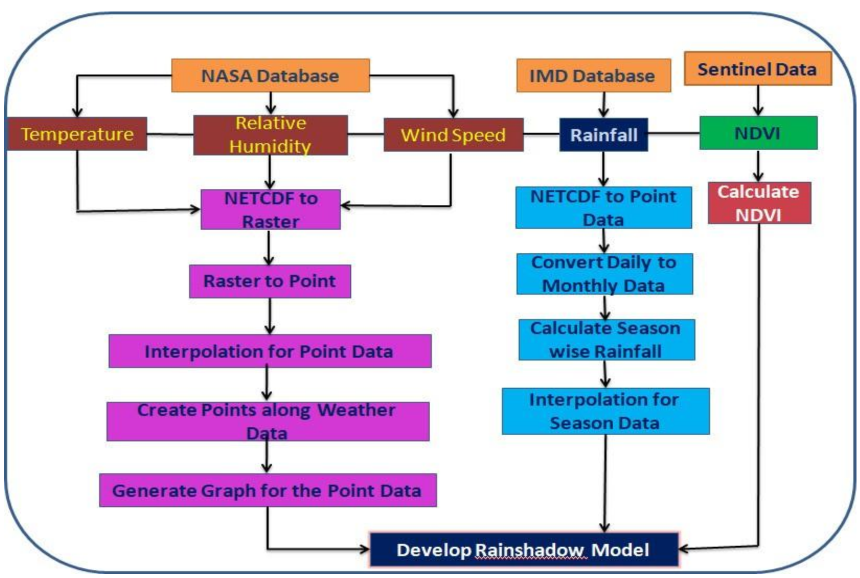
Difference Vegetation Index) is crucial in demarcating rain shadow areas. These parameters influence hydrological processes and vegetation dynamics, particularly in mountainous terrains.

To model the rain shadow zone, six climatic variables like rainfall, elevation, wind speed, relative humidity, NDVI, and temperature were selected based on the study that these variables play a crucial role in determining a region's potential to form a rain shadow. The various satellite images were sourced from different online platforms for the purpose. Table 5.1 provides an overview of the data sources used to create six thematic layers: rainfall, elevation, wind speed, relative humidity, NDVI, and temperature. The thematic layers were processed using advanced Geographic Information System (GIS) tools. The methodology adopted for this model is illustrated in Fig.5.1 through a schematic diagram. The methodology is briefly explained here as follows.

The climatic data, such as temperature, relative humidity, and wind speed, were downloaded from the NASA Power Data Access website in NETCDF format. These datasets were converted to raster format in the QGIS environment, enabling further analysis. Subsequently, the raster data were transformed into point vector layers, where each point contained specific climatic attributes corresponding to a particular location. To understand spatial variations and adjacent climatic patterns, an Inverse Distance Weighted (IDW) interpolation technique was applied.

Rainfall data with a spatial resolution of 28 km from the year 1981 to 2023 were obtained from the Indian Meteorological Department (IMD) in NETCDF format. Using the ArcGIS Multidimension Toolbox, the NETCDF data were converted to feature layers and subsequently into point data. Similar to other climatic datasets, the interpolated rainfall data were integrated for further analysis. For vegetation analysis, the Normalized Difference Vegetation Index

(NDVI) was calculated to examine vegetation changes across the study area. Sentinel-2 satellite data with a resolution of 10 meters for the year 2024 were processed in the Google Earth Engine platform using JavaScript. In general, climatic variables such as vegetation density, relative humidity, and wind speed demonstrate significant variation between the windward and leeward sides of the study region. To capture this variability, the relationship between interpolated climatic data and vegetation patterns was carefully analyzed. A sample line was drawn from Ponnani (west) to Coimbatore (east), crossing the Attappady region from the windward to the leeward side. Along this sample line, points were created at 100-meter intervals using the Points Along Geometry algorithm. This tool generates a layer of evenly distributed points along the lines of an input vector layer, with the distance between points and start/end offsets specified as parameters. These offsets ensure the first and last points do not fall directly on the start or end nodes of the line. Using the Sample Raster Values tool in QGIS, climatic attribute data for each variable were extracted and attached to the sample point data. Finally, the point geometry was exported as a Comma Separated Value (CSV) file. This dataset was used to develop the rain shadow model. A schematic representation of the .methodology is illustrated in figure 5.3.



Source: Prepared by Researcher

Fig. 5.3: Methodology Chart of Developing Rain Shadow Model

5.5 Theoretical Understanding of Rain Shadow Mechanism in the Attappady Hilly Region

The rain shadow model for Attappady focuses on understanding the interplay of geographic and climatic factors that create a distinct dry zone on the leeward side of the Western Ghats. This phenomenon occurs as moist winds from the west lose their moisture on the windward slopes, leaving the eastern slopes dry. By integrating spatial data such as rainfall, elevation, wind speed, vegetation, and temperature, the model aims to highlight the environmental and socio-economic impacts of the rain shadow effect. It provides critical insights for sustainable resource management and strategies to mitigate land degradation in this ecologically and culturally significant region. In the rain shadow analysis in Attappady, the entire area is classified into three zones based on elevation and rainfall patterns: Phase-1(Ponnani to Mannarkkad: 0-70 Km), Phase-2 (From Mannarkkad to Kottathara: 30-60 Km), and Phase-3 (From Kottathara to Karamadai: Above 60 Km). In each of these zones, the variation of microclimatic factors and their impacts has been studied elaborately.

Table 5.1: Data sources used for modelling of Rain shadow region

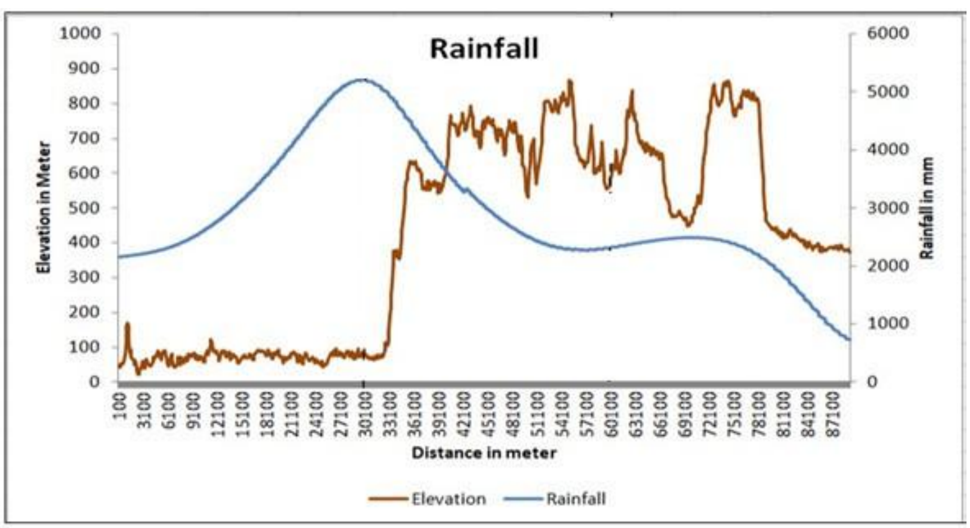
Sl. No	Parameter	Data source
1	Rainfall	https://disc.gsfc.nasa.gov/earthdata and IMD
2	Elevation	ASTERDEM (30 Meter Resolution)
3	Wind Speed	NASA POWER | Data Access Viewer
4	Relative Humidity	NASA POWER | Data Access Viewer
5	Temperature in^{0} C	NASA POWER | Data Access Viewer
7	NDVI	https://earthexplorer.usgs.gov/-Landsat 8 OLI/TIRS C1 Level-1, Path 144, Row: 052, Dated from 01-January, 2022 to 31-12-2024.

Source: Prepared by Researcher

This study investigates the complex and dynamic relationship between elevation and microclimate factors with a specific emphasis on Attappady. Elevation emerged as crucial determinant affecting temperature, precipitation patterns, wind speed, relative humidity and vegetation cover of the Attappady. Topography itself has a strong effect on spatial patterns of precipitation both globally and regionally (Smith, 1979) and characteristics of the topography, including the length, width, and height of the mountain range determine how the atmosphere interacts with the mountains (Houze, 1993). Orographic effect brings not only the initiation and intensification of precipitation on the windward side of mountains and hills but also the relative deficit of precipitation on the lee side (Atkinson, 1983; Smith, 1979) known as the rain shadow effect (Davie, 2008).The basic mechanism of the rain-shadow effect is that on windward slopes, ascending air expands, cools and condense, and enhances precipitation, but on the leeward slope, precipitation is suppressed as the descending air warms and liquid water evaporates, forming as rain shadow region (Smith 1979; Roe 2005). The Attappady area is flanked by mountain ranges, the Nilgiris in the north and extensions of the Western Ghats in the south and in the west. The terrain of Attappady area is marked by hills and valleys, particularly high mountains and narrow valley in the western half. Attappady lies between the two ranges of Western Ghats, and the general slope of the area is towards north-east. From the south-west the elevation increases from 90 m to 550 m at Mukkali. From Mukkali to Anakkatty towards east, the elevation is between 500 m and 575 m (Manikandan and Kurian M, 2016). The northern boundary of Attappady block lies at an elevation of around 2300 m in the Nilgiris peak. From there it decreases along the south-west and later climbs up to 2000 m at Muthikulam. Around 51 % of Attappady have an elevation between 600m to 1000m and 71.6%of the area has a slope between 15 to 30 degrees, showing the environmentally sensitive nature of the region (Velluva 1999). This geographical location and topographic barrier of Attappady hills influences the climatic pattern, especially rainfall and temperature distribution and make distinct micro climatic region in Attappady. The following paragraphs try to find the relationship between the climatic variables and physiography. For the experiments, the climatic variables like distribution of rainfall, temperature, wind speed, relative humidity, and natural vegetation were used

5.5.1 Rainfall Distribution in the Attappady Hilly Region

Rainfall patterns are closely connected to topographical diversity and location on the Attappady hill ranges. The western parts receive the bulk of precipitation from both the south-west and retreat monsoon. The rainfall distribution of Attappady is mainly influenced by the topographic barrier of Attappady hills. The IMD and satellite rainfall data for the last 43 years (1981-2024) shows maximum rainfall of about 5218 mm received on the Western part to 650 mm on the Eastern part of Attappady. This significant difference in rainfall between the two sides are influenced by orographic lift. On the windward side, moist air is forced to rise over the mountains, leading to enhanced rainfall due to adiabatic cooling and condensation. On the leeward side, the descending air experiences adiabatic warming, reducing its moisture-holding capacity, which results in lower rainfall (Fig.5.4).



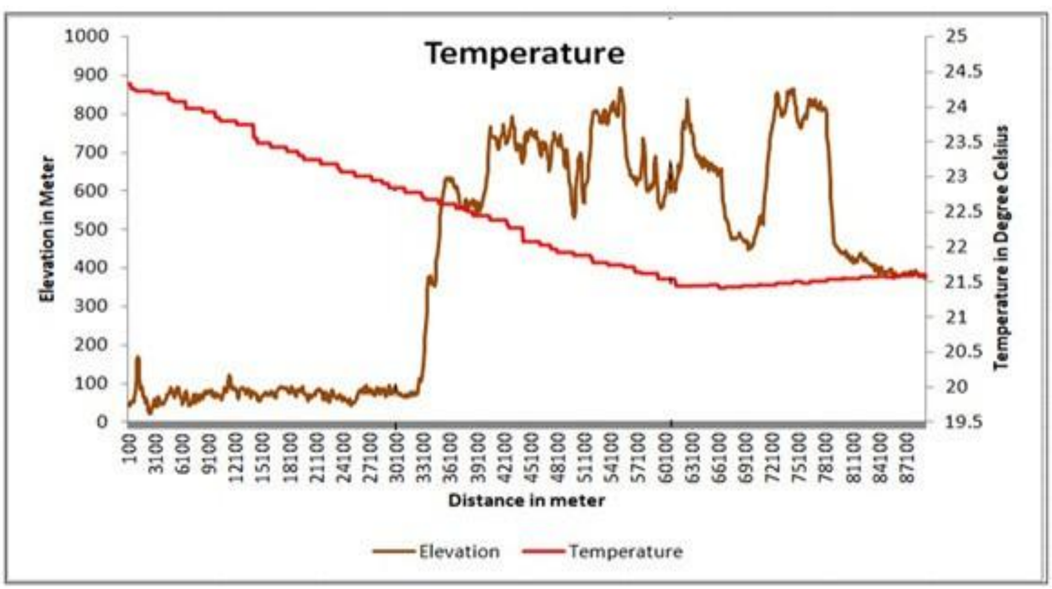
Source: Prepared by Researcher

Fig. 5.4: Relationship between Elevation and Rainfall in the Attappady Hilly Region

5.5.2 Temperature in the Attappady Hilly Region

Temperature is a vital component in a rain shadow region model as it affects the rate of evaporation, condensation, and cloud formation, thereby influencing precipitation patterns. It also plays a significant role in determining soil moisture, vegetation health, and overall microclimatic conditions in both the windward and leeward sides.

The temperature distribution of Attappady is also influenced by topographic barrier of Attappady hills. It experiences a minimum temperature of 21.26°C, and a maximum of 22.84°C, and the mean is 22.56°C for the last 43 years (1981-2024). This significant difference in temperature between the two areas is influenced by orographic effects. This temperature variation can be attributed to the rain shadow effect on the lee ward side of Attappady. As air rises on the windward side, it cools, leading to lower temperatures. Conversely, as air descends on the leeward side, it warms, resulting in higher temperatures. (Fig.5.5).

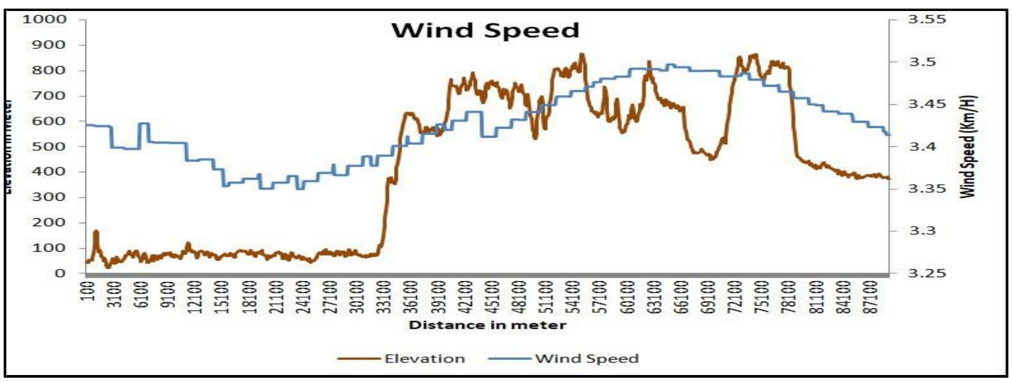


Source: Prepared by Researcher

Fig. 5.5: Relationship between Elevation and Temperature in the Attappady Hilly Region

5.5.3 Wind Speed in the Attappady Hilly Region

Wind speed is a crucial factor in a rain shadow region model as it determines the movement of moist air masses and the extent of orographic lifting, which influences rainfall distribution. It also impacts evaporation rates and surface temperature variations, shaping the microclimatic conditions on both the windward and leeward sides. The geographic location and topographic effect influence the speed and direction of wind in Attappady. Wind speed varies between 3.43 and 3.46 m/s, with a mean of 3.45 m/s for the last 43 years (1981-2024). Wind speed variations may result from the complex interactions of local topography and regional wind patterns. Windward sides often experience stronger winds due to the interaction of onshore breezes and the orographic lifting of air. But, on the Leeward sides, it experiences cool and dry wind with the lower mean wind speed (Fig.5.6).



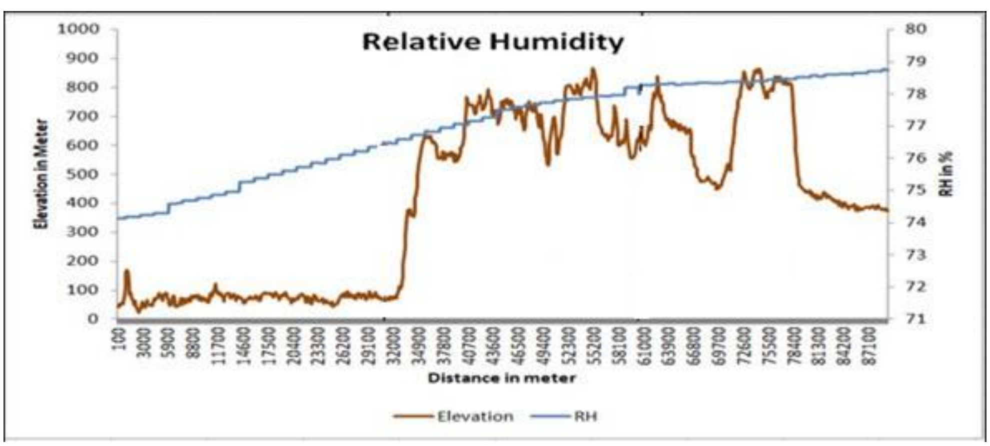
Source: Prepared by researcher

Fig. 5.6: Relationship between Elevation and Wind Speed in the Attappady Hilly Region

5.5.4 Relative Humidity in the Attappady Hilly Region

Relative humidity plays a critical role in a rain shadow region model as it influences the distribution of moisture and the formation of clouds, impacting precipitation patterns on both windward and leeward sides. It also directly affects vegetation growth and soil moisture retention, making it a key factor in understanding microclimatic variations and ecological balance in rain shadow areas. Relative humidity ranges from 77.27% to 78.54%, with a mean of 77.86% for the last 43 years (1981-2024). The higher relative humidity on the windward side can be attributed to the cooling effect of the increased rainfall and reduced temperatures. On the leeward side, where temperatures are slightly higher and rainfall is lower, the air is drier on average with low relative humidity (Fig.5.7).

In Attappady, relative humidity appears to be higher on the leeward side, which is contrary to the typical expectation of lower humidity due to the presence of dry, descending air in rain shadow zones. This unexpected pattern is likely the result of a secondary moisture source that offsets the usual drying effect. The local topography plays a significant role in this phenomenon. At night, cool air tends to settle in the leeward valleys, trapping moisture from nearby rivers, soil, and vegetation. This accumulation of ground-level moisture can lead to elevated relative humidity, and in some cases, the formation of early morning fog. These localized microclimatic conditions create a more humid environment than is usually observed in rain shadow regions. Fig.5.7 Relationship between Elevation and Relative Humidity.



Source: Prepared by Researcher

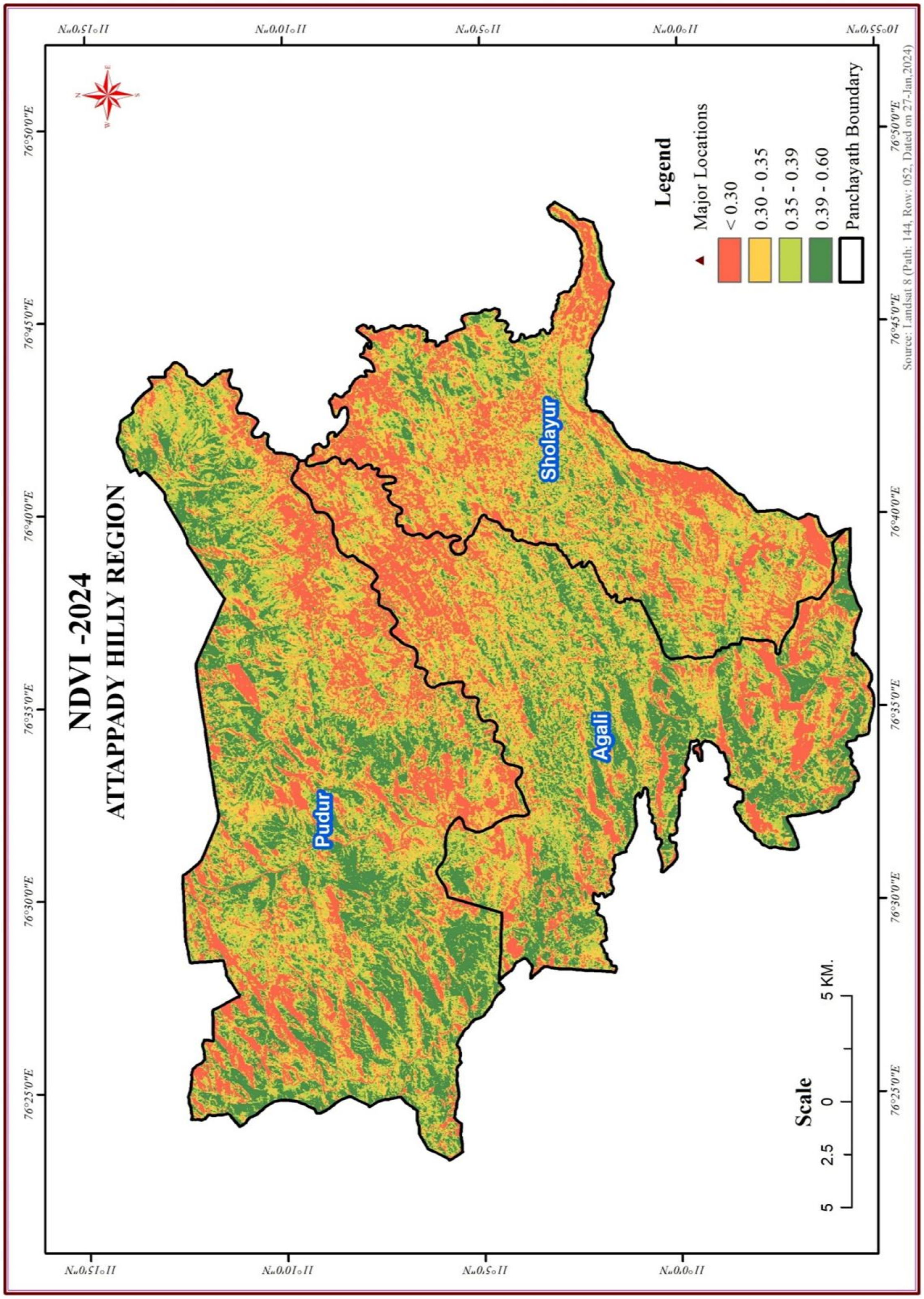
Fig. 5.7: Relationship between Elevation and Relative Humidity in the Attappady Hilly Region

5.5.5 Vegetation in the Attappady Hilly Region

The nature of vegetation is one of the most reliable indicators of the prevailing climate in any region. In the context of Attappady, the Normalized Difference Vegetation Index (NDVI) reveals a mosaic pattern of scattered vegetation (Fig. 5.8), which reflects the region's uneven climatic conditions influenced by both climate change and the rainshadow effect. Areas receiving relatively higher rainfall, particularly in the western part of the region, display higher NDVI values (0.39-0.60), indicating denser vegetation, especially in forested zones. In contrast, lower NDVI values (<0.30 to 0.39) are predominantly observed in the eastern parts, which lie in the rain shadow zone and are characterized by sparse vegetation, barren land, and dry wind gap areas (Fig. 4.6). This stark contrast highlights how the orographic barrier of the Western Ghats obstructs monsoonal rainfall, depriving eastern Attappady of adequate moisture, leading to scrub vegetation and degraded landscapes.

Moreover, climate change has intensified this ecological disparity by altering rainfall patterns, increasing temperatures, and reducing soil moisture retention, particularly in the eastern dry zones. As noted in the AHADS (2010) status report, the region shows a distinct ecological transition from wet tropical forest in the west to dry thorny scrubland in the east. The cumulative effects of forest loss, combined with erratic climatic conditions, have significantly reduced water absorption and soil fertility across the rainshadow area. The prevalence of dry deciduous and euphorbiaceous scrub forests in the east further reflects long-term vegetation stress caused by both climatic variability and anthropogenic pressures.

The degradation has been exacerbated over the past three decades by deforestation, land use changes, and agricultural expansion, often driven by population pressures and migration. The growing percentage of barren land is a direct consequence of this unsustainable transformation. However, initiatives like agroforestry have been recognized as critical adaptation strategies to



Source: Prepared by Researcher

Fig. 5.8 Relationship between Elevation and Vegetation Condition at Attappady Hilly Region

climate change, offering carbon sequestration, biodiversity conservation, and sustainable land use solutions. As documented by Sonalkar S. (2016), the plantation zones in Agali, Kottathara, Sambarkode, and other areas still serve as vital carbon sinks and green buffers in this ecologically fragile region. Addressing the twin challenges of rainshadow-induced aridity and climate-induced variability is therefore essential for restoring the vegetation and ecological balance of Attappady.

5.6 Rain Shadow Mechanism at Attappady Hilly Region

The term rain shadow denotes the decrease in precipitation on the leeward side of a topographical obstacle and explains that the maximum of orographic precipitation falls on the windward side and decreases beyond the summits. Petersen et al. (2017) compare it to a shadow effect. As a result, a rain shadow location receives relatively less rainfall than the windward slope. This impact is most noticeable when the air circulation has a dominant pattern, because the effect is otherwise even off (Schumann, 1998; Siler et al., 2013). There are many studies dealing with the causes and scales of the rain shadow effect, mostly focusing on mid-latitudes. According to Davie (2008), any topographical obstacle can cause a rain shadow effect. This can also occur on different scales, i.e., there is the large-scale orographic impact that causes greater precipitation on the windward side of the mountains and less on the leeward side owing to dominating circulation patterns. On a smaller scale, local topography influences local winds that can disperse the falling raindrops. This rainfall distribution may even be diametrically opposed to that of the macro scale (Geiger et al., 1995). Topographic rain zones and rain shadows, on the other hand, can occur at a variety of topographical scales, ranging from rain shadows on the leeward side of enormous mountain ranges that can span hundreds of kilometers, to rain shadows on the slopes of minor peaks and hills (Nicholson, 1994; Davie, 2008).

Quantifying the orographic rain shadow effect requires two precipitation zones namely regions of orographic enhancement and regions of depletion (Malaby et al., 2007). Many researchers have studied the relationship between the spatial and temporal distribution of rainfall and topographic factors such as altitude, aspect, location, and slope. And applied these topographic features as factors to explore the relationships between topography and the spatial distribution of mean annual, seasonal, and monthly rainfall totals in different parts of the world (Basist et al., 1994; Alijani, 2008; Sevruk et al.,1998, and Oettli et al., 2005). Several studies have also explored the association between rainfall, altitude, and distance from the sea using multiple regression analysis and results showed noticeable differences in the amount of rainfall between windward and leeward stations (Konrad, 1996; Buytaert et al., 2006; Hayward and Clarke, 1996). Prudhomme and Reed (1998) investigated the rain shadow effect and noted that the rain shadow effect is due to the simple relationship between elevation and rainfall. Dore and Choularton (1992) also identified the ratio between rainfall rates and peak precipitation rates associated with mountain summits. Similarly, Diffenbaugh et al., (2005) used Regional Climate Model (RCM) output to examine anomalies in leeside mean annual precipitation in the orographic rain shadow regions and Brady and Waldstreicher (2001) also used radar imagery to depict the rain shadow effect. Tomonori Sato (2005) using RCM investigated the role of mountain ranges upon the formation of the rain shadow region. Vaks et al. (2003) used carbon and oxygen isotope composition to reconstruct the rain shadow effect over glacial/interglacial cycles and found weaker rain shadows during glacial periods. By using various climate models, Venkatesh et al., (2007) investigated rainfall mechanism over the rain shadow region of north peninsular India and found that steep spatial rainfall gradient from windward to leeward side of the Western Ghats Mountain in monthly and seasonal scale.

5.6.1 Rain Shadow Mechanism of climatic Features Phase-I (Ponnani to Mannarkkad)

When moist air from Arabian Sea encounters a mountain range of Western Ghats, it is forced to rise due to the elevation of the Western Ghats. As the air rises, it cools and condenses, leading to the formation of clouds and precipitation. This phenomenon is known as an orographic lift, and it is responsible for significant rainfall on the windward side of mountains. According to the windward side rainfall data of Attappady (Table.5.2), it receives maximum rainfall of about 5218 mm, minimum of 2155 mm and mean rainfall of 3670 mm, indicating a high level of annual precipitation in the windward side. The standard deviation is 1068. This is a measure of dispersion or spread of the rainfall data points around the mean. A higher standard deviation indicates greater variability in the data, suggesting that the rainfall amounts vary widely from the mean value. It shows, rainfall has been gradually increasing towards the hilly side of the windward side. Some effects of this rainfall on the windward side of mountains include the formation of lush and rainy environments on the windward side, often referred to as the "wet side" of the mountain and the consistent rainfall on the windward side can promote the growth of lush vegetation, and other plant life. The combination of water and sunlight can create favorable conditions for plant and agricultural growth. The minimum temperature recorded is 22.44°C, while the maximum temperature is 24.22°C. These values suggest that the region has a relatively mild temperature range. The mean temperature is 23.13°C, indicating a temperate climate in this area.

The wind on the windward side of Attappady is relatively gentle, with little variation between the lowest and highest speeds. Even though the winds aren't particularly strong, they still play a crucial role in bringing moisture from the Arabian Sea into the region. The real game-changer, though, is the Western Ghats. These mountains force the moist air upwards, causing it to cool down and release its moisture as rain. So, even with calm winds, this process keeps the area consistently wet. The air on the windward side is consistently humid, with humidity levels hovering between 74% and 77%. This high humidity means there's plenty of moisture in the air, leading to regular rainfall. The steady humidity levels also show that the weather here doesn't change too dramatically and stay moist and damp, just as expected from a windward side where moist air is constantly pushed up the mountains. The windward side of rain shadow regions (Phase-1) exhibits distinct flora, soil moisture, and biodiversity conditions due to orographic effects. This phenomenon significantly influences vegetation patterns and species diversity. The windward slopes typically support lush vegetation due to higher rainfall, with studies showing increases of up to 150% in precipitation compared to leeward sides (Hende et al., 2021). Soil moisture is a critical factor for plant regeneration, particularly in semi-arid regions. Increased soil moisture correlates positively with seedling density, indicating its importance for vegetation establishment (Qing-tao, 2012). The windward slopes often retain higher soil moisture levels, supporting diverse plant communities compared to drier leeward areas (Jiang et al., 2013). Biodiversity is generally richer on windward slopes due to favorable moisture and climatic conditions, although specific studies indicate variability in species richness and abundance based on local environmental factors (Jiang et al., 2013). The data generated for Attappady windward side reveals that lush vegetation and healthy soil conditions implicit good biodiversity. For example, Silent Valley National Park is situated in the same phase. The Rain shadow Mechanism in Phase-1 is given in Fig.5.9

Table 5.2: Phase I: Climate features - Ponnani to Mannarkkad (0 – 30Km)

Rain Shadow Mechanism phase-1 (0 to 30 Km) From Ponnani to Mannarkkad				
	Min	Max	Mean	SD
Rainfall in mm	2155	5218	3670	1068
Temperature ^{0} C	22.44	24.22	23.13	0.54
Wind Speed (Km/h)	3	3.42	3.38	0.02
RH (in %)	74	77	76	0.87
NDVI	0.34	0.90	0.67	
Height in meter	53	630	195	

Source: Prepared by Researcher

5.6.2 Rain Shadow Mechanism of climatic Features: Phase-II (Mannarkkad to Kottathara)

The phase- 2 receives a minimum of 2264mm and a maximum of 3649mm of rainfall, with a mean of 2668mm. The significant difference in rainfall between the two sides is typical of areas influenced by orographic lift. On the windward side, moist air is forced to rise over the mountains, leading to enhanced rainfall due to adiabatic cooling and condensation. On the leeward side, the descending air experiences adiabatic warming, reducing its moisture-holding capacity, which results in lower rainfall.

Minimum temperature is 21.26°C, and maximum is 22.84°C, and the mean is 22.56°C (table 5.3). The temperature variation can be attributed to the rain shadow effect. As air rises on the windward side, it cools, leading to lower temperatures. Conversely, as air descends on the leeward side, it warms, resulting in higher temperatures. The windward side's higher mean temperature can be explained by cooler temperatures caused by increased cloud cover and rainfall.

Table 5.3: Phase: II: Climate features- Mannarkkad to Kottathara (30– 60Km)

Rain shadow Mechanism: Phase-II (30-60 Km) (From Mannarkkad to Kottathara)				
	Min	Max	Mean	SD
Rainfall in mm	2264	3649	2668	0.30
Temperature ^{0} C	21.26	22.84	22.56	0.54
Wind Speed (Km/h)	3.43	3.46	3.45	0.02
RH (in %)	77.27	78.54	77.86	0.37
NDVI	0.64	0.91	0.63	
Height in meter	416	819	700	

Source: Prepared By Researcher

Wind speed varies between 3.43 and 3.46 m/s, with a mean of 3.45 m/s. Wind speed variations may result from the complex interactions of local topography and regional wind patterns. Windward sides often experience stronger winds due to the interaction of onshore breezes and the orographic lifting of air. Leeward sides, on the other hand, may be sheltered from strong winds, which can explain the lower mean wind speed. Relative humidity ranges from 77.27% to 78.54%, with a mean of 77.86%. The higher relative humidity on the leeward side can be attributed to the cooling effect of the increased rainfall and reduced temperatures. On the windward side, where temperatures are slightly higher and rainfall is greater, the air may be drier on average. Condition of vegetation varies from -0.64 to 0.91, with an average of -0.63. The differences in vegetation can be largely attributed to conditions of varied rainfall. More rainfall on the windward side supports denser vegetation, while the leeward side's lower rainfall limits vegetation growth. The Rain shadow Mechanism in Phase-II is given on Fig.5.9.

5.6.3 Rain Shadow Mechanism of climatic Features: Phase-III (Kottathara to Karamadai)

Phase-III experiences a wide range of variations of rainfall distribution, with a minimum of 731mm, and a maximum of 2490mm, and shows a mean of 2038mm. The observed decrease in rainfall from Windward to Leeward Side-1 is a clear result of the rain shadow effect. As moist air rises over the windward mountains, it cools, condenses, and precipitates, leading to high rainfall. Conversely, the descending air on the leeward side warms, which reduces its moisture-holding capacity and results in less rainfall. Phase-III experiences minimum temperatures of 22.78°C, and maximum of 23.10°C, and a mean of 22.90°C. Temperature variations can be attributed to elevation differences and the availability of moisture. Higher temperatures on the windward side could be influenced by cloud cover and cooling due to rainfall. Leeward Side-2 exhibits intermediate temperatures between Leeward Side-1 and Windward Side, possibly due to its transitional position.

Wind speed ranges from 3.43 to 3.49 m/s, with a mean of 3.46 m/s. Wind speed variations are influenced by local topography and regional wind patterns. The increasing trend from windward to leeward Side-2 could be due to the accelerated descent of air, which increases wind speed on the leeward side (table 5.4). Relative humidity ranges from 78.32% to 78.62%, with a mean of 78.48%. The increase in relative humidity from windward Side to leeward Side-2 is a result of the orographic lifting of air on the windward side, leading to increased moisture in the air. As air descends on the leeward side, it warms and its relative humidity rises, creating a more humid environment.

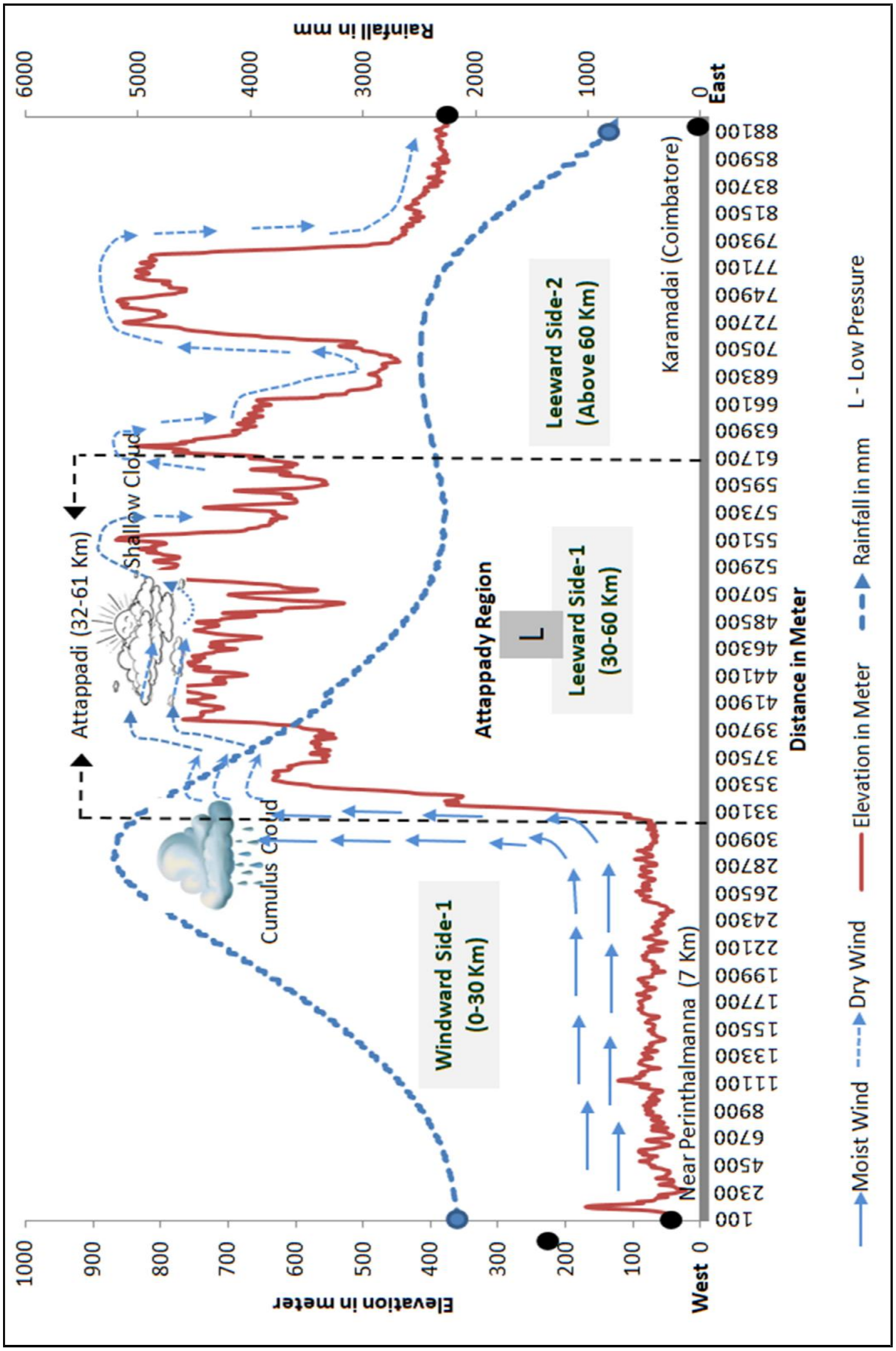
Table 5.4: Phase III: Climate features- Kottathara to karamadai (Above 60Km)

Rain shadow Mechanism: Phase-3 (Above 60 Km) (From Kottathara to Karamadai)				
	Min	Max	Mean	SD
Rainfall in mm	731	2490	2038	554
Temperature ^{0} C	22.78	23.10	22.90	0.024
Wind Speed (Km/h)	3.43	3.49	3.46	0.02
RH (in %)	78.32	78.62	78.48	0.13
NDVI	0.41	0.87	0.16	
Height in meter	381	839	611	

Source: Prepared by Researcher

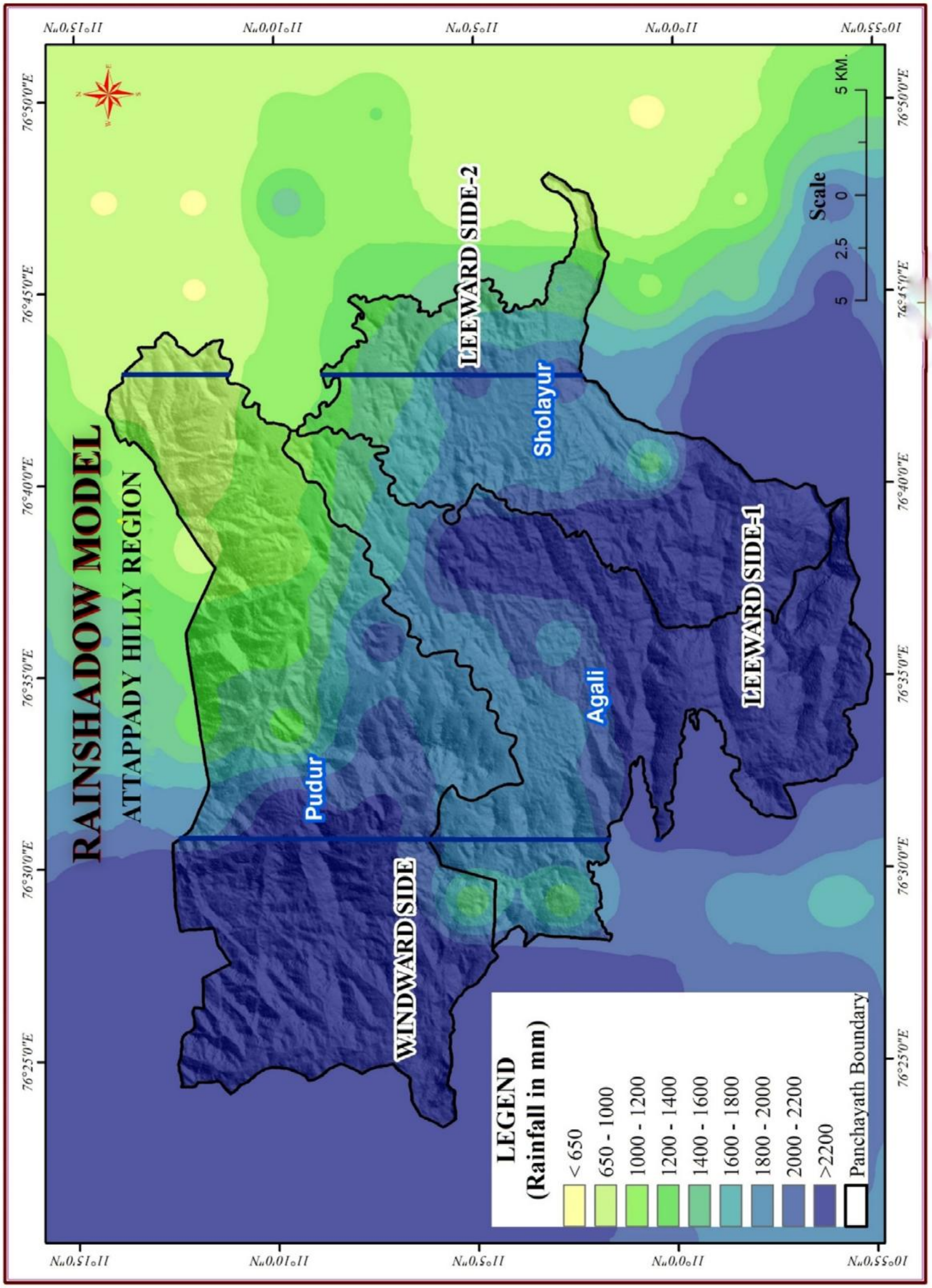
Phase-III: The average vegetation condition is 0.16, indicating sparse vegetation. Variations in vegetation can be attributed to differences in available water due to varying rainfall patterns. More rainfall on the windward side supports denser vegetation, whereas decreasing rainfall from windward to phase-3 results in sparser vegetation. The rain shadow mechanism in Phase-III is given in Fig.5.9.

The rain shadow effect significantly influences flora, soil moisture, and biodiversity on the leeward side of mountains. This phenomenon creates distinct ecological zones, impacting plant species richness and soil characteristics. The leeward side often exhibits unique plant communities adapted to drier conditions, with studies showing a rich diversity of species, including 99 identified in eastern Moroccan rangelands, highlighting the prevalence of



Source: Prepared By Researcher

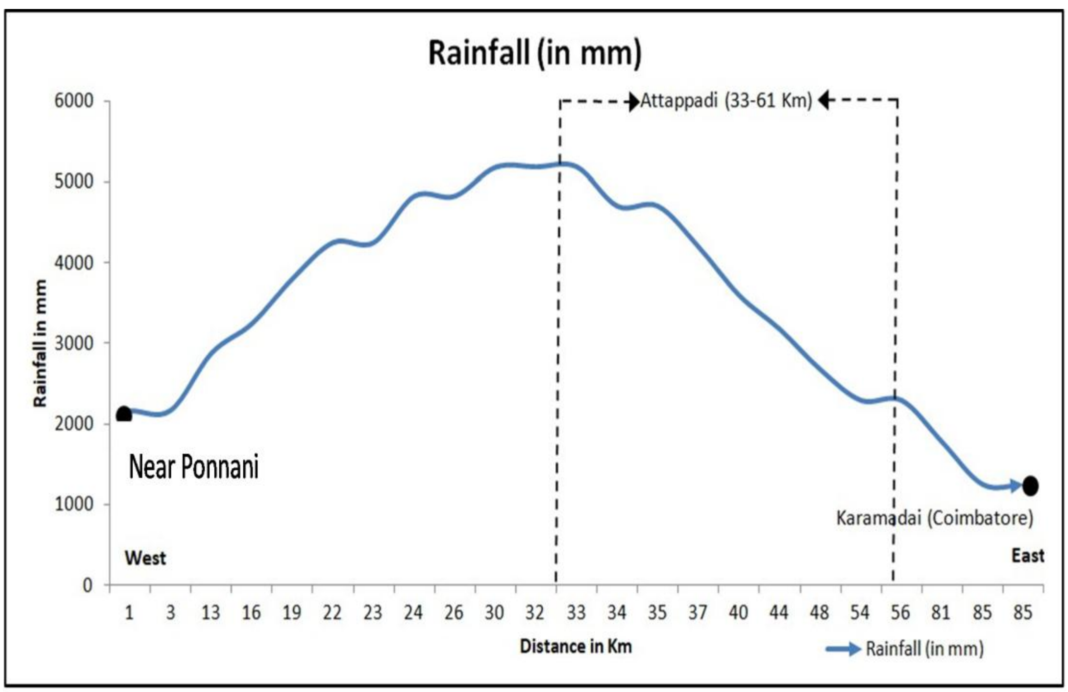
Fig. 5.9: Theoretical and Graphical illustration of the Rain shadow mechanism of Attappady Hilly Region



Source: Prepared By Researcher

Fig.5.10: Rainfall Variation from Windward side to Leeward Side Map of Attappady Hilly Region

Mediterranean biogeographic species (Hachmi et al., 2023). Terophytes dominate these areas, indicating adaptations to seasonal moisture availability (Hachmi et al., 2023). Soil moisture is crucial for sustaining biodiversity. Research indicates that rainwater harvesting techniques can enhance soil water content, leading to increased vegetation diversity and productivity (Singh et al., 2010). The relationship between soil moisture and plant diversity is evident, with higher soil water levels correlating with greater species richness (Singh et al., 2010). Soil biodiversity plays a vital role in ecosystem health, influencing nutrient cycling and plant growth. The interconnectedness of soil organisms and plant life is essential for maintaining ecological balance (Khaziev, 2011). Conservation efforts must consider both soil and plant biodiversity to ensure ecosystem resilience against climate change and human impacts. While the leeward side benefits from unique adaptations and resource availability, it also faces challenges from climate variability and land use changes, necessitating integrated conservation strategies.



Source: Prepared By Researcher

Fig. 5.11 Rainfall Variation from Windward side to Leeward Side in the Attapady Hilly Region

5.7 Statistical Explanation for Rain Shadow Model of Attappady Hilly Region

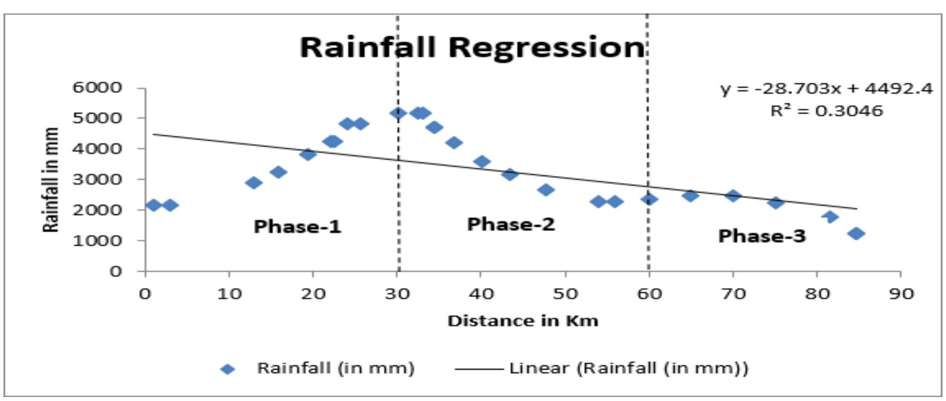
The Rain shadow model, which describes the phenomenon of reduced rainfall on the leeward side of mountains, necessitates a robust mathematical and statistical framework to accurately represent the complex interactions between meteorological variables. This framework is essential for effective urban stormwater management and predictive modeling. Statistical analysis of rainfall data is crucial for understanding storm events, as demonstrated by Branham and Behera, who emphasize the need for probabilistic modeling based on rainfall characteristics like volume and intensity. The use of probability density functions (PDFs) to characterize rainfall events allows for more accurate simulations in urban planning and infrastructure design. Rodriguez-Iturbe and Eagleson explore point process techniques to model the spatial and temporal structure of rainfall, highlighting the importance of mathematical models in predicting rainfall intensity and cumulative rainfall. Rogers discusses the application of statistical rain cell models to predict microwave communication performance, underscoring the necessity of statistical foundations in understanding precipitation effects. Goyen presents a method to integrate stochastic elements of rainfall with deterministic runoff processes, illustrating how statistical models can enhance traditional approaches to urban runoff analysis. While the mathematical and statistical explanations are vital for the Rain shadow model, some researchers argue that qualitative assessments and observational studies can also provide valuable insights into rainfall patterns, suggesting a balanced approach may be beneficial.

Linear regression is often used for prediction, forecasting, and understanding the relationship between variables. However, it is essential to keep in mind that it assumes a linear relationship, and the model's performance may suffer if the actual relationship is not linear. There are other regression techniques available for more complex relationships, such as polynomial regression, logistic regression, etc.

5.7.1 Distribution of Rainfall in the Attappady Hilly Region

Regression analysis is a valuable tool in studying rainfall patterns, particularly in rain shadow regions where precipitation is unevenly distributed due to topographical influences. It helps analyse long-term rainfall trends and variations on the windward and leeward sides of mountains, offering insights into how the rain shadow effect impacts local climate. A regression value of 0.30 indicates a moderate relationship between the rainfall and horizontal distance. It suggests that approximately 30% of the variability in the rainfall variable can be explained by the distance variable in the linear regression model. In other words, the model accounts for 30% of the variance in the data (Fig.5.12).

This regression model of distribution of rainfall explains the trend of rainfall in the both side of the hilly region of Attappady and it explains the changing trend of rainfall distribution over the horizontal distance from western part of Attappady to its eastern part. The significant difference in rainfall between the two sides is influenced by the orographic lift. On the windward side, moist air is forced to rise over the mountains, leading to enhanced rainfall due to adiabatic cooling and condensation. On the leeward side, the descending air experiences adiabatic warming, reducing its moisture-holding capacity, which results in lower rainfall.

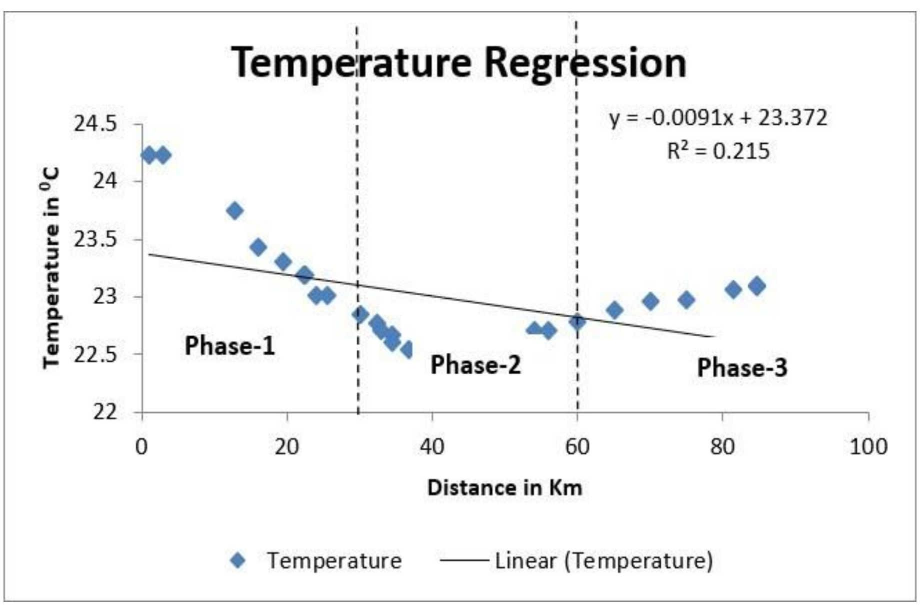


Source: Prepared By Researcher

Fig. 5.12 Rainfall Regression in the Attappady Hilly Region

5.7.2 Distribution of Temperature in the Attappady Hilly Region

Regression analysis plays a crucial role in understanding temperature variations, especially in regions influenced by the rain shadow effect. These areas often experience significant temperature differences between the windward and leeward sides of mountains due to reduced moisture and altered climatic conditions. The presence of a rain shadow region can have an impact on temperatures as well. In general, rain shadow regions tend to experience higher temperatures compared to the windward side of the mountain range. The phenomenon can be explained by a combination of factors. When moist air rises on the windward side of Palakkad, and Chittur of the mountain range, it undergoes adiabatic cooling, which means it cools as it ascends and expands due to decreasing atmospheric pressure. This cooling effect can result in lower temperatures on the windward side, especially at higher elevations. On the interlocked Attappady leeward side, where the rainshadow region is located, the descending air undergoes adiabatic warming as it compresses and descends. This warming effect can lead to higher temperatures in the rainshadow region compared to the windward side.



Source: Prepared By Resercher

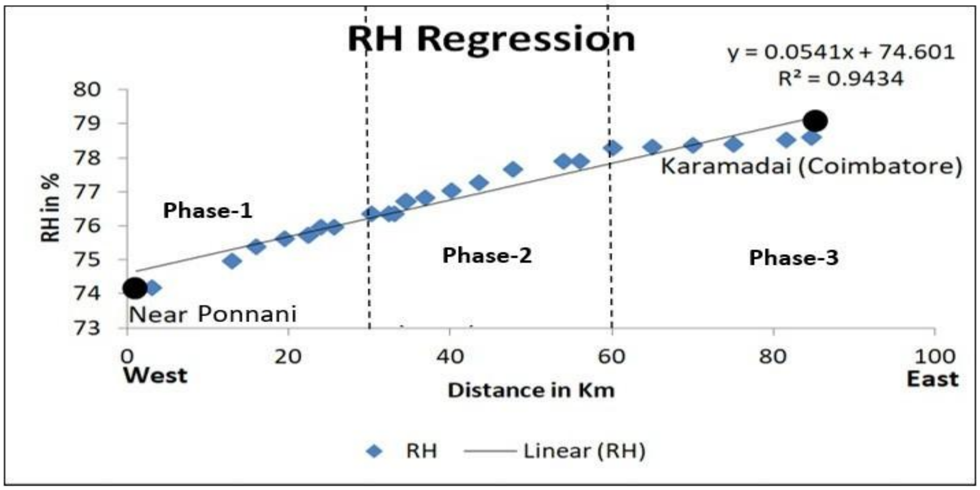
Fig. 5.13: Temperature Regression in the Attappady Hilly Region

Usually, the lack of significant cloud cover and rainfall in the rainshadow region allows for more direct sunlight and less moisture in the air, which can contribute to higher temperatures. But, in the study area, it's important to note that the specific temperature conditions in a rainshadow region can vary depending on factors such as latitude, elevation, proximity to bodies of water, prevailing weather patterns, vegetation cover and surface characteristics. The temperature data collected from NASA power data access reveals that temperature has been slightly decreasing from 24.22ºC in Western part of Perinthalmanna near Mallappuram to 3.10ºC in the eastern part of Coimbatore (Fig.5.9).

A regression value of 0.215 in the context of linear regression in temperature variable, represents the correlation or coefficient of determination (R-squared) between the dependent variable of temperature and the independent variable of horizontal Distance. The lower R-squared value suggests that elevation is a relatively weak predictor of temperature in the rainshadow region of Attappady, and there are other factors at play in determining temperature patterns in this area. This could be due to higher elevation within rain shadow region and high vegetation thickness specific to Attappady's rain shadow region (Fig.5.13).

5.7.3 Distribution of Relative Humidity in the Attappady Hilly Region

As per the physics, in a rainshadow region, the relative humidity tends to be lower compared to the windward side of a mountain or mountain range. This lower relative humidity is a result of the descending air on the leeward side, which warms adiabatically and can hold more moisture as it descends. As the moist air rises and cools on the windward side, it undergoes adiabatic cooling, leading to condensation and the formation of clouds and precipitation. By the time the air reaches the leeward side, it has lost much of its moisture, resulting in lower relative humidity (Sad, F. et al., 2018). The drier air in the rainshadow region can lead to arid or semi-arid conditions, as the reduced moisture availability inhibits the formation of clouds and rainfall. Consequently, the relative humidity in the rainshadow region is often lower, contributing to the aridity of the area. But in the case of Attappady, the satellite data shows an increasing trend of Relative Humidity (RH) percentage. Relative Humidity increases from 74.18% in the western part of Ponnani to 78.62% in the Eastern side of Karamadai.



Source: Prepared By Researcher

Fig. 5.14: Relative Humidity Regression in the Attappady Hilly Region

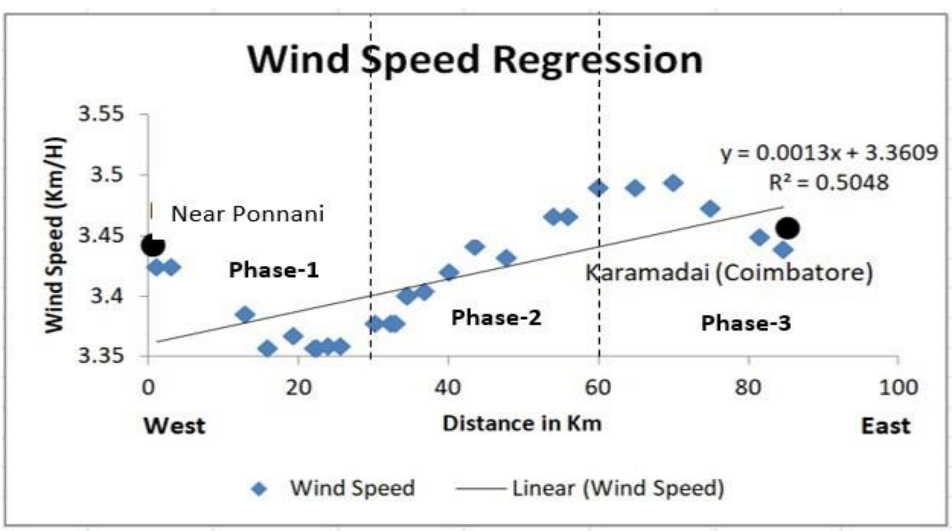
Relative humidity measures the amount of moisture in the air compared to the maximum amount the air can hold at a given temperature, and it usually decreases as air descends and warms. However, in the case of the Attappady the high relative humidity in the leeward side of the mountain range, can be explained by several other scientific factors (Fig.5.14).

5.7.4 Distribution of Wind Speed in the Attappady Hilly Region

The presence of a rain shadow region can have an impact on wind speed. Generally, wind speed tends to be higher in rain shadow regions compared to the windward side of a mountain or mountain range (David M. Schultz et al., 2017). As moist air approaches a mountain range, it is forced to rise, leading to the formation of clouds and precipitation on the windward side.

This upward movement of air can result in a vertical component of wind, known as upward vertical motion. This vertical motion tends to decrease the horizontal wind speed on the windward side.

On the leeward side of the Attappady, where the rain shadow region is located, the descending air tends to accelerate and increase the average horizontal wind speed from 3 km/h to 3.80 km/h. In the western side of Perinthalmanna, the wind speed is 3.42 km/h but when it reaches the eastern part of Karamadai the wind speed slightly increases to 3.43 km/h (Fig.5.4). In between the area, the windspeed is gradually increasing within the rainshadow region of Attappady. This is due to the adiabatic warming and compression of the air as it descends. The descending air in the rain shadow region can create a downslope wind known as a "katabatic wind" or "foehn wind." These winds can be strong and gusty, contributing to higher wind speeds in the rain shadow region. The increased wind speed in the rain shadow region can have implications for the local climate and ecosystem. It can lead to higher evaporation rates, greater water loss from vegetation, and increased desiccation. These factors contribute to the arid or semi-arid conditions often associated with rain shadow regions (Fig.5.15).



Source: Prepared By Researcher

Fig. 5.15: Wind Speed Regression in the Attappady Hilly Region

A regression value of 0.50, in the context of linear regression and the coefficient of determination (R-squared), represents the proportion of the variance in the wind speed (y) that can be explained by the horizontal distance (x). Therefore, an R-squared value of 0.50 means that approximately 50% of the variability in the windspeed variable can be explained by the distance variable in the linear regression model. In other words, the model accounts for 50% of the variance in the data (Fig.5.15).

5.7.5 Mann-Kendall Tests for the Rain Shadow and Wet Regions of Attappady, Focusing on Rainfall and Temperature

The Mann-Kendall Trend Test is a method used to study long-term changes in climate data like rainfall, and temperature. This Mann-Kendall statistical analysis helps to check whether these values are increasing or decreasing over time. Since this test does not require any specific type of data distribution, this test is useful. This test handles changes even if the data is not perfect (Yue & Wang, 2004; Mavromatis & Stathis, 2011). It becomes especially important in regions of Attappady, where the climate plays a big role in people's lives. In the rain shadow areas, rainfall is usually low, and temperatures are high. Therefore, understanding the direction of climate change is crucial in the rain shadow region. Hence, this test is useful to analyse the trends in temperature and rainfall data over time.

As per our analysis, the Attappady has two different climatic zones, the leeward (dry) rain shadow region and the windward (wet) region. The wet region generally receives more rainfall and lower temperature. On the other hand, the rain shadow zone remains hot and dry. For more understanding of the climatic pattern in the dry region, the Mann-Kendall test helps to find out whether these weather patterns are shifting over the years. This result is very important to understand the changes in temperature or rainfall as it directly affects farming, water sources, and daily livelihood in the study area. In Attappady, temperature and rainfall distribution are already investigated in 5.6.1 and 5.6.2, but we did not know whether these values were going up or down over time. This test helps in identifying whether the Attappady region is getting hotter or wetter or staying the same.

The Mann-Kendall test is applied to analyse the 40 years of climatological data from both dry and wet regions of Attappady. This test verified if there is a consistent upward or downward trend exist in the data. It gives three values: the p-value, Z-value, and H-value. These numbers help to decide whether the changes in the data are significant or just random. With the help of these values, we can understand with confidence if temperature or rainfall is truly increasing or decreasing.

The p value reveals that whether the trend is likely to be real or just due to random chance. A p value of 0.05 or less means that there is a strong chance of trend is real and not just a coincidence. A p value higher than 0.05 suggests that the trend might be due to natural variation. For example, a p value of 0.10 means there is a 10% chance the observed change is just random, so we can't accept the trend as really exists. The lower the p value means the stronger the evidence that a trend exists.

The Z value and H value give more meaning to the trend analysis. The Z value shows the direction and strength of the trend. If the Z value is positive, the trend is going up; if it is negative, the trend is going down. A value close to zero means there is no trend. if $H = 1$, it means we can reject the idea that there is no trend, so a trend does exist. If $H = 0$, it means the trend is not significant. These values together help us to understand what is really happening in the climate data.

In Attappady, the Mann-Kendall test showed different results for the dry and wet regions (table 5.5). In the dry region, temperature shows a steady increasing trend, with a p value of 0.05, a very high Z value of 29.78, and H = 1. These value shows the trend is strong and significant. Rainfall in this region, however, has a p-value of 0.10 and Z value of 1.63, which is not strong enough to confirm a real trend (H = 0). This means temperature is rising significantly, but rainfall doesn't show a meaningful trend in the dry area.

Table 5.5: Mann-Kendall Trend Test

Parameters	**Dry Region**		**Wet Region**	
	Temperature	**Rainfall**	**Temperature**	**Rainfall**
Trend	Increasing	No Trend	Increasing	Increasing
h	True	False	True	True
p	0.05	0.10	9.99	2.44
z	29.78	1.63	7.73	7.62

Source: Prepared by Researcher

In the wet region, both temperature and rainfall are increasing. The Z values are high 7.73 for temperature and 7.62 for rainfall with H = 1 in both, confirming the trends. Even though the p values are reported as 9.99 and 2.44, they still suggest clear upward trends due to the strong Z values. These results show that both regions are warming, but rainfall trends showing different. Rising temperatures increase evaporation and reduce soil moisture, which affect farming and water availability. Overall, the Mann-Kendall test gives a clear picture of how climate is changing in Attappady.

5.8 Conclusion

Mountains have a predominant influence on the atmosphere, and they alter the movement of air and disturb the vertical stratification of the atmosphere by acting as physical barriers. The Western Ghats, a prominent mountain range along the western coast of India, played a crucial role in creating orographic effects and rain shadow regions. Attappady, a region located in the Eastern parts of the Western Ghats, is no exception to this phenomenon. In Attappady, the

Western Ghats act as a formidable barrier to the moisture-laden southwest monsoon winds, forcing them to rise as they approach the windward side. This ascent cools and condenses the air, leading to the release of moisture in the form of rain. As a result, the windward side of the western part of Western Ghats, which includes Malappuram and western parts of Palakkad, receives abundant rainfall, contributing to the lush greenery and high biodiversity of these regions. However, on the leeward side of the Western Ghats, such as in the eastern part of Attappady, a rain shadow effect was observed. As the moist air masses have already lost much of their moisture while ascending the western slopes, they descend on the eastern side, leading to drier and less rainy conditions. This orographic effect in Attappady created comparatively lower annual precipitation levels and a semi-arid climate and made water availability and agriculture more challenging for the local communities. The study of orographic effects and rain shadow regions in Attappady underscores the significance of understanding the complex interplay between topography and climate patterns in shaping local environments. The significant difference in rainfall between the two sides was influenced by orographic lift. On the windward side, moist air is forced to rise over the mountains, leading to enhanced rainfall due to adiabatic cooling and condensation. But as the air reaches on the leeward side, the descending air experiences adiabatic warming, reducing its moisture-holding capacity, which results in lower rainfall. More rainfall on the windward side supports denser vegetation, while the leeward side's lower rainfall limits vegetation growth. The third phase of rain shadow mechanism region covers Kottathara to Karamadai. The Phase-3 experienced a wide range of rainfall, with a minimum of 731mm, maximum of 2490mm, and a mean of 2038mm. The observed decrease in rainfall from Windward to Leeward Side-2 is a clear result of the rain shadow effect. As the descending air on the leeward side warms, which reduces its moisture-holding capacity and results in less rainfall and made a rain shadow in the eastern part of Attappady region. The rain shadow effect significantly influenced flora, soil moisture, and biodiversity and human livelihood dynamics on the leeward side of Attappady region. This phenomenon created distinct ecological zones, impacting on the plant species richness and soil characteristics. Overall, the rain shadow model showed that the leeward side of Attappady region comes under the rain shadow of a mountain range. The microclimate variations in Attappady were mainly driven by the rain shadow effect, which leads to differences in rainfall, temperature, wind speed, relative humidity, and vegetation cover between the windward and leeward sides of the region. Thus, the rain shadow modelling helped to understand the influence of the mountains on the atmosphere and how they alter the movement of air and disturb the vertical stratification of the atmosphere by acting as physical barriers and creating wet region on wind ward side and rain shadow region on lee ward side of Attappady region of the Western Ghats of Kerala.

CHAPTER 6

RAIN SHADOW INDUCED LAND DEGRADATION AT ATTAPPADY HILLY REGION

CHAPTER 6

RAIN SHADOW INDUCED LAND DEGRADATION AT ATTAPPADY HILLY REGION

6.1 Introduction

Land degradation is a major environmental challenge across the world. Countries in Asia is highly affected by land degradation than European countries (D. Barman 2013). About 40-75% of the world's agricultural land's productivity was reduced due to land degradation (Kiage, L.M. 2013). Due to severe land degradation, approximately 205 million people and 1.9 billion hectares of land are currently vulnerable worldwide (Senapati & Das, 2020), and around 1.5 billion people have already been affected by this environmental issue (Nachtergaele et al., 2010). According to Barrett-Lennard and Hollington (2006), approximately 10-20 million populations, existent on land, are influenced by salts with very low productivity and alarming threats of environmental degradation. This number has been increasing in recent times. Approximately 6 million hectares of agricultural land become unproductive due to various processes of land degradation every year. Globally about 20% of cropland areas, 30% of forest, and 10% of grasslands are under various kinds of land degradation processes. Intense plowing, excessive grazing, lack of vegetation, shifting cultivation, and deforestation are the causes of land degradation in the under developing countries (Ligonja and Shrestha 2015), while in other countries, which are developing, the physical factors of land degradation are stimulated by various socio-economic factors (Feoli et al., 2002).

Land degradation and climate change are becoming increasingly linked, each intensifying the other. According to the Intergovernmental Panel on Climate Change (IPCC), poverty rates were closely linked with land degradation (Hoffmann, 2022). People and ecosystems throughout the world are both affected by “land degradation” along with “Climatic Change” (Reed & Stringer, 2016). Climate induced land degradation is a pressing environmental issue characterized by the deterioration of land quality due to climate change effects. This phenomenon encompasses a range of processes, including soil erosion, loss of vegetation, and reduced agricultural productivity, which are accelerated by changing climatic conditions such as temperature fluctuations and altered precipitation patterns. Increased temperatures and altered rainfall patterns significantly impact soil moisture and plant biomass, leading to reduced agricultural yields and increased land degradation (Dharumarajan et al., 2019). Climate change also accelerates soil erosion and nutrient depletion, which diminishes land productivity and ecological integrity (Roy et al., 2022). The degradation of land due to climate change poses serious threats to food security, particularly in developing regions where agricultural dependence is high (Roy et al., 2022). The decline in land productivity can lead to economic deterioration, affecting livelihoods and increasing poverty levels (Javed et al., 2012). Climate induced land degradation results from climate change impacts, altering vegetation types and atmospheric circulation. This degradation exacerbates CO_2 emissions from cleared vegetation and diminishes carbon sequestration (Ioras et al., 2014).

The unstable and changing climate is affecting the soil through destroying ecosystem processes and changes in structure and texture (Lal, 1994). Land degradation aggravates CO2-induced climate change through the release of CO2 from cleared and dead vegetation and through the reduction of the carbon sequestration potential of degraded land. Generally high temperatures and low precipitation in the dry lands lead to poor organic matter production and rapid oxidation. Low organic matter leads to poor aggregation and low aggregate stability leading to a high potential for wind and water erosion. The severity, frequency, and extent of erosion are likely to be altered by changes in rainfall and intensity and changes in wind. Soil is the most significant carbon storage in naturally occurring environments. Soils become a source of greenhouse gases due to soil erosion and deterioration. The greenhouse gas impact of nitrous oxide from fertilizers and biomass burning is 310 times more than that of CO2 from the same sources (Singh et al., 2010). Due to climate change, species may move into new territories or even go extinct. The variety of ecosystem services provided by land, including those involved in recharging groundwater, purifying water and protecting against flooding, is also susceptible to change due to "climate change" (Roy et al., 2022). Degradation of land decreases the soil's capacity to absorb carbon, which speeds up global warming. Changing climatic conditions trigger soil fertility depletion, habitat elimination for native species and general decline in biodiversity (Pani, 2020).

6.2 Conceptual Background of Land Degradation and its Societal Impacts

The present section scientifically examines the research question of how microclimates trigger land degradation. For finding the facts, standardized land degradation model is developed for the assessment of land degradation severity at Attappady hilly region, in considering the variables of land, soil, climate and biodiversity. Land is the basic of all natural resources and it gives space for living and livelihood. Land degradation refers to a reduction in the capacity of land to supply benefits to humanity (Daily G, 1995). Socio-economical and biophysical factors interact and exert influences that vary in space and time, resulting in reduced productivity of land (Barrow C J, 1994). Land degradation has become a critical issue worldwide, especially in the developing countries, which leads to great concerns about food security, livelihoods of human beings, sustainable development of human society, healthy land ecosystems. (Zhihui Li et al, 2015) Land degradation refers to the reduction in the ability of land to provide essential benefits to humans (Daily, 1995). It involves a significant decline in biological productivity or usefulness, often caused by human activities (Johnson et al., 1995). Therefore, it is a significant reduction of the productive capacity of land (Zhihui Li et al ,2015). This issue arises from a complex interaction of social, economic, cultural, political, and environmental factors, all operating over varying timeframes and spatial scales. Land degradation is defined as a negative trend in land condition, caused by direct or indirect human-induced processes including anthropogenic climate change, expressed as long-term reduction or loss of at least one of the following: biological productivity, ecological integrity or value to humans. Land degradation takes different forms in different parts of the world including depletion of soil nutrients, salinization, agrochemical pollution, soil erosion, vegetative degradation. Soil structure is the important property that affects all degradative processes. Factors that determine the kind of degradative processes include land quality as affected by its intrinsic properties of climate, terrain and landscape position, climax vegetation and biodiversity, especially soil biodiversity (Senapati U and Das T K., 2020).

There is a close relationship between the decline of the quality of land and the activities on which people depend to sustain their life. By the land degradation, in most developing countries, agricultural productivity showed a dramatic decline and reached the level beyond the subsistence requirement of a household (Kirui, O. K., and Mirzabaev, A. 2014). The prolonged effect of land degradation resulted in erratic rainfall which caused severe droughts at irregular intervals and these droughts threaten the livelihoods of million people. Drought caused by erratic rainfall brings incapability of farmers to acquire food and hence causes extreme food crises. Land degradation in the form of soil degradation and nutrient depletion affects household's production and investment decision (Abdulmalik, IsrealZewide, 2021). Land degradation is not an inevitable consequence of population growth or cultural traits; rather, it results from the interaction between human activities and the physical environment within an exploitative socio-economic framework (Tsighe, 1995). This implies that human actions are the primary drivers of land degradation, making humans key contributors to desertification (Kishk, 1990). While environmental factors play a role in land degradation, the focus should be on human misuse and mismanagement of the soil, as these are both significant and controllable. For example, deforestation exposes soil to rainfall, resulting in severe erosion (Ellis et al., 1993). The issue is not just a technical problem related to soil science; it is deeply rooted in economic factors (Barbier et al., 1997). Increased land degradation often coincides with the expansion of agricultural activities into forest frontiers and marginal lands, further intensifying degradation. Grazing also exacerbates the problem, as cattle and goats damage young trees while herdsmen burn vegetation to create new pastures. This leads to vegetation destruction along grazing routes, contributing to widespread soil erosion (Mashalla, 1988). Another key driver of land degradation is poverty, particularly in rural areas. The link between rural poverty, deforestation, and land degradation is well-established (Barbier et al., 1997; Hoffman et al., 2000). In many countries, agriculture accelerates land degradation, such as in Ethiopia, where impoverished farmers overuse land beyond its productive capacity, worsening the problem (Tsighe, 1995). From the various study, it is very clear that land degradation and climate change affects people's livelihood activities and ecosystems especially in developing countries like India where agricultural activities are dominant one.

The prolonged effect of land degradation has resulted in erratic rainfall causing severe droughts at irregular intervals, and these droughts threaten the lives and livelihoods of millions of people (Nwokoro and Chima, 2017). Drought caused by erratic rainfall brings the capability of farmers to acquire food and hence causes extreme food crises. Land degradation in the form of soil erosion and nutrient depletion affects households' production and investment decisions. The relationship between land degradation and livelihoods is deeply interconnected, as defined by the sustainable livelihood's framework, as how individuals and households secure the necessities of life, including life, including food, water, shelter, and income (DFID, 1999). For many rural communities, especially in agrarian economies, land is the primary asset and source of livelihood. When land degrades, its capacity to support agricultural production, grazing, and other ecosystem services diminishes, directly impacting the livelihoods of those who depend on it (Toulmin, 2009). Land degradation exacerbates poverty and food insecurity, creating a vicious cycle. Poor households, often lacking access to alternative resources, are forced to overexploit already degraded land, further accelerating its deterioration (Barbier & Hochard, 2018). This cycle is particularly evident in Sub-Saharan Africa, South Asia, and parts of Latin America, where land degradation is widespread and poverty rates are high (Nkonya et al., 2016).

Moreover, land degradation disproportionately affects vulnerable groups, including women, indigenous communities, and smallholder farmers. These groups often have limited access to land tenure, credit, and technology, making them more susceptible to the adverse effects of land degradation (Leach et al., 2012). For example, women in many developing countries rely on land for subsistence farming, and its degradation can lead to increased workloads, reduced income, and diminished food security (Agarwal, 2010).

6.3 Materials and Methods for the Assessment of Land Degradation at Attappady Hilly Region

Delineating land degradation is done through the Multi-Influencing Factor (MIF) technique. The Multi Influencing Factor (MIF) methods have been widely accepted by academics since the 1990s for the spatial decision-making process (Roy.S et.al, 2023); in addition, with the integration of GIS and remotely sensed data it is possible to solve critical problems regarding spatial distribution and choosing desirable locations (Alkaradaghi et al., 2019; and Hussein et al., 2018). Therefore, several researchers have found that geographic information systems (GIS) and remotely sensed data in combination with the MIF method have a great potential for enhancing land related applications (Pramanik, 2016; Orhan et al. 2021; Everest et al., 2021; Mendas et al., 2021). FAO (1976) also provided a method to evaluate land suitability, which ranges from highly suitable to unsuitable depending on climatic data, topographical features, and factors related to soil parameters. Additionally, a weighted aggregation method based on equations was proposed by Bandyopadhyay et al. (2009) for assessing agricultural land suitability potentials using remote sensing and GIS. However, when it comes to spatial mapping, the interplay between different thematic layers is critical (Thomas & Duraisamy, 2018). Therefore, despite several methods, it is always appropriate to integrate remote sensing and GIS with MIF technique for critical evaluation of land degradation assessment, as it benefits planners and managers, as well as helps to determine the most appropriate spatial pattern for sustainable agrarian management (Kumar et al., 2021).

Multi-criteria analysis approach is assessing more than one criterion together, which have different measurement units and are incoherent among each other and which are weighed to determine and group more than one alternative and to determine priority choices (Yoon, K., Hwang, C. 1995). There are different methods that are used to conduct multi-criteria analysis within the environment of GIS. These methods are mainly based on Boolean operator principles of AND and OR. When degree of significance is considered among the criteria in addition to that, the weighting process among criteria has been made (Malczewski, J.1999). Land degradation is a complex process influenced by both natural and human factors. The study area, encompassing the Attappady region in the rain shadow zone of the Western Ghats, was subjected to a comprehensive assessment of climate change impacts on land conversion and degradation. The detailed methodology adopted for this study is given below. Data that were used in models and methods for land degradation analysis in Attappady have been obtained from different web sources, institutions and organizations. Data sources and their detailed metadata are given in Table 6.1.

Slope, relief, rainfall, groundwater, soil, TWI, Drainage Density, Road Density, land use land cover, and vegetation condition are the major parameters considered for the delineation of land degradation (Fig 6.2). The selection of these factors and their importance to land degradation analysis has been discussed in section 6.7 given below. Each parameter is interdependent on other parameters viz. each parameter has a major effect (A) and minor effect (B) upon other parameters. For each major and minor inter-related factor, a weightage of 1 and 0.5 is assigned respectively. A relative rate is calculated for each factor by cumulating all the weights of major and minor interrelated factors (A+B). A factor with higher relative rate shows a larger impact on the land degradation and vice versa. This relative rate is further used to calculate a score for each influencing factor using the following formula (equation 3).

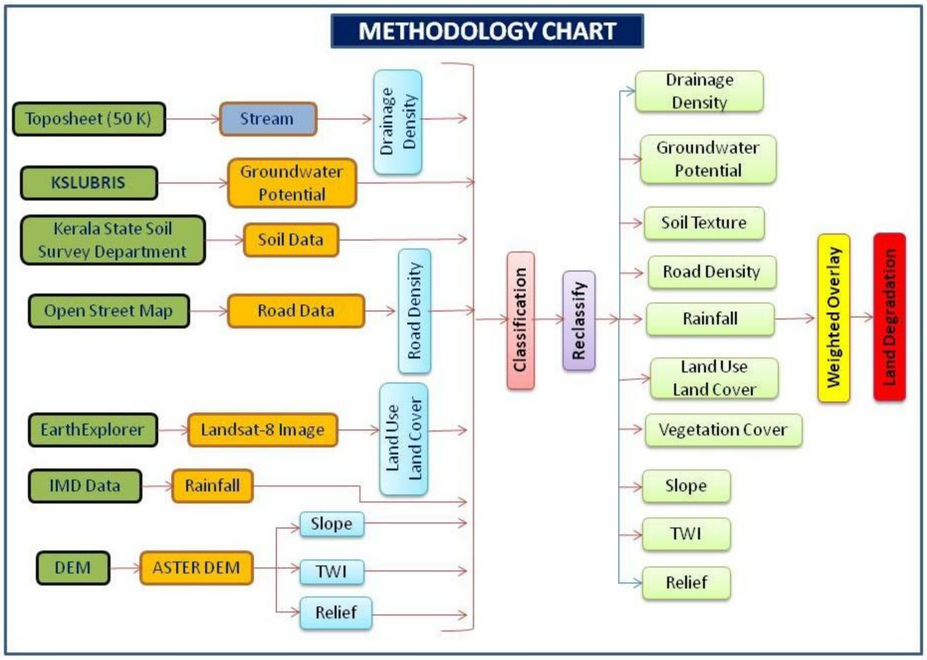
$$= \{\frac{A+B}{\sum A+B}\} X100 \text{.........Equation 3}$$

Where A is the major inter-relationship between two factors B is the minor inter-relationship between two factors A+B is the relative weight of each factor (table 6.2). Detailed calculation procedure has been given in Appendix 2 and Appendix 3.

Table 6.1: Data used for Land degradation analysis

Sl No	Parameter	Data source	Year	Band / Toposheet Number
1	Rainfall	https://dsp.imdpune.gov.in/	1951-2023	
2	Slope, TWI, Relief	ALOS DEM (12.5 Meter Resolution)	2024	
3	Land use land cover	https://earthexplorer.usgs.gov/ r-Landsat 8 OLI/TIRS C1 Level-1, Path 144, Row: 052	2023	Band 2, Band 3, Band 4, Band 5, Band 10, Band 11
4	NDVI	Landsat-8 from Google Earth Engine.		Band 4, Band 5
5	Road Density	www.openstreetmap.com	2023	
6	Drainage Density	Survey of India (1: 50,000) toposheet)	1970	58A08, 58A12, 58A16, 58 B09
7	Groundwater Potential	Kerala State Land Use Board	2023	
8	Soil Texture	https://www.keralasoils.gov.in	2020	

Source: Prepared by Researcher



Source: Prepared by Researcher

Fig. 6.1: Scheme shows the methodology for Land degradation analysis

Attappady is a region with two climatic condition such as heavy rainfall in the windward side and less rainfall in the leeward side. This affects land, soil moisture conditions, vegetation cover and groundwater. Land use land cover reflects human and natural activities on the land such as deforestation, agriculture and built-up expansion. Changes in land use land cover affect soil erosion, biodiversity loss and decreased productivity. Drainage density represents the extent of streams and rivers in a given area, influencing runoff and erosion. High drainage density often correlates with steep slopes and increased surface runoff, leading to higher erosion rates. Soil characteristics like soil texture and organic component determine its vulnerability to erosion and degradation. Understanding soil types and their properties helps identify areas prone to erosion, salinity or fertility loss, which are critical components of land degradation.

Table 6.2: Classification of weighted factors influencing Land degradation

Land Degradation Parameters	Features	Land Degradation	Weightage
Rainfall	Very Low	Very High	11
	Low	High	10
	Medium	Medium	8
	High	Low	6
	Very High	Very Low	4
Land Use Land Cover	Agricultural Land	Medium	8
	Barren Land	Low	6
	Builtup	Very High	10
	Forest	Very Low	4
	Plantation	Medium	8
	Scrub	Low	6
	Waterbody	Low	2
Vegetation Type	Very Low	Very High	10
	Low	High	8
	Medium	Medium	6
	High	Low	4
	Very High	Very Low	2
Drainage Density	Very Low	Very High	10
	Low	High	8
	Medium	Medium	6
	High	Low	7
	Very High	Very Low	2
Soil	Clay	Low	4
	Gravelly Clay	Medium	6
	Gravelly Loam	High	10
Groundwater Prospects	Poor	Very High	11
	Moderate	High	9
	Good to Moderate	Medium	7
	Very Good to Good	Low	5
	Very Good	Very Low	3
Slope	0-5	Very High	9
	5-15	High	8
	15-25	Medium	7
	25-55	Low	5
	>55	Very Low	3
Road Density	Low	Low	2
	Moderate	Moderate	5
	High	High	7
	Very High	Very High	9
Topographic Wetness Index	Very Low	Very High	10
	Low	High	8
	Medium	Medium	6
	High	Low	4
	Very High	Very Low	2
Relief	0 – 100	Very Low	2
	100 – 500	Low	4
	500 – 1000	Moderate	6
	1000 – 1500	High	8
	Above 1500	Very High	9

Source: Prepared by Researcher

6.4 Triggering Factors of Land Degradation in Attappady Hilly Region

The Western Ghats of southern India plays a crucial role in shaping the climate of Peninsular India. Acting as a mountain barrier, the Western Ghats interact with the southwest monsoon, leading to diverse climate patterns across the region (Gunnell, 1997). The orography of the Western Ghats significantly influences rainfall distribution, with the windward side (western slopes) receiving the highest rainfall, while the leeward side (eastern slopes) experiences lower rainfall due to the depletion of moisture in the clouds as they cross the mountains (Sahu, 2018). As a result, Kerala, located on the windward side of Western Ghat, receives substantial rainfall, whereas much of Tamil Nadu, on the leeward side, lies within the rain shadow zone, experiencing significantly less rainfall (Sahu, 2018). In India, about 120.72 million hectares (36.7%) of the total geographical area, is under various categories of land degradation (Sandeep et al., 2020). About 6.73 million hectares in arid, semi-arid, and sub-humid regions of India are affected by soil salinity and alkalinity alone (Sandeep et al., 2020). The maximum percentage of area is degraded due to water erosion (10.21%), compared to water degradation (9.63%). Total estimated cost of land degradation in India is about 25,944 million rupees (Senapati U and Das T K., 2020). Land degradation in Kerala is a multifaceted issue driven by both natural and anthropogenic factors. Urbanization and land conversion have also led to soil degradation, affecting soil quality and agricultural variability (Aneesh et al., 2020).

Attappady hilly region straddling the ecological divide between the region of orographic precipitation to the west and the rain shadow to the east. Since Attappady lying leeward of the Western Ghats Mountain, the region receives less rainfall and more dry air leaving the region parched compared to Kerala's lush western parts. Drought is a regular phenomenon in the eastern area of Attappady due to low rainfall. The geomorphological features have shaped Attappady's identity as an arid enclave challenging ecosystem and livelihoods. The process of deforestation, low rainfall, cultivation on steep slopes, over-grazing, change in land use and land cover with the influx of non-indigenous settlers have badly affected the soil quality of this region and led to land degradation in Attappady. The indigenous people of Attappady belongs a large part of the degraded land in Attappady, faces the problem of extreme poverty, health problems and food insecurity among them (Manikandan 2016)

In Attappady, increased immigration has intensified land use, leading to unsustainable agricultural practices (A.D & Kurian, 2016). Indigenous communities of Attappady face loss of land rights, which undermines their traditional farming systems and contributes to food insecurity (Manjusha & Jojo, 2022) (Edison & Devi, 2019). Deforestation and soil degradation have reduced agricultural productivity, making farming economically unviable in Attappady (A.D & Kurian, 2016). Many indigenous people have shifted to low-paying manual labor and government assistance due to the decline in viable farming (A.D & Kurian, 2016). The loss of land and traditional practices has led to a decline in cultural identity and community cohesion among the *Adivasis* (Manjusha & Jojo, 2022).

Attappady is a unique geographical location and physiography of Palakkad district in Kerala, differs from the rest of the state. The rainfall and wind speeds change abruptly on the leeward side of the mountains, leading to heavier rainfall in the western part of Attappady and drier conditions on its eastern side. This dryness is attributed to the rain shadow effect created by the mountains. One of the contributing factors to the land degradation is the rain shadow effect, a climatic phenomenon that significantly influences the region's hydrology and vegetation. Studying land degradation in Attappady, is crucial for understanding its effects on rural livelihoods. Land degradation in Attappady, a prime tribal region (40.9%) of Kerala, has significant implications for the livelihoods and poverty levels of its inhabitants. The literacy rate of tribes is only 38.62% and above 80% of tribal groups are below poverty line (Census, 2011). Rapid population growth due to in-migration has led to significant land degradation, causing unsustainable livelihoods among the indigenous communities (Manikandan, 2016). Farming has become economically unviable for most indigenous farmers, pushing them to diversify into irregular, low-paying farm and non-farm work, and increasing reliance on government aid (Mohamed, 2019). The loss of forests, shifting cultivation practices, and degradation of fertile land have further marginalized these communities' socio-economically (Das et al., 2023).

Soil moisture stress is a critical factor in Attappady, leading to extreme moisture conditions, such as flooding or drought (Várallyay, 2009). Water stress, in particular, has intensified land and ecological degradation in the region (Subha et al., 2012). Attappady's unique combination of severe land degradation, poverty, and a predominantly tribal population makes it distinct both hydrologically and socially (Franke et al., 2005). Climate change has exacerbated land degradation along the mountain gradient in Attappady, further accelerating the loss of soil organic carbon, which diminishes soil quality and productivity while contributing to climate change (Manikandan et al., 2016). The release of CO_2 from degraded land intensifies climate change, highlighting the interconnected nature of land degradation and climate impacts. The differential rainfall contributes to the region's ecological and hydrological dynamics, affecting soil moisture, vegetation cover, and ultimately land use practices (The Hindu, 2015). The degradation of land led to a decline in agricultural productivity. Traditional food crops of the region are being replaced by cash crops, which has resulted in nutritional insecurity among the tribal populations. This shift is exacerbated by climate change and deforestation, which further diminishes soil quality and water availability. The economic pressures resulting from reduced agricultural productivity often led to changes in land use. The conversion of land for agriculture, coupled with the loss of forest cover, leads to increased vulnerability to erosion and landslides, particularly during heavy rainfall events.

The degradation of land in Attappady has profound socioeconomic implications for local communities. Many residents rely on agriculture for their livelihoods, and declining soil health directly affects their income and food security (Kemalo Abdulmalik and Israel Zewide, 2021). As the capacity of the land to support traditional agricultural practices diminishes, tribal communities may face increased poverty, increased malnutrition which culminates in infant deaths, and migration pressures as individuals seek alternative livelihoods elsewhere (Manikandan, 2016). The land degradation further exacerbates social inequalities and increased difficulties in accessing resources, education, and healthcare again entrenching poverty within these communities.

In Attappady land degradation is a slow imperceptible process and so many people are not aware that their land is degrading. Climate change over the Attappady mountain gradient has had severe impacts on land degradation. The deforestation, shifting cultivation, and loss of fertile land has resulted in soil moisture stress, water stress, and ecological degradation. This degradation has made a pressing issue on extreme socio-economic marginalization of the indigenous people. Therefore, assessment of land degradation is not an easy task, and a wide range of methods are used, including remote sensing and satellite technology as well as computer based statistical models for the up-to-date and accurate land degradation generation. Assessing land degradation induced by climate variation in the rain shadow region of Attappady is the prime objective of the study. The analysis integrates Multi-Influencing Factor (MIF) technique in association with geospatial technologies such as remote sensing data, Geographic Information Systems (GIS), and statistical analysis to explore the land degradation area in Attappady hill region. This chapter also try to highlight land use changes and encroachment on tribal lands in Attappady.

Land degradation is a pressing environmental issue that significantly impacts ecosystems, biodiversity, and human livelihoods. In Attappady, the primary drivers of land degradation include deforestation, unsustainable agricultural practices, overgrazing, and erratic rainfall patterns. Human activities, such as the conversion of forests into agricultural land and the excessive use of chemical fertilizers, have disrupted the natural balance of the ecosystem (Joseph & Anil, 2020). These practices have led to soil erosion, loss of organic matter, and reduced water retention capacity, making the land increasingly barren and unproductive. Additionally, climate change has exacerbated the situation, with prolonged droughts and unpredictable weather patterns further stressing the already fragile environment (Kumar et al., 2019).

The consequences of land degradation in Attappady are far-reaching, affecting not only the environment but also the socio-economic well-being of local communities. Farmers, who rely heavily on the land for their livelihoods, face declining crop yields and reduced income, pushing many into poverty (Nair & Krishnakumar, 2021). The loss of biodiversity and ecosystem services further compounds the challenges, creating a vicious cycle of environmental and economic decline. To address these issues, it is essential to integrate both ecological and human dimensions in delineating land degradation in Attappady.

6.4.1 Rainfall of the Attappady Hilly Region

Rainfall plays a significant role in land degradation. High-intensity rainfall can cause soil erosion, leading to degradation of land (Leo, Stroosnijder 2007) and (Ratan, Priya 2021). Lack of rainfall, on the other hand, can hinder vegetation growth and the survival of plants, further contributing to land degradation (Sabova, Z et al., 2022). Understanding the spatial and temporal patterns of rainfall is crucial in studying land degradation at different scales (C., K., Birkett et al., 2016). By analyzing past and future rainfall events, it is possible to predict the development of degradation processes and assess the effectiveness of different management practices in mitigating land degradation. Rainfall data for the study area is derived from the IMD source from 1990 to 2024 (34 years). According to IMD data, there is an observed decline in rainfall from the western to the eastern regions (Fig 6.3). Attappady experienced the highest rainfall (1400 mm) exclusively during the southwest monsoon, with the Western Ghats serving as an obstacle causing a reduction in rainfall on the leeward side to less than 850 mm (table 6.3).

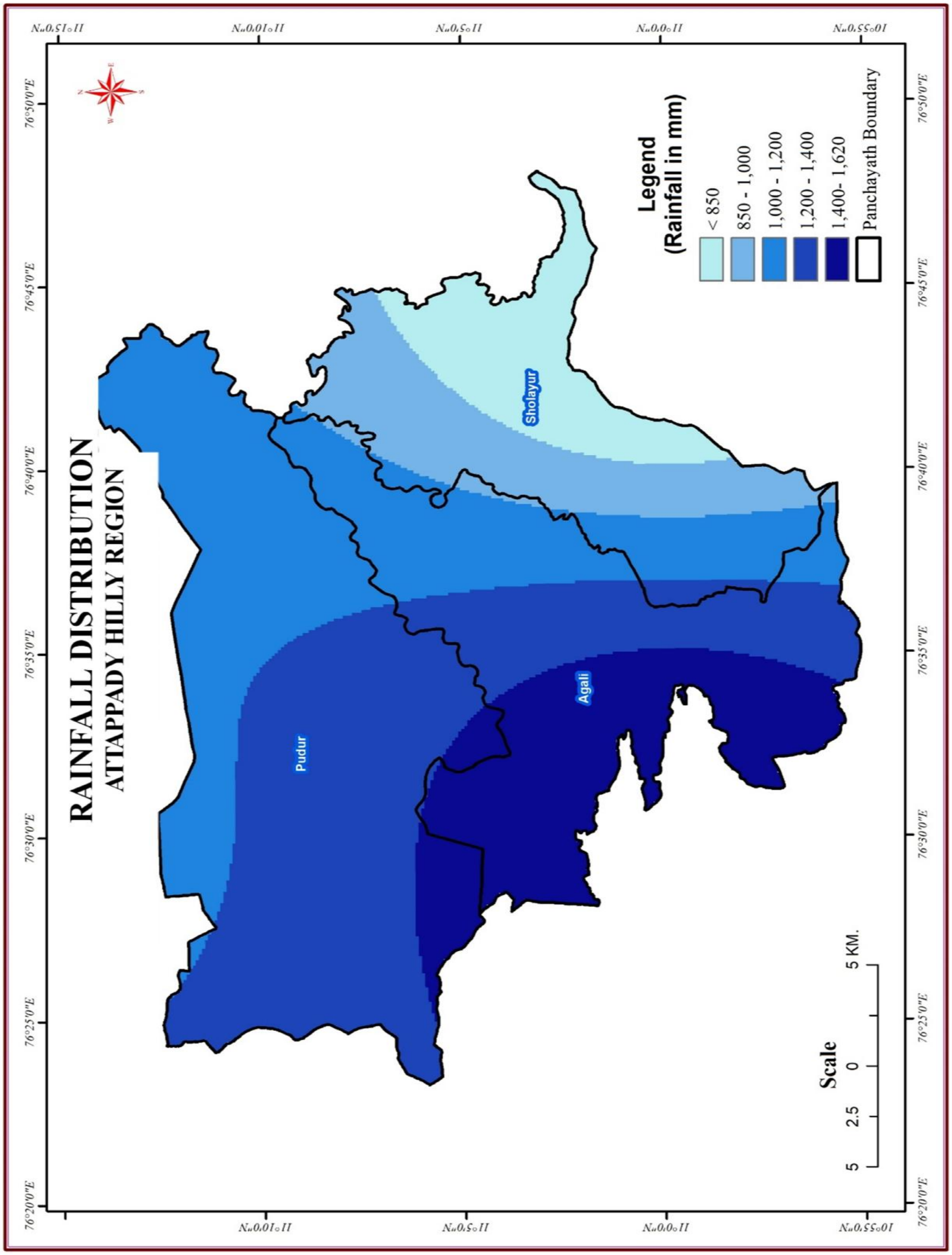
Table 6.3: Rainfall Distribution of the Attappady Hilly Region (1990-2024)

Sl.No	Rainfall in mm	Area in Km^2	Area in %
1	<850	71.77	8.65
2	850-1000	87.38	10.53
3	1000 – 1200	250.26	30.17
4	1200 – 1400	278.73	33.60
5	1400 - 1620	141.17	17.02

Source: https://dsp.imdpune.gov.in/

6.4.2 Decadal Changes (1970 to 2024) in the Land Use and Land Cover Dynamics of the Attappady Hilly Region

Land is the most basic of all natural resources and it provides the space for living and livelihood. Land carries ecosystems and is itself is a part of these ecosystems. Soil is a main component of land and is also a complex ecosystem containing animals and plants of different sizes and activities. Land use simply refers to the human uses of land. The term land use relates to human activity or economic function associated with a specific piece of land. It means how the land is being used by human beings or can be considered as the human employment of land. Land cover relates to the type of feature present on the surface of the earth. It means the biophysical materials found on the land. In short land use refers to the management regime humans impose on a site (eg., plantations

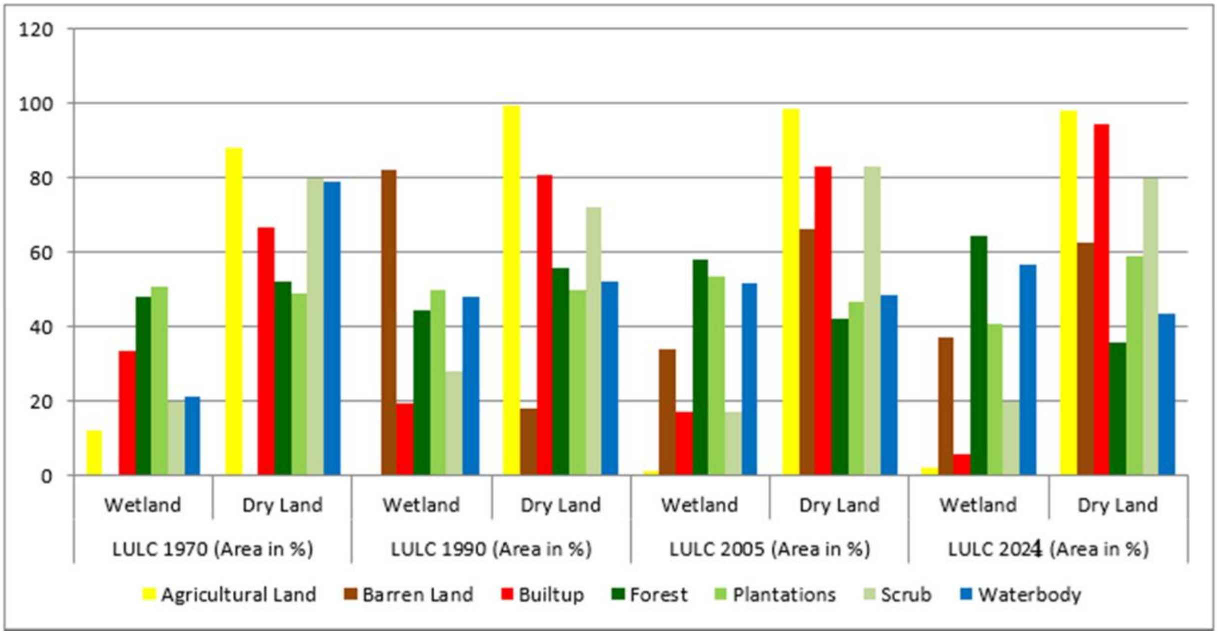


Source: Prepared by Researcher

Fig. 6.2: Rainfall Distribution of the Attappady Hilly Region

or agro forestry) and land cover is the descriptor of the status of the vegetation at a site (eg., forest, crop). Understanding the complex interactions between climate change and land use change is crucial for implementing effective mitigation strategies like sustainable land management practices and policy incentives to conserve soil and biodiversity (Runhuan, Feng 2023).

The present study adopted a modified version of the land use classification proposed by the National Remote Sensing Centre (NRSC). This modification was necessary because not all land use types defined in various classification schemes are found uniformly across all areas. Therefore, it became essential to develop a classification scheme suitable to the specific characteristics of Attappady. Land use maps for the year 1991, 2005 and 2024 were prepared using data from the Landsat 5, 7 and 8 satellite program, which was downloaded from www.earthexplorer.com.This source provides open-access satellite imagery with a relatively high resolution of 15 meters (by applying resolution merge with 15-meter PAN data), which is valuable for addressing various environmental issues. In this study, a Supervised Classification-Maximum Likelihood technique was employed for image classification. QGIS 3.28 version and ERDAS Imagine software were used for data generation, analysis and map preparation. The 1970 land use was vectorized from Survey of India (SOI) (1:50,000) topographical maps. The study area was divided into seven land use categories, namely Cultivated land, Built-up, Scrub, Waterbody, Barren land, Forest, and Plantation. To collect regions of interest from the Landsat data and validate the accuracy of the generated results, virtual Google Earth images and Survey of India (1:50,000) topographical maps were utilized. Change detection analysis was conducted on the LULC maps to identify trends in land conversion and degradation over time.

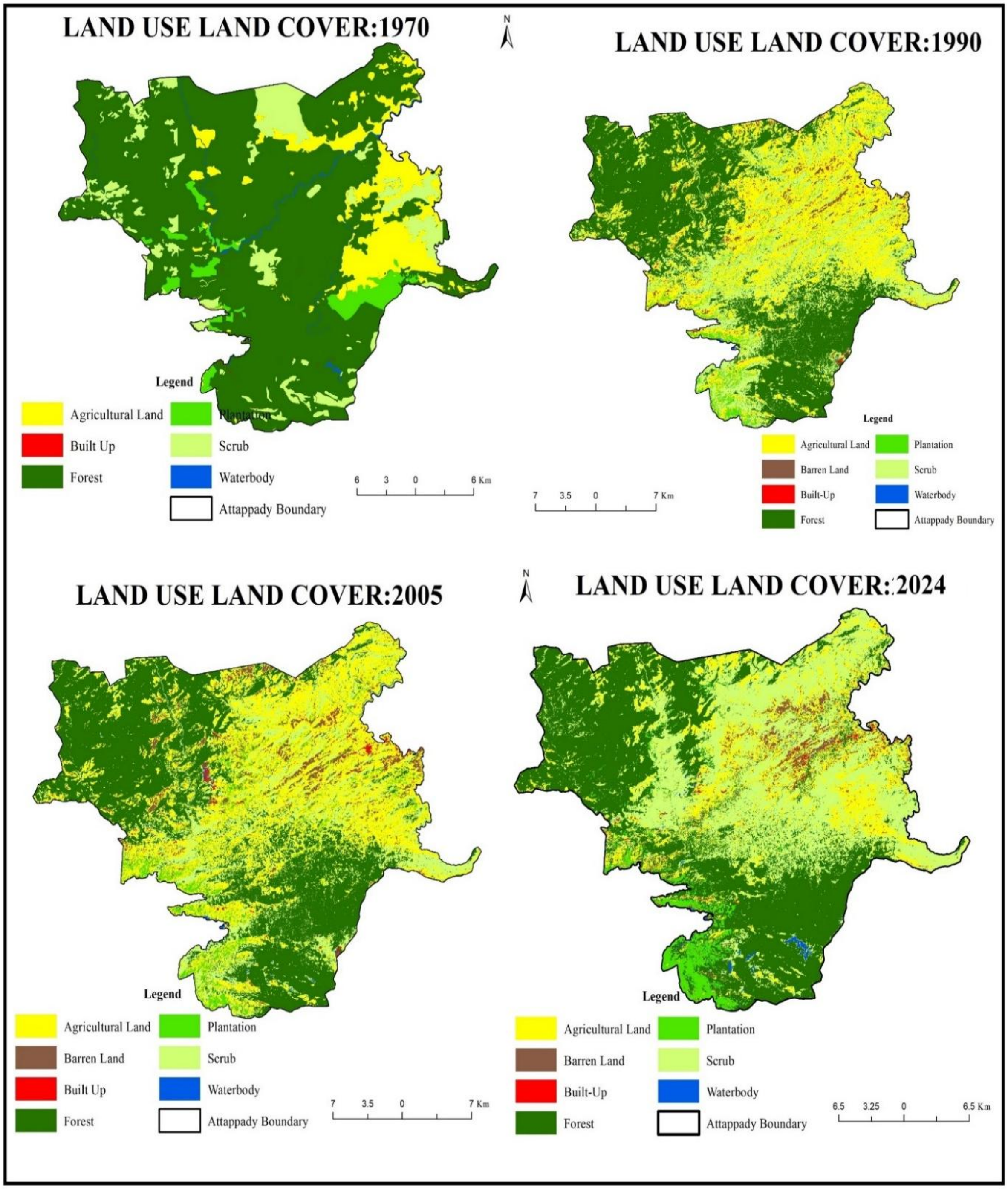


Source: Prepared by Researcher

Fig. 6.3: Land Use Land Cover change from 1970 to 2024 of the Attappady Hilly Region

The changes in Attappady's land use over the years have directly impacted both the environment and people's lives. Forests that once covered nearly 74% of the area have shrunk to just 42%, while farmland and unused land have expanded. This shift has made the land more fragile - without trees to protect it, soil washes away during heavy rains, and water sources are drying up. What was once productive farmland is now turning into barren patches, forcing many farmers to abandon their fields. The shrinking water bodies mean less water for crops, animals, and families. These changes create real challenges for local communities who depend on the land for their food and income. As more natural areas disappear, the land becomes less able to support life, showing how closely connected human activities are to the health of the environment.

According to the land use land cover classification in Attappady, Agricultural land in wet land region shows steady decrease over the years whereas in rain shadow region remains high, with slight fluctuations. Barren land in rain shadow region increases over the years, especially



Source: Prepared by Researcher

Fig. 6.4: Land Use Land Cover (a-1970 Land Use Land Cover, b-1991 Land Use Land Cover, c-2005 Land Use Land Cover, d-2024 Land Use Land Cover) of the Attappady Hilly Region

Table 6.4: Comparison of the land use and land cover statistics for the rain shadow and wet regions of the Attappady Hilly Region: 1970 – 2024

Sl. No	LULC Name	LULC 1970 (Area in %)		LULC 1990 (Area in %)		LULC 2005 (Area in %)		LULC 2024 (Area in %)		Change (1970 – 2024)	
		Wetland	Dry Land	Wetland	Dry Land	Wetland	Dry Land	Wetland	Dry Land	Wetland	Dry Land
1	Agricultural Land	11.93	88.07	0.44	99.56	1.25	98.75	1.88	98.12	10.05	10.05
2	Barren Land	0.00	0.00	82.01	17.99	33.85	66.15	37.20	62.80	37.2	62.8
3	Builtup	33.33	66.67	19.18	80.82	16.99	83.01	5.71	94.29	27.62	27.62
4	Forest	47.93	52.07	44.34	55.66	57.81	42.19	64.27	35.73	16.34	16.34
5	Plantations	50.86	49.14	50.00	50.00	53.46	46.54	40.88	59.12	9.98	9.98
6	Scrub	20.01	79.99	27.79	72.21	17.00	83.00	19.91	80.09	0.1	0.1
7	Waterbody	21.24	78.76	47.89	52.11	51.44	48.56	56.69	43.31	35.45	35.45

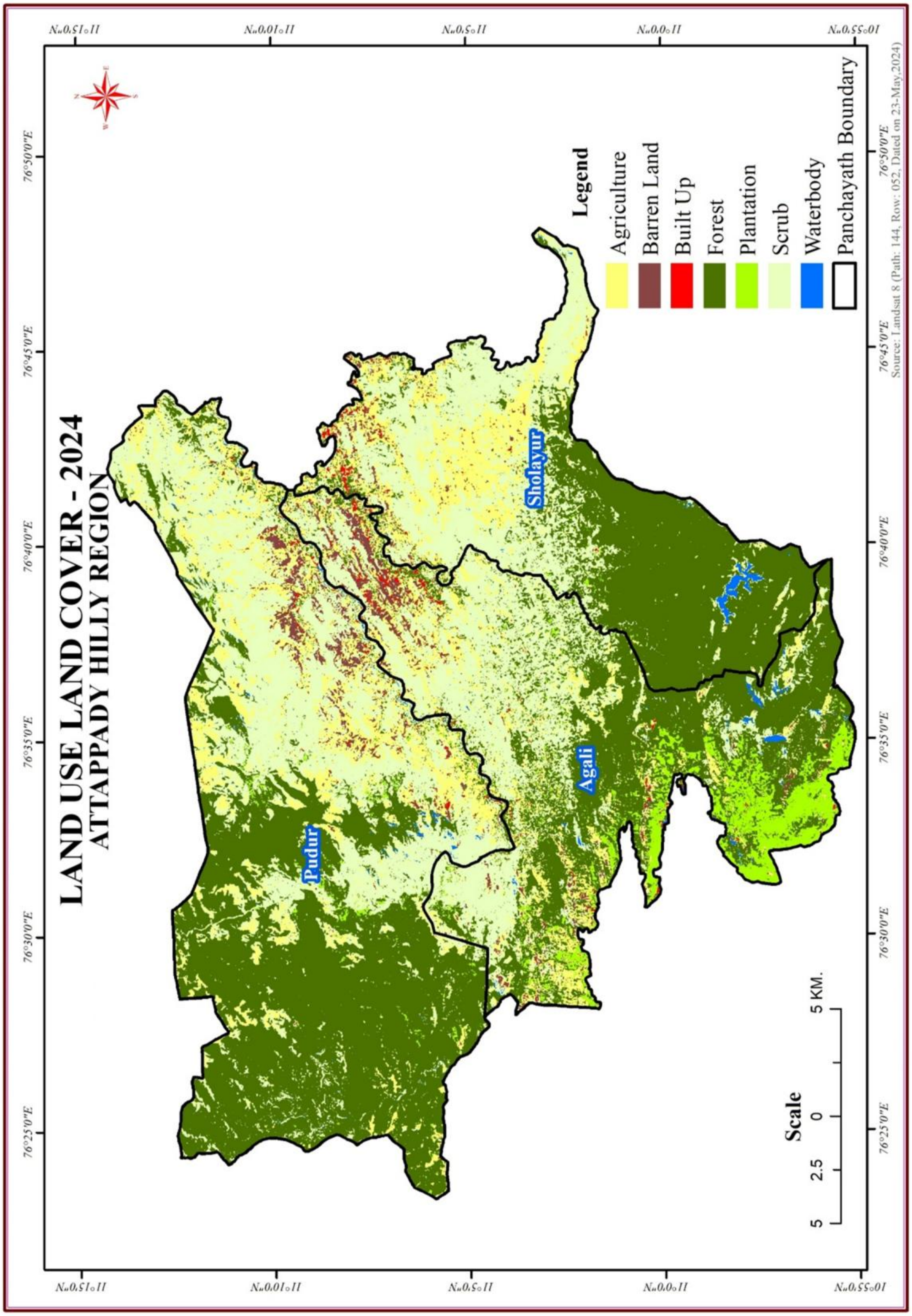
Source: Landsat and Sentinel-2 Data

From 1970 to 2024, the persistent rain shadow conditions intensified dryness, leading to a significant decline in forest cover and a simultaneous expansion of barren land, especially in the dryland zones. Reduced rainfall and prolonged moisture stress caused many agricultural areas to shift from water-demanding crops to drought-tolerant land uses, resulting in a notable increase in plantations and a reduction in traditional agriculture. The combined impact of declining vegetation cover and recurring soil erosion accelerated land degradation, which is reflected in the increase of scrublands and exposed dryland surfaces.

noticeable after 1990. In wet regions it also sees an increase but not as prominent as in the rain shadow region. Built-up areas show a decreasing trend, especially after 1990 in the wet region and in the rain shadow region it shows an increasing trend, indicating more urbanization in this region. Forest area gradually decreases from 47% in 1970 to 35% in 2024 in the rain shadow region but in contrast it shows an increasing trend in the wet region (western part) from 48% in 1970 to 64% in 2024 (Fig 6.17). Decreasing forest cover affects the carbon budget and has long term climate impacts. Reducing green cover can modify the reflectance of the land surface, determining the fraction of the sun's energy absorbed by the surface and thus affecting heat and moisture fluctuations to the atmosphere. This natural landscape conversion affects a wide range of changes in rainfall as well as the alteration of seasonality and frequency of convection. Decreasing natural cover alter transpiration from vegetation and surface hydrology which collectively determine the partitioning of surface heat into latent and sensible heat fluctuations over the last five decades (Fig 6.18). Plantation in the rain shadow region has increased from 49% to 57% over the last five decades whereas in wet regions it shows some fluctuations but remains relatively stable (Table 6.16). Altering current land use / land cover affects the biological system and the ecological services to support human needs. The degradation of forest and agricultural land, along with a decline in net primary productivity, poses a major threat to food security and hinders the poverty-reducing impact of overall income growth among poor rural inhabitants in Attappady.

Land degradation in Attappady is a multifaceted process driven by the complex interplay of natural environmental factors and anthropogenic pressures, as evidenced by the provided data. The region's relief and the Western Ghats establish a fundamental environmental gradient, creating a pronounced rainfall pattern with high precipitation (>1400 mm) on the western windward slopes and significantly lower rainfall (<850 mm) in the eastern rain shadow zone (Fig 6.3, Table 6.3). This gradient strongly influences vegetation cover, fostering dense forests

(High/Very High NDVI) in the well-watered west but limited to the growth of scrub and sparser vegetation (Low/Moderate NDVI) in the drier east (Fig 6.5, Table 6.5), increasing the latter's vulnerability. Compounding this natural susceptibility is significant in Land Use / Land Cover (LULC) change over recent decades, notable among them are a drastic reduction in Forest cover (from 73.89% in 1970 to 42.44% in 2024) and a concurrent expansion of agriculture and emergence of barren land (14.51% in 2024) (Table 6.4, Text p.4). This transformation, facilitated partly by increased accessibility provided by road density (Fig 6.15), directly contributes to degradation by removing protective vegetation and exposing soil. The region's soil texture, predominantly composed of clay (59.26%) and gravelly loam (36.52%) (Table 6.7), plays a crucial role in land vulnerability. The text highlights that clay has a positive correlation with soil erodibility, rendering large areas particularly susceptible to erosion once vegetation is disturbed. Topography further modulates erosion risk: steeper slopes (significant areas classified as moderate to very steep, Table 6.12) accelerate runoff and erosion, particularly where vegetation is sparse or rainfall is intense. Hydrological characteristics reflect these pressures; high drainage density (Fig 6.6) in certain areas indicates concentrated surface runoff pathways prone to fluvial erosion, while Topographic Wetness Index (TWI) highlights zones of water accumulation where saturation can enhance runoff and erosion potential (Fig 6.12). Furthermore, the predominantly poor groundwater potential (80.48% of the area, Table 6.10) signifies stressed water resources, limiting vegetation resilience and agricultural sustainability, acting as both a consequence and contributor to land degradation. Collectively, these interacting factors – variable rainfall, LULC changes driven by human activity, vulnerable soil types, topographic influences (slope, relief, drainage, TWI), and



Source: Prepared by Researcher

Fig. 6.5: Land Use Land Cover of the Attappady Hilly Region

stressed groundwater resources - create a landscape susceptible to various forms of land degradation, including soil erosion, loss of biodiversity, reduced water retention, and potential desertification, particularly pronounced in the central and eastern rain shadow areas.

Table 6.5- Land Use / Land Cover 1970 and 2024 of the Attappady Hilly Region

Sl.No	Name	Area in Km^2 (2024)	Area in %	Area in Km^2 (1970)	Area in % (1970)	Risk Category
1	Agriculture	160.79	19.38	95.12	11.47	Moderate
2	Barren land	120.39	14.51	0	0.00	High
3	Built-up	2.90	0.35	0.63	0.08	High
4	Forest	352.06	42.44	612.84	73.89	High
5	Plantation	44.56	5.37	31.10	3.75	Moderate
6	Scrub	147.56	17.79	84.62	10.20	Low
7	Waterbody	1.28	0.15	5.03	0.61	High

Source: Landsat-8 Data and SOI Toposheet

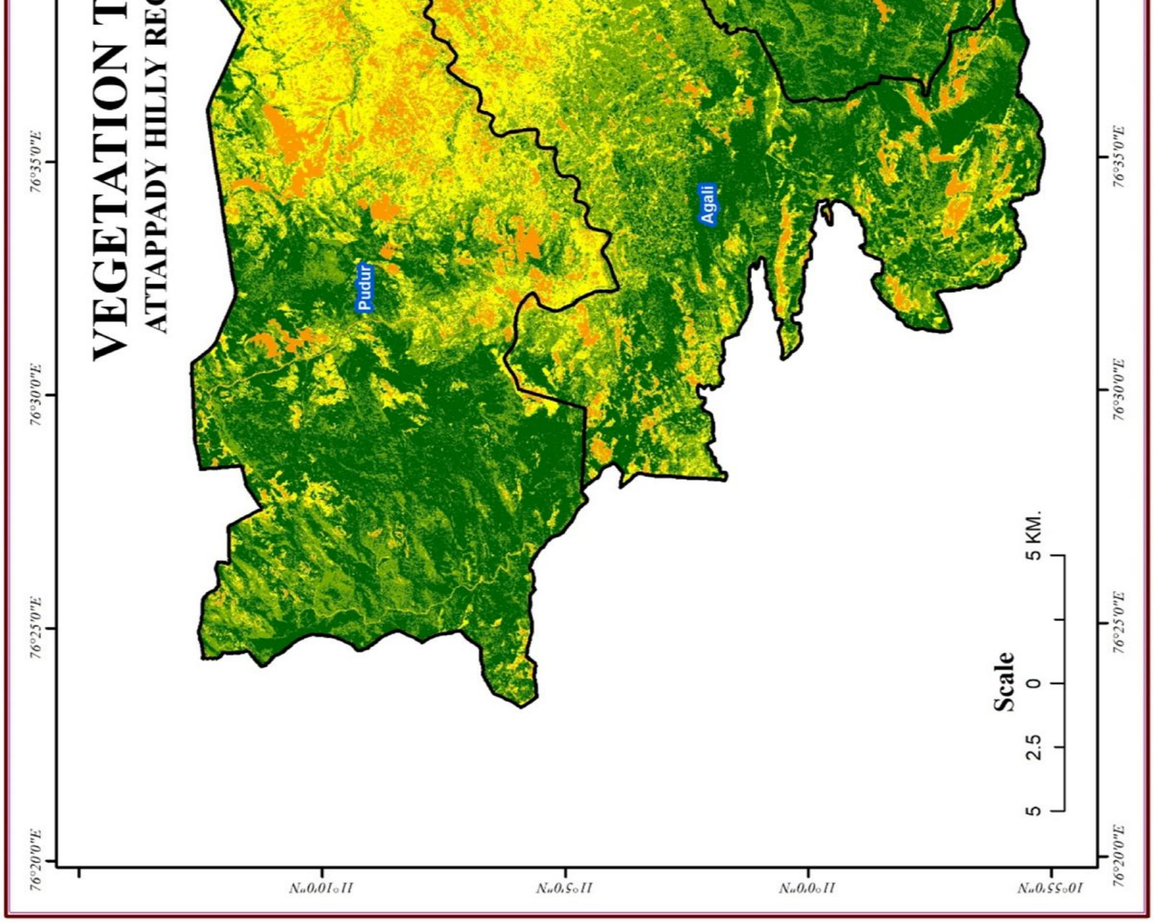
6.4.3 Vegetation Condition of the Attappady Hilly Region

Vegetation thickness is closely related to land degradation. Studies have shown that soil degradation intensity can lead to a decrease in the absolute density of vegetation, particularly in the second stratum. The relationship between vegetation cover indices and land degradation has also been examined; revealing an inverse relationship between the size of land degraded and tree density, leaf cover index, area covered by litter, surface cover index, and tree crown fullness (Adewuyi et al., 2017). Normalized difference vegetation index is one of the most prominent vegetation indices used in image processing to investigate the green cover of photosynthetic plants. The following is the mathematical formula (Equation 2) for calculating NDVI:

$$NDVI = (NIR - RED) / (NIR + RED) \text{ …… Equation 2}$$

The NDVI values are unitless and vary on a scale with an upper limit of +1 and a lower limit of -1, with the higher the value on the NDVI scale, the more photo-synthetically active the surface vegetation is. Negative NDVI values are used to represent non-vegetated environments such as ice, lake bodies, and rocks (i.e., values less than 0). Low vegetation is defined as having NDVI values between 0 and 0.2; medium vegetation is defined as having NDVI values between 0.2 and 0.4; and mature vegetation is defined as having NDVI values greater than 0.4. In general, a region's NDVI reaches its maximum at the height of the growth season, which in Kerala is from June to December. NDVI-derived values are frequently employed as a geographical and temporal measure of vegetation health. Whether natural or farmed, the growth pattern of vegetation is constantly impacted by climatic elements such as precipitation, temperature, and so on making it critical to investigate the impact of precipitation on vegetation pattern. Natural breaks were used to further categorize the data once these factors are calculated.

In Attappady, dense mixed jungle, dense mixed jungle with bamboo, open jungle, open mixed jungle, open scrub, dense jungle, coffee plantation, fairly dense scrub, cardamom, and rubber plantation are the dominant vegetation arrangements from west to east direction. The elevated terrain and abundant rainfall contribute to a dense forest cover in the western section of the Attappady hill region showing high positive value in the NDVI. In contrast, the eastern part, receiving limited rainfall, fosters vegetation growth characterized by scrub and thorny forests showing less positive value (Fig.6.5). The center part of the study area, i.e. rain shadow region, is mainly occupied by food crop cultivation. Due to irregular rainfall and rainfall deficit, cultivation around the year is not possible. Hence, people left the field without any cultivation. These conditions reflect in the NDVI result (table 6.5). From the map, it is noted that the central portion does not have thick vegetation. This might affect soil oxidation, less humus content and lead the way for soil erosion.



Source: Prepared by Researcher

Fig. 6.6: Vegetation Types of the Attappady Hilly Region

Table 6.6: Vegetation Type of the Attappady Hilly Region

Sl.No	Vegetation Cover	Area in km^2	Area in %
1	Very Low	0.01	0.001
2	Low	86.07	10.37
3	Moderate	234.33	28.25
4	High	251.50	30.32
5	Very High	257.48	31.04
	Total	829	100

Source: Google Earth Engine and Landsat-8

6.4.4 Drainage Density of the Attappady Hilly Region

Drainage networks in the study area were derived from topographical maps at a scale of 1:50,000, and drainage density was calculated using a 1 km^2 grid in QGIS (table 6.6). The region is characterized by several non-perennial, east-flowing rivers such as the Bhavani and Siruvani, along with their extensive tributary systems. Despite the presence of these water courses, the undulating terrain and steep slopes play a significant role in directing the flow patterns, causing most of the drainage to flow towards the western part of the region. As these rivers progress downstream, they converge and accumulate in the central and eastern parts of the study area, forming significant hydrological zones (Fig. 6.6).

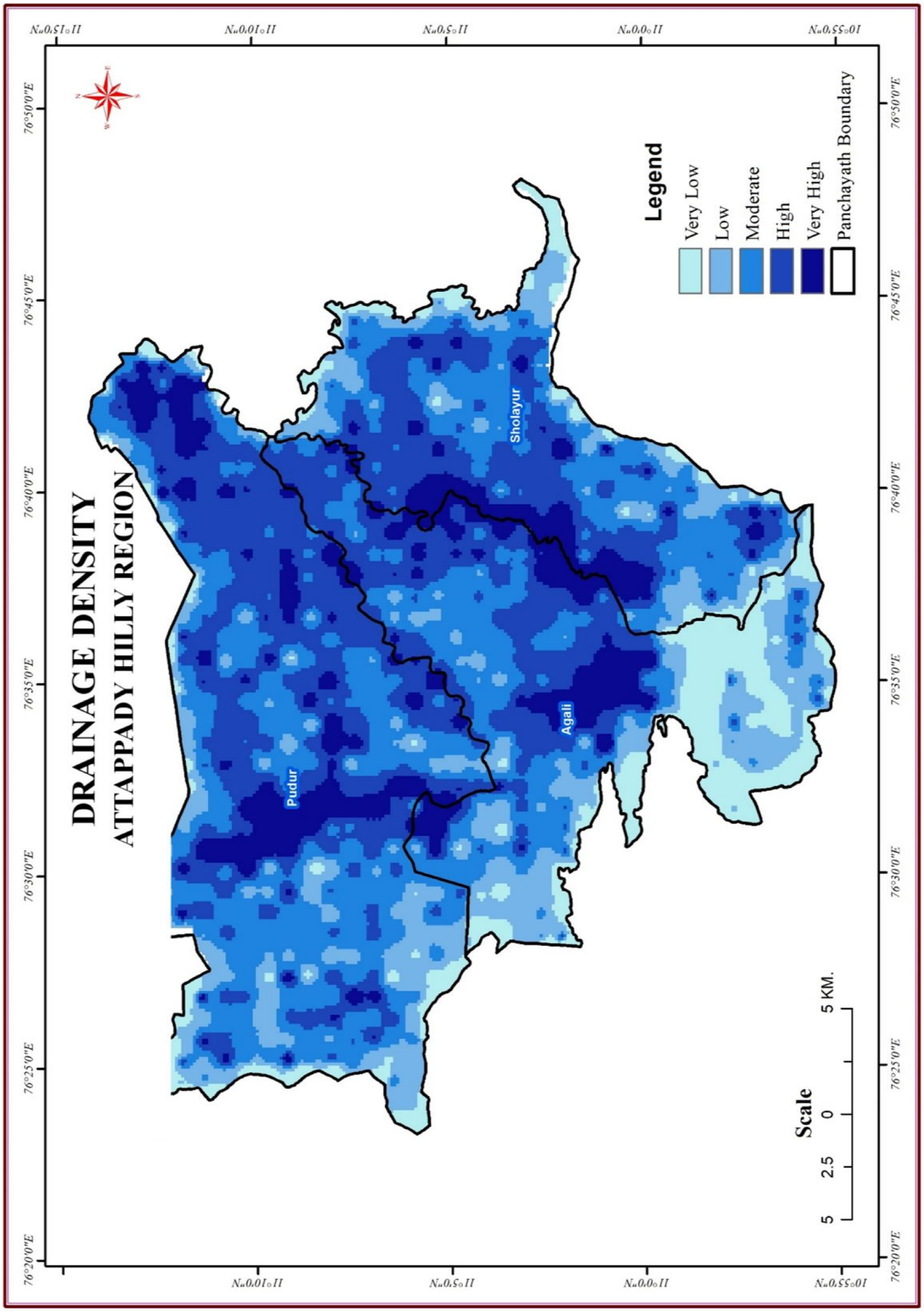
The total length of the drainage network in the study area is approximately 3,080 km, resulting in an average drainage density of 3.71 km/km^2. Drainage density, a crucial geomorphological parameter, reflects the degree of landscape dissection and serves as an essential indicator for assessing soil erosion and land degradation. Areas with high drainage density are often associated with increased runoff, reduced infiltration, and heightened susceptibility to erosion, all of which contribute to land degradation. This is particularly evident in the study area, where the non-perennial nature of the rivers leads to water scarcity during dry periods, intensifying the stress on agricultural lands and making crops more vulnerable to degradation.

High drainage density is prominently observed along the major tributaries of the Siruvani and Bhavani rivers, especially near their confluence points in the eastern part of the study area. These zones are more prone to soil erosion due to the combined effects of steep slopes, concentrated water flow, and the intermittent nature of the streams. The interplay between the region's geomorphology, drainage characteristics, and hydrological patterns underscores the importance of integrating drainage density analysis in understanding and managing land degradation processes in Attappady. The eastern part of Attappady, especially around Sholayur and Agali, has less streams and water channels compared to the western part. This is because it gets less rainfall as it lies in the rain shadow of the Western Ghats. With less rain, there is not much water flowing on the ground, so the land doesn't form many natural streams. Most of the rainwater in the flat valley is filled with fine textured area that absorb the rainwater instead of runoff. In contrast, the central and western parts of Attappady received more rainfall, and so they have more streams and sufficient water flow. These variations make the eastern side drier with less natural drainage system and vice-versa.

Table 6.7:Drainage Density of the Attappady Hilly Region

Sl.No	Drainage Density	Area in Km^2	Area in %
1	Very Low	83.05	10.02
2	Low	139.24	16.81
3	Moderate	257.13	31.05
4	High	250.44	30.24
5	Very High	98.22	11.86

Source: Survey of India (1: 50,000) Toposheet



Source: Prepared by Researcher

Fig. 6.7: Drainage Density of the Attappady Hilly Region

6.4.5 Soil Texture of the Attappady Hilly Region

Soil texture plays a significant role in land degradation. In Attappady, soil texture was derived from district wise benchmark of soils from Kerala State Soil Survey Department. Approximately 60% of the study area is characterized by clay-textured soil, with gravelly and clay-textured soil covering the remaining eastern portion of the study area (table 6.7). The clay content in the soil was positively correlated with soil erodibility, while sand content was negatively correlated. This indicates a significant correlation between robust vegetation growth and comparatively less vegetation in the eastern part (Fig.6.7).

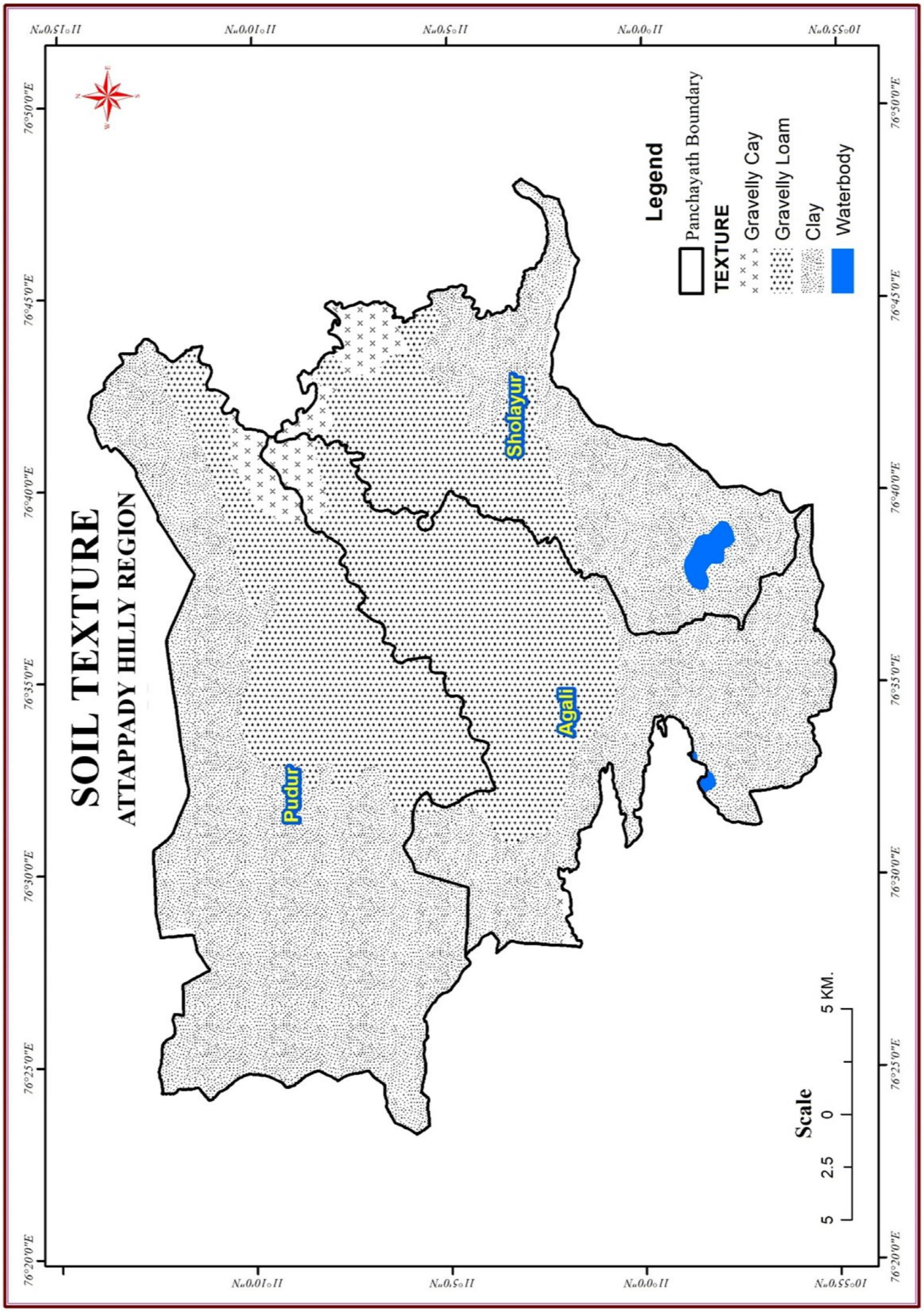
Table 6.8: Soil Texture of the Attappady Hilly Region

Sl.No	Soil Texture	Area in km^2	Area in %
1	Clay	488.88	59.26
2	Gravelly Clay	29.85	3.61
3	Gravelly Loam	301.33	36.52
4	Waterbody	4.84	0.58
	Total	824.91	100

Source: https://www.keralasoils.gov.in

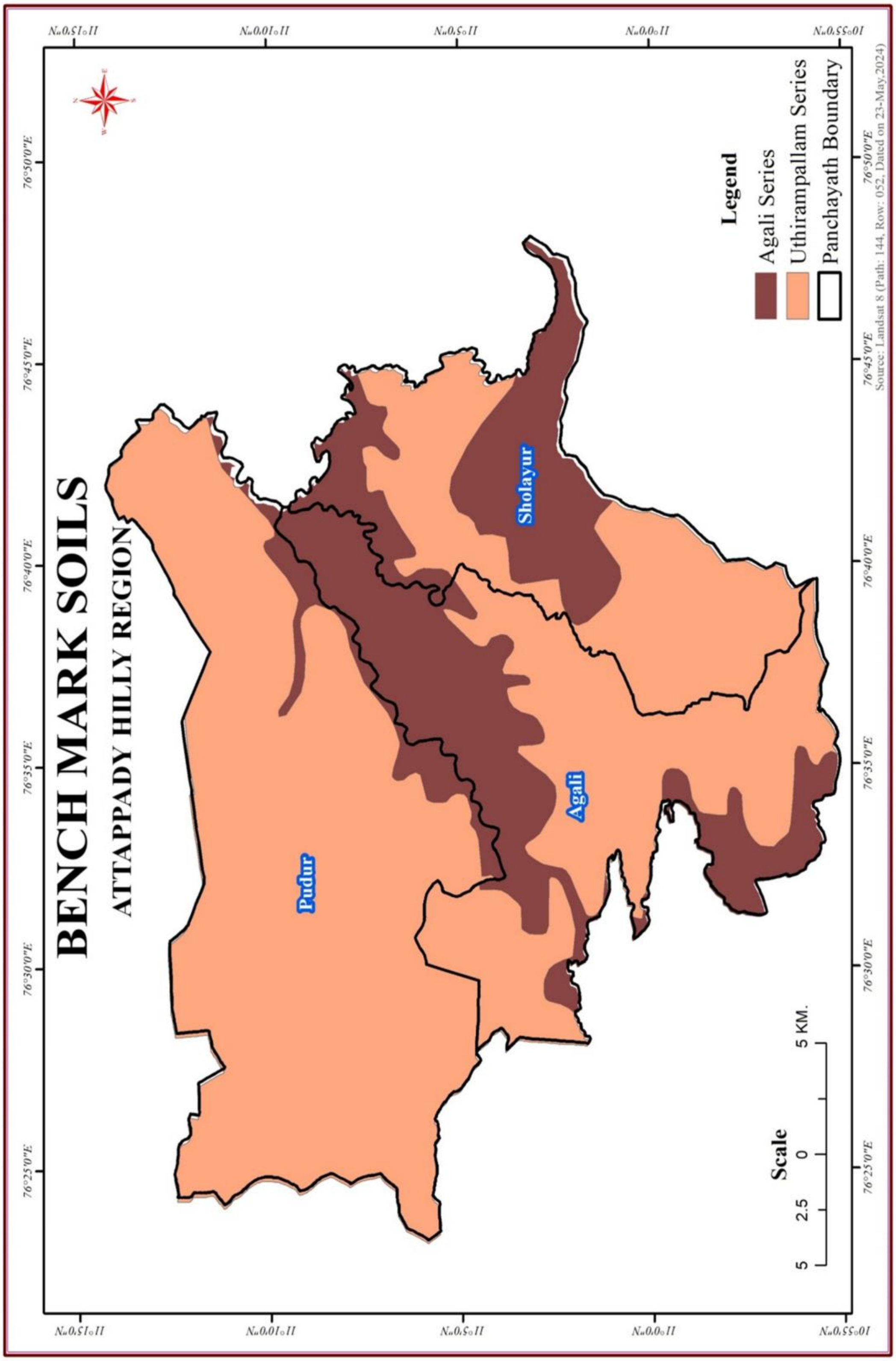
In Kerala, 82 soil series have been identified as Benchmark Soils by Soil Survey Organization, Kerala (2007). These soil groups are primarily categorized to facilitate understanding and interpretation for specialty crops, engineering purposes, and other applications. The soil series focuses on morphological characteristics, chemical properties, crop-growing periods, and the in-situ climate, geomorphology, land utilization, agriculture, and hydro-physical properties of each soil type.

To study the soil properties in Attappady, Palakkad district, benchmark soils were selected. In Palakkad district, there are seven soil groups: Thirunarayanapuram, Karakurissi, Mannur, Bhavaji Nagar, Anupur, Uthrampallam, and Agali. However, in Attappady, only two soil groups are



Source: Prepared by Researcher

Fig. 6.8: Soil Texture of the Attappady Hilly Region

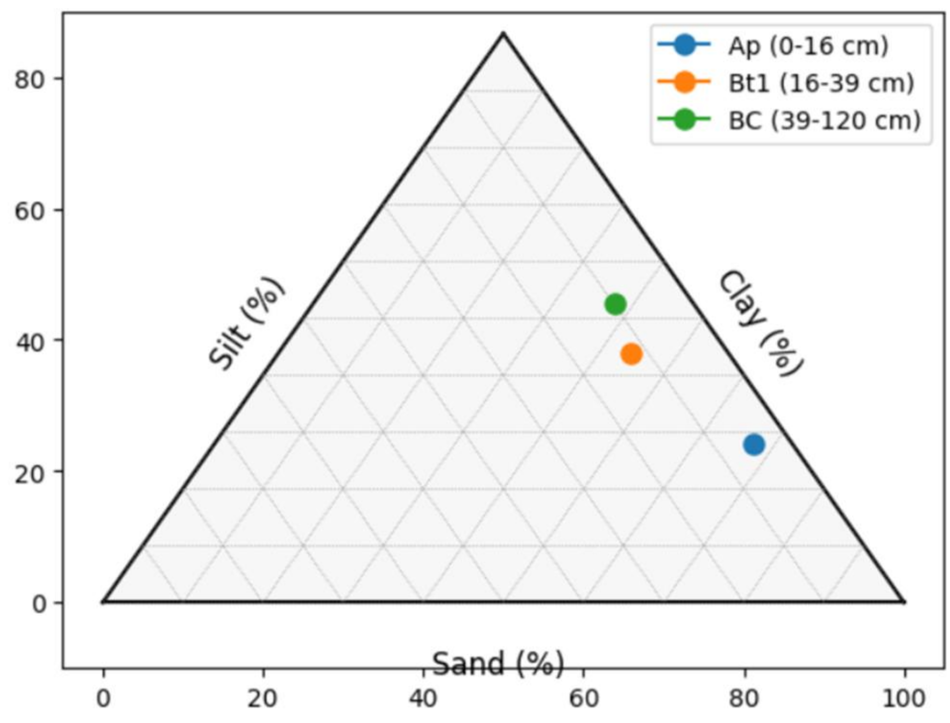


Source: Prepared by Researcher

Fig. 6.9: Benchmark Soils of the Attappady Hilly Region

present: Uthampallam and Agali. A detailed description and map (Fig. 6.10) of these two soil groups are provided below.

The soil texture of Attappady taluk shows that the eastern part of the study area is occupied by gravelly clay and gravelly loam soils especially around Sholayur. These types of soil do not allow water to flow easily on the surface. Instead, they tend to hold the little rainwater they get. Due to the topographical influences and the soil texture, very smaller number of perennial streams formed in this area, which matches with the earlier observation that this region has low drainage density. This soil texture along with low rainfall, makes the land drier and less supportive of natural water channels. This is another reason why the eastern part of Attappady looks drier and less drained.



Source: Prepared by Researcher

Fig. 6.10: Uthampallam Series Soil Texture

The soil texture of the Uthampallam (75%) and Agali series (25%), as illustrated in Table 6.8 and Table 6.9, along with their respective texture diagrams (Fig 6.8 and Fig 6.9), plays a critical role in understanding land degradation in the rain shadow eastern region of Attappady. The Uthampallam series, with its gravelly sandy clay loam to gravelly clay loam texture in the A horizon and gravelly clay loam to gravelly clay in the B horizon, exhibits moderate permeability and severe moisture stress. Despite its high nutrient status (high nitrogen: 1.65–2.05%, medium to high phosphorus: 21–26 kg/ha, and medium potassium: 150–175 kg/ha), the soil's texture limits its water retention capacity, making it prone to erosion and nutrient loss under arid conditions. The texture diagram (Fig 6.8) highlights the dominance of sand and clay fractions, which influence its susceptibility to degradation.

On the other hand, the Agali series (25% area), with its sandy clay loam to clay loam A horizon and gravelly clay loam to gravelly clay B horizon, is more vulnerable to land degradation. The texture diagram (Fig 6.9) reveals a higher proportion of sand and gravel in the subsoil, which reduces the effective soil volume and water-holding capacity. This, combined with frequent calcium carbonate nodules and moderate permeability, exacerbates moisture stress and erosion. The soil's reduced depth and gravelly nature further limit its ability to sustain vegetation, making it highly susceptible to degradation in the rain shadow region.

The texture diagrams and tables provide critical insights into the physical and chemical characteristics of these soils, emphasizing their vulnerability to land degradation. The Uthampallam series, despite its nutrient richness, faces challenges due to its texture and moisture stress, while the Agali series is more prone to degradation due to its structural limitations and reduced water retention. These findings underscore the importance of soil texture analysis in assessing land degradation dynamics in the rain shadow eastern region of Attappady.

Table 6.9: Uthampallam Series: Physical, Chemical and Biological Characteristics

Depth cm	Horizon	Gravel Content Vol %	Particle Size Distributions (%)								pH 1:2.5	EC 1:2.5 ds/m
			Sand Fractions						Silt 0.002 – 0.05	Clay <0.0 02		
			Very Cour se 1-2	Coarse 0.5-1	Mediu m Coarse 0.25-0.5	Fine 0.1-0.25	Very Fine 0.05 – 0.1	Total Sand				
0-16	Ap	23	4.5	11.1	25.6	21.0	5.2	67.4	1.5	27.8	5.9	0.1
16-39	Bt1	25	3.8	5.2	13.4	17.1	4.5	44.0	10.2	43.8	6.3	0.1
39-120	BC	28	3.9	4.3	12.6	12.2	3.6	37.6	8.2	52.5	6.0	0.1

Depth cm	Organic Carbon %	Exchangeable Bases					Extractable acidity BaC12-TEA	Cation Exchange Capacity NH4OAc	Base Saturation	
		Na+	K+	Ca++	Mg++	Total			NH4 OAc	Sum of Cation
0-16	3	0.06	1.36	6.17	2.19	9.78	18.4	10.5	93	35
16-39	2	0.05	0.64	3.41	1.62	5.72	20.1	11.1	52	22
39-120	1.7	0.05	0.57	2.19	1.25	4.06	21.2	12.6	32	16

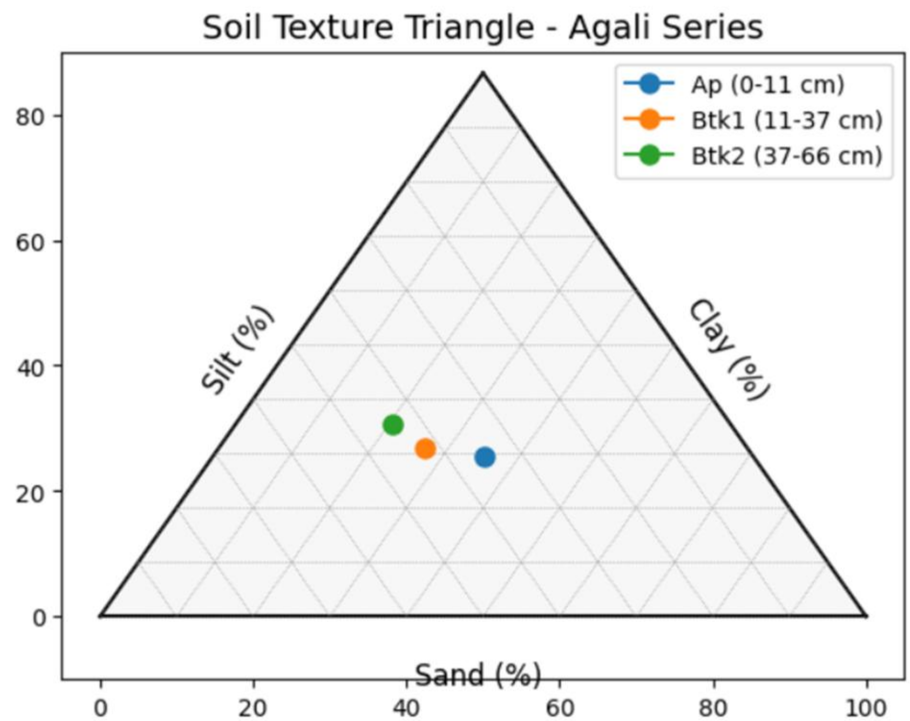
Source: Soil Survey Organisation, Kerala (200

Table 6.10: Agali Series Physical, Chemical and Biological Characteristics

Time	Horizon	Gravel Content Vol %	Particle Size Distributions (%)								pH 1:2.5	EC 1:2.5 ds/m
			Sand Fractions						Silt 0.002 – 0.05	Clay <0.002		
			Very Course 1-2	Coarse 0.5-1	Medium Coarse 0.25-0.5	Fine 0.1-0.25	Very Fine 0.05 – 0.1	Total Sand				
			……………………………………mm……………………………………………									
0-11	Ap	6.25	2.25	3.68	3.70	15.78	9.68	35.09	35.51	29.40	8.1	0.25
11-37	Btk1	30.00	1.70	3.51	9.01	19.38	8.45	42.05	26.82	31.13	8.1	0.18
37-66	Btk2	26.67	1.66	3.59	8.36	19.81	10.64	44.36	20.41	35.50	8.2	0.21

Depth cm	Organic Carbon %	Exchangeable Bases					Extractable acidity BaC12-TEA	Cation Exchange Capacity NH4OAc	Base Saturation	
		Na+	K+	Ca++	Mg++	Total			NH4OAc	Sum of Cation
0-16	3	0.06	1.36	6.17	2.19	9.78	18.4	10.5	93	35
16-39	2	0.05	0.64	3.41	1.62	5.72	20.1	11.1	52	22
39-120	1.7	0.05	0.57	2.19	1.25	4.06	21.2	12.6	32	16

Source: Soil Survey Organisation, Kerala (2007)



Source: Prepared by Researcher

Fig. 6.11: Agali Soil Texture Triangle

6.4.6 Groundwater Potential of the Attappady Hilly Region

The groundwater potential and land degradation in Attappady is intricately linked, with significant implications for the local population's livelihoods. The region has experienced severe land degradation due to factors such as population growth and land alienation, plantation crops, removal of natural vegetation, non-perennial streams, which have adversely affected groundwater resources. Groundwater potential data for Attappady was vectorized from www.kslublris.com (Fig.6.11). Due to hilly undulating terrain, about 80% of the study area shows poor groundwater potential and only 20% study area especially in the central low-lying area having good groundwater prospects (table 6.10). This result shows groundwater is at an alarming state and needs an urgent action. Therefore, including groundwater potential data in land degradation analysis of Attappady is unavoidable.

Table 6.11: Groundwater Potential of the Attappady Hilly Region

Sl.No	Groundwater Potential	Area in km^2	Area in %
1	Poor	663.15	80.48
2	Moderate	1.09	0.13
3	Good to Moderate	28.26	3.43
4	Very Good to Good	1.88	0.23
5	Very Good	128.08	15.54
6	Waterbody	1.54	0.19
	Total	824	100

Source: Kerala State Land Use Board

Although the eastern part of Attappady is situated in a rain shadow and receives less rainfall, it still has good groundwater potential in the low-lying valley filled area. This is due to the slope of the land from west to east causing rivers of the Bhavani and Siruvani along with their tributaries flow in that direction. These rivers, even though seasonal, flow water from the western side and confluence in the eastern areas. When they meet and slowdown in the low-lying valley filled area, water gets absorbed into the ground, recharging underground reserves. So, due to the topograpical alignment and drainage accumulation, a portion of the eastern part becomes a natural collection zone for groundwater despite low rainfall.

6.4.7 Topographic Wetness Index of the Attappady Hilly Region

Topographic wetness index (TWI) indicates the effect of topography on runoff generation and the amount of flow accumulation at any locations in a river catchment. The formula to calculate the TWI can be expressed in equation 3.

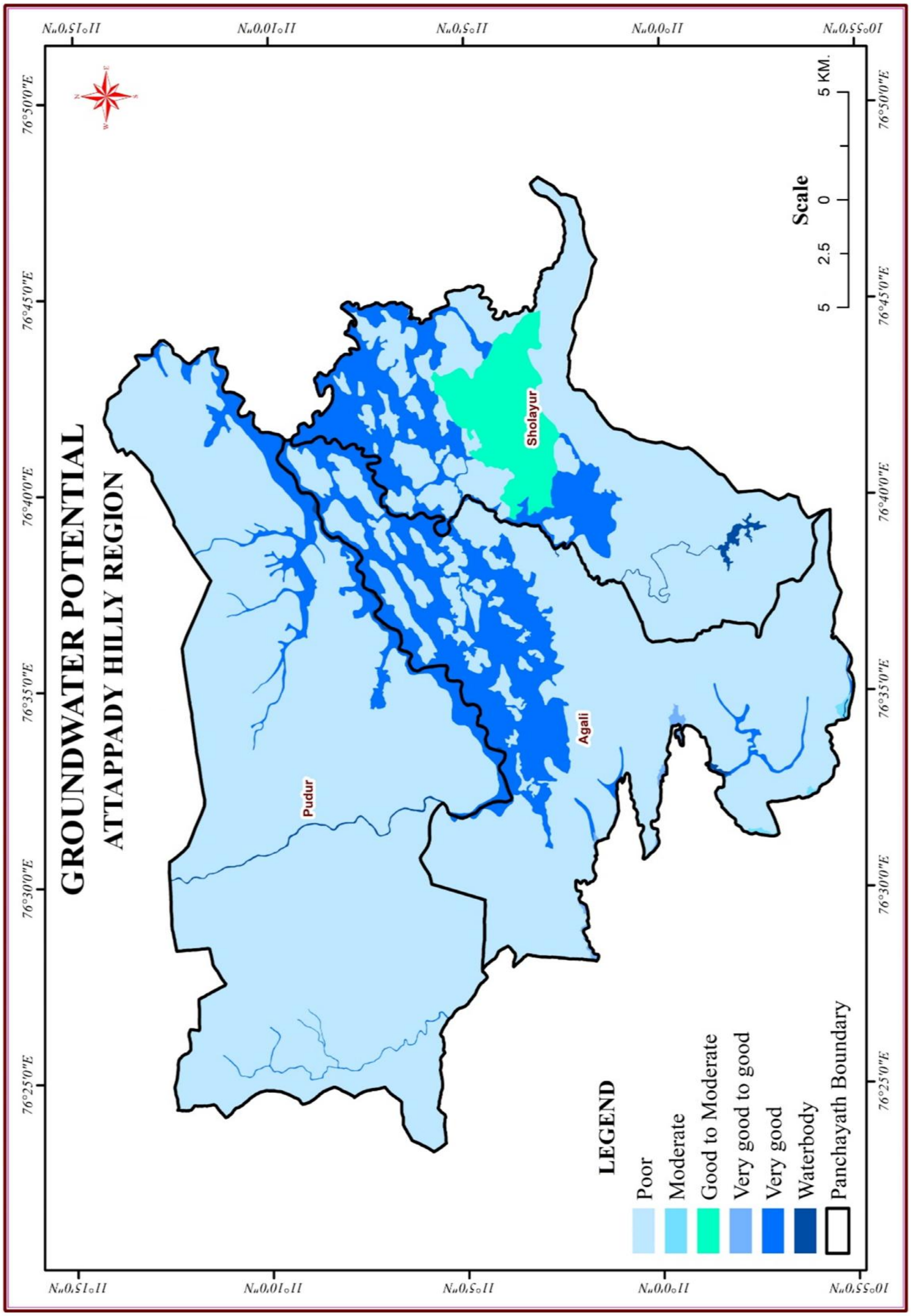
$$\text{TWI}=Ln\left(\frac{FaScaled}{\text{TanSlope}}\right)\text{..................... equation 3}$$

Where

Fa_Scaled= (Fa+1) x 30; Fa= Flowaccumulation

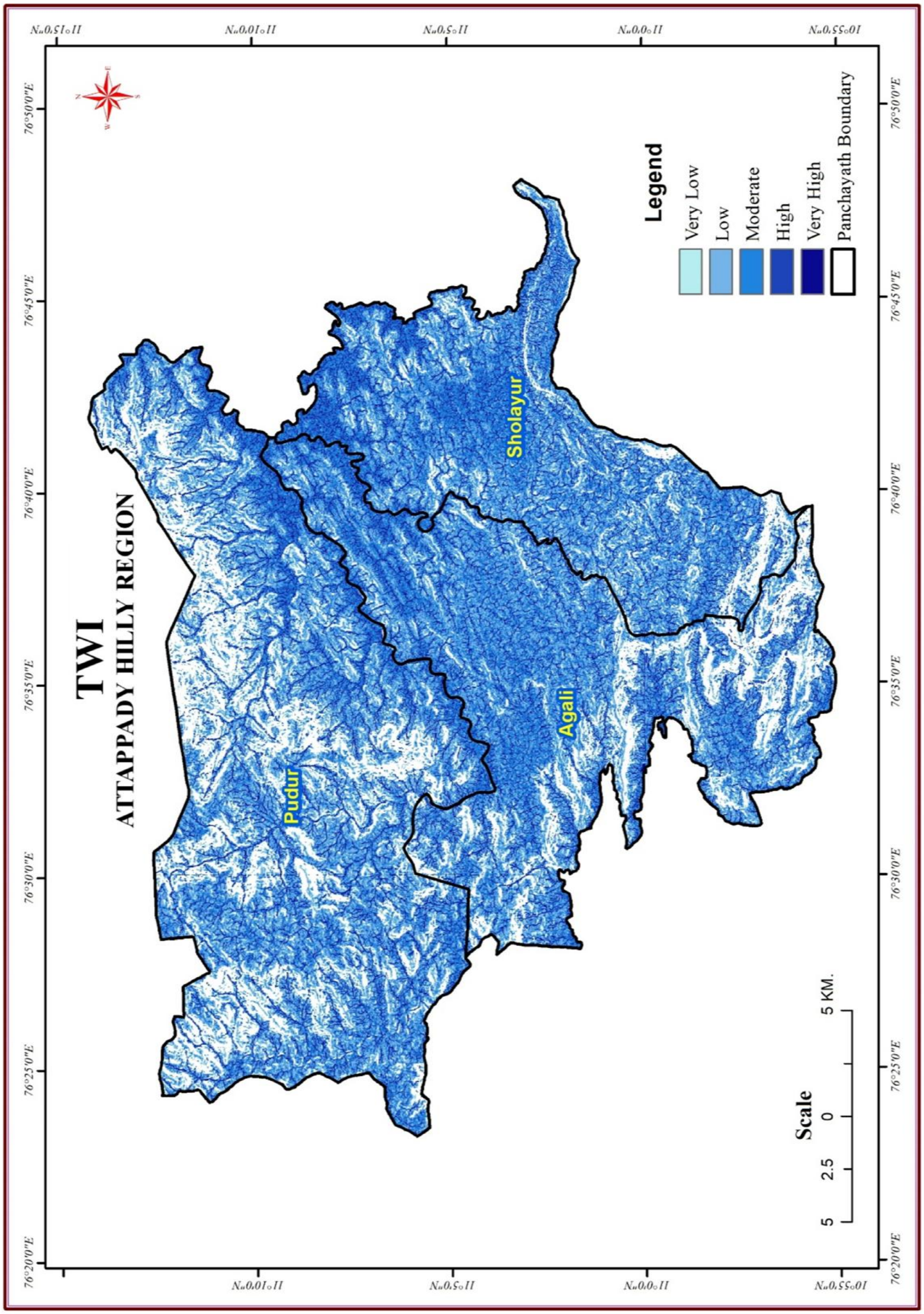
TanSlope = Con (Slope1>0, Tan (Slope1),0.001)

Slope1 = Slope x 1.570796 /90



Source: Prepared by Researcher

Fig. 6.12: Groundwater Potential of the Attappady Hilly Region



Source: Prepared by Researcher

Fig. 6.13: Topographic Wetness Index of the Attappady Hilly Region

where Fa Scaled represents flow accumulation. Higher TWI regions have a higher vulnerability of floods. Inversely, the lower TWI regions have lower vulnerability. Calculation of the TWI has been carried out directly through processing of ASTERDEM (30-meter resolution) in QGIS for Attappady hill region (Fig.6.12). The Digital Elevation Model (DEM) analysis reveals that the topography inclines towards the east, resulting in flow accumulation and flow direction predominantly in the eastern part. Consequently, the topographic wetness is notably high along the major river courses and flow accumulation areas, particularly in the southeastern section where slope is gentle in nature (table 6.11).

Table 6.12: Topographic Wetness Index of the Attappady Hilly Region

Sl.No	TWI	Area in km^2	Area in %
1	Very Low	90.62	11
2	Low	281.94	34.21
3	Moderate	258.72	31.39
4	High	130.08	15.78
5	Very High	62.78	7.62
	Total	824.14	100

Source: ALOS DEM

6.4.8 Slope details of the Attappady Hilly Region

Slope is a significant factor contributing to land degradation. High slopes, especially those between 16-25%, have been found to have the highest impact on soil degradation, leading to increased soil bulk density and decreased porosity (table 6.10). Improper land use on steep slopes, combined with high rainfall, has been identified as one of the major causes of land degradation. Additionally, the geological structure of an area, soil properties such as dispensability, and specific climate conditions also contribute to slope failure and land degradation (Bappa et al., 2023). Understanding the relationship between slope and land degradation is crucial for formulating effective soil and water conservation measures to mitigate the negative impacts of land degradation and promote sustainable development. Slope in degree was processed and derived from ASTER DEM (30-

meter Resolution). The undulating topography of the area contributes to a varied slope, ranging from very gentle to extremely steep (Fig.6.13).

Table 6.13: Slope Category of the Attappady Hilly Region

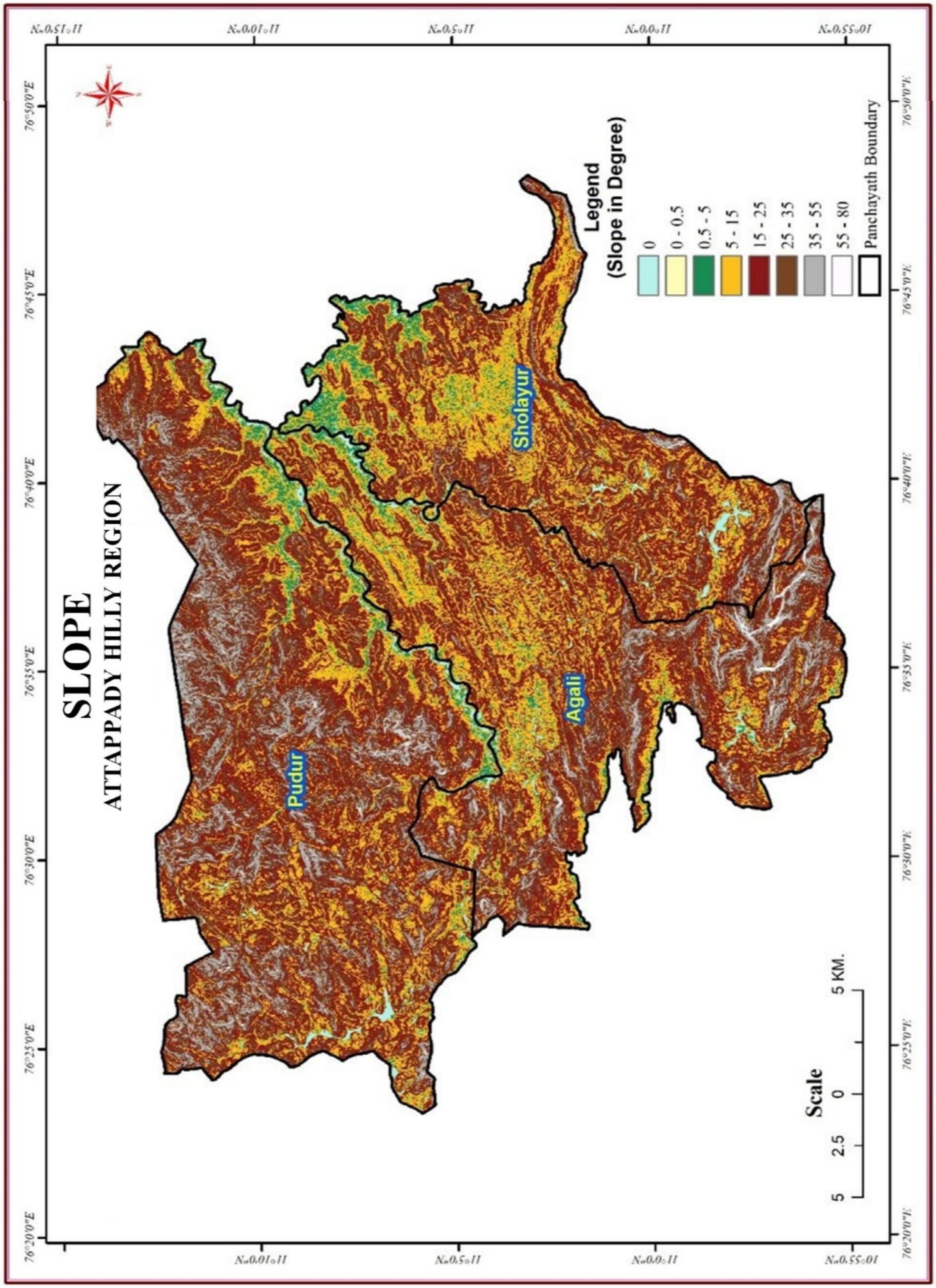
Sl.No	Slope in Degree	Area in km^2	Area in %
1	Level Slope	14.1	1.7
2	Very Gentle Slope	44.98	5.46
3	Gentle Slope	225.53	27.37
4	Moderate Slope	287.83	34.93
5	Moderately Steep Slope	179.83	21.82
6	Steep Slope	68.09	8.26
7	Very Steep Slope	3.64	0.44
	Total	829	100

Source: ALOS DEM

The slope of Attappady shows that the eastern part has mostly gentle slopes, while the western and northern regions are steeper and more rugged. These slope variations play an important role in the area's rainfall distribution. The western highlands act as a topographical barrier to the southwest monsoon winds forcing the air to rise and drop its moisture on the windward side. As a result, the eastern side receiving much less rainfall makes rain shadow region. The gentle slopes in the eastern portion allow water to spread and soak slowly into the ground, but the limited rainfall affect the area relatively dry. So, the combination of gentle slope and low rainfall makes the eastern part of Attappady a typical rain shadow zone.

6.4.9 Relief features of the Attappady Hilly Region

Elevation has an important role in the distribution of climatic elements, especially in rainfall, humidity and wind speed. In the study area the elevation divides the region into two sections: the western side of the windward, which receives a lot of rain, and eastern side, the leeward, which receives less rain. Fig 6.14 shows that the central and eastern part have relatively low relief features and north and west parts have high relief. These undulating topography affects the rainfall



Source: Prepared by Researcher

Fig. 6.14: Slope of the Attappady Hilly Region

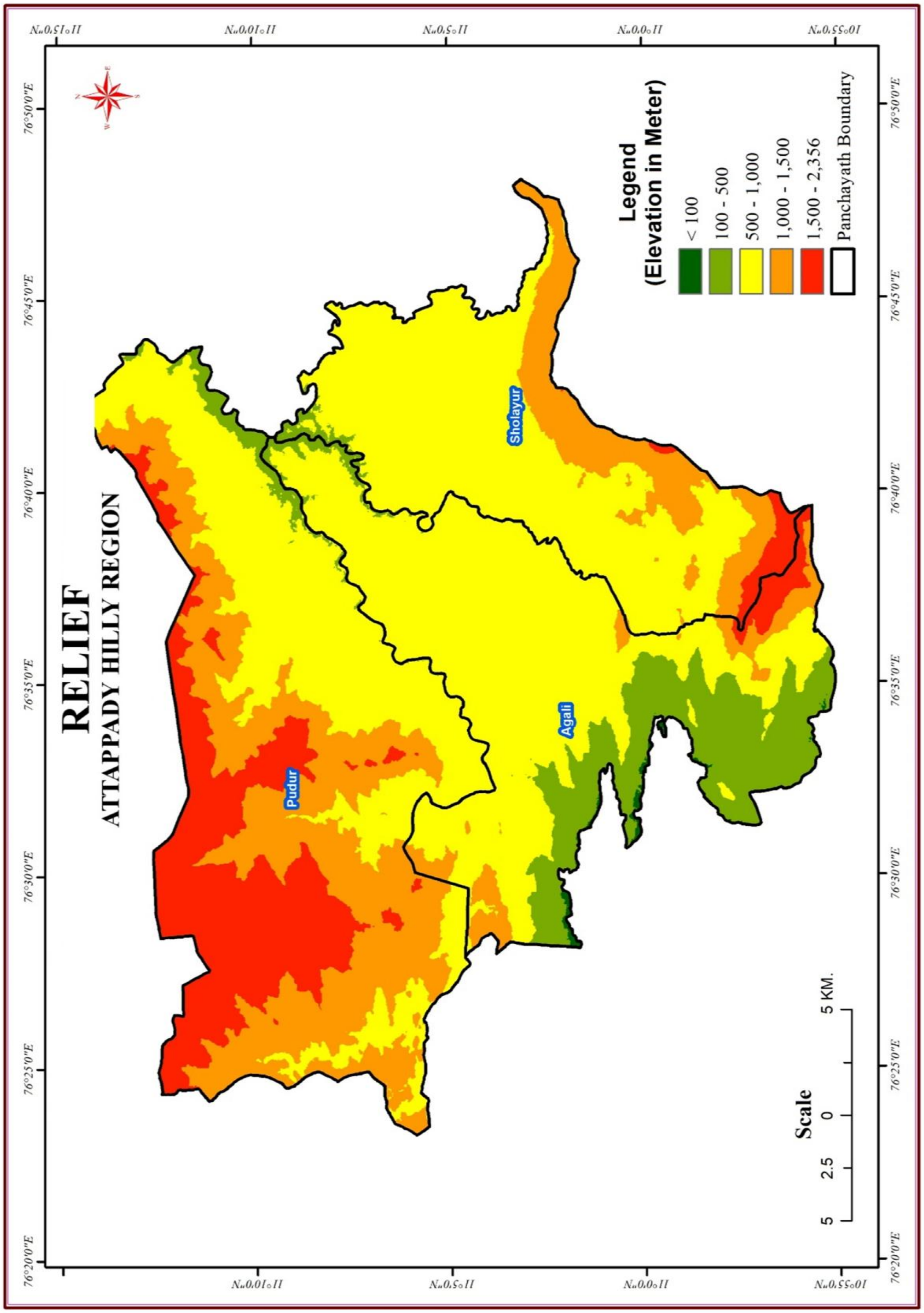
distribution of the study area. The topography of this region is carved out by tectonic, denudational and fluvial (Bhavani River and its tributaries) agents. The maximum height has been observed in the NW part (Anginda peak 2383 meters) and the lower elevation is recorded in the Bhavani's valley and the southern part of the study area (table 6.13).

Table 6.14: Relief Category of the Attappady Hilly Region

Sl.No	Elevation in meter	Area in km^2	Area in %
1	<100	2.55	0.31
2	100 – 500	79.52	9.59
3	500 - 1000	451.16	54.41
4	1000 – 1500	189.72	22.88
5	1500 -2356	106.27	12.82
	Total	829	100

Source: ALOS DEM

The relief of Attappady taluk shows that the elevation gradually decreases from west to east. The western and northern parts, especially around Pudur have higher altitudes, whereas the southern and eastern areas lie at lower elevations. This slope plays an important role in deciding the region's natural water flow and land conditions. Since water naturally origin from the western upland areas and flows towards the eastern lowlands where many tributaries of the Bhavani and Siruvani rivers gather and merge in the eastern region. Even though the eastern side receives less rainfall, its lower elevation and drought conditions facilitate the absorption of water flowing from higher areas, supporting better groundwater storage. At the same time, the lower relief areas in the eastern portion are more exposed to intensified mechanical weathering, leading to soil formation with the aid of other denudational agents such as wind and running water. In general, a greater number of small streams originate in the high relief and slope area, whereas a smaller number of streams originate in the gentle and low relief areas. From these perspective, we can understand why drainage density is lower in the eastern portion of Attappady.



Source: Prepared by Researcher

Fig. 6.15: Relief Category of the Attappady Hilly Region

6.4.10 Road Density details of the Attappady Hilly Region

Road density has been identified as a significant factor contributing to land degradation in various ways. Higher road density facilitates access to previously remote areas, leading to deforestation and the loss of fertile land as agricultural activities expand (A.D. & Kurian, 2016). Roads also contribute to landscape fragmentation, disrupting ecosystems and reducing biodiversity, which in turn exacerbates land degradation (Jana et al., 2024). The influx of population due to improved road access intensifies land use, resulting in unsustainable farming practices and the economic marginalization of indigenous communities (A.D. & Kurian, 2016). In Attappady the calculated maximum road density is 3.39 km^2, minimum 0.04 km^2 and mean road density is 1.13 km^2 (table 6.14). Prominent settlements like Kottathara, Pudur, Anaikatti, Attappadi, Sholayur, Agali, Mukkali, Kalkandi, and Thavalam exhibit high road density (Fig. 6.15). In contrast, the western part of the study area, characterized by dense vegetation, experiences significantly lower road density. The increased accessibility provided by road development has led indigenous farmers to shift from traditional, sustainable practices to less sustainable livelihoods, which has been a direct result of land degradation.

The road density of Attappady shows that the eastern part has a higher concentration of roads, while the western side, near Pudur, has very few roads. This difference is associated with physical features and human activities in the region. The western side of Attappady is covered by reserved forests and the Silent Valley National Park. These ecologically protected areas have steep terrain which controls construction of roads and settlements. On the other hand, the eastern part lies in a valley and is connected to the flat plains of Coimbatore in Tamil Nadu. Due to this gentle slope and openess of the eastern portion, this area is more accessible and suitable for settlements.

Because of this, migrant communities and indigenous people have historically settled in the eastern rain shadow region, where the terrain allowed for farming, housing, and road development. Over time, this increased population and infrastructure growth requisites the need for more roads being built, which is clearly visible in the high road density around Sholayur. But this development alters the natural landscape, leading to deforestation and land degradation, especially in the rain shadow environment.

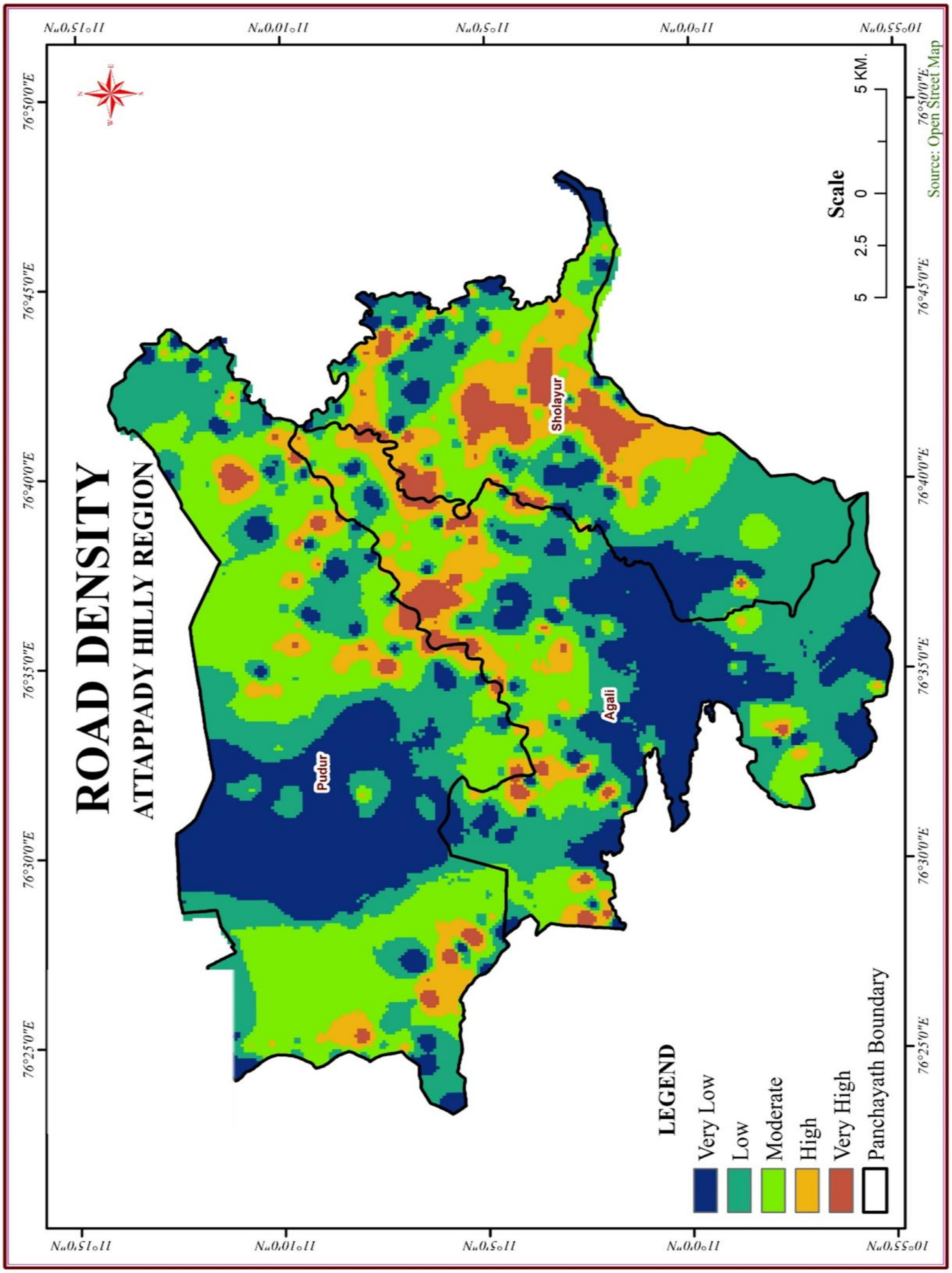
Table 6.15: Road Density of the Attappady Hilly Region

Sl.No	Road Density	Area in km^2	Area in %
1	Very Low	193.51	23.48
2	Low	258.15	31.33
3	Moderate	241.58	29.32
4	High	93.52	11.35
5	Very High	37.28	4.52
	Total	824.04	100

Source: www.openstreetmap.com

6.5 Assessment and Demarcation of Land Degradation Zone in Attappady Hilly Region

Attappady hilly region in the Western Ghats, is a stunning valley surrounded by lush forests and rolling landscapes. It lies at the start of the Bhavani River, with the Nilgiri Hills standing tall nearby. The area is known for its untouched beauty, with small streams flowing through the land, adding to its charm. Attappady is also home to Kerala's largest tribal community, including Irulas and Mudugars, along with people who moved here long ago from Tamil Nadu and other parts of Kerala. Sadly, the region has faced serious environmental challenges. Over time, people have cut down forests to make space for farming and settlements. This has been made worse by poor planning, overgrazing, and lack of proper forest care. As the environment suffers, so do the people who depend on it. The result has been frequent landslides, mudflows, and floods, especially in tribal villages like Thindakki, Pottikal, Kakkuppadi, Kallamala, and Kottiarkandi.



Source: Prepared by Researcher

Fig. 6.16: Road Density of the Attappady Hilly Region

The region's rough terrain and the recurrence of natural disasters have hindered effective relief efforts, leaving many communities in a state of persistent struggle. Attappady, once renowned for its natural beauty, now bears visible scars of environmental degradation largely driven by human activities. To safeguard this ecologically fragile landscape and the well-being of its inhabitants, there is an urgent need for comprehensive environmental planning and sustainable management practices. Land degradation is a complex process influenced by both natural and human factors. In the study area, encompassing the Attappady region of the Western Ghats. In Attappady, a tribal-dominated region in Kerala, recurring droughts and deficient rainfall during the southwest monsoon have exacerbated land degradation. This has contributed to severe water scarcity, significantly affecting the livelihoods of tribal communities dependent on the land for agriculture and sustenance.

Table 6.16: Land Degradation of the Attappady Hilly Region

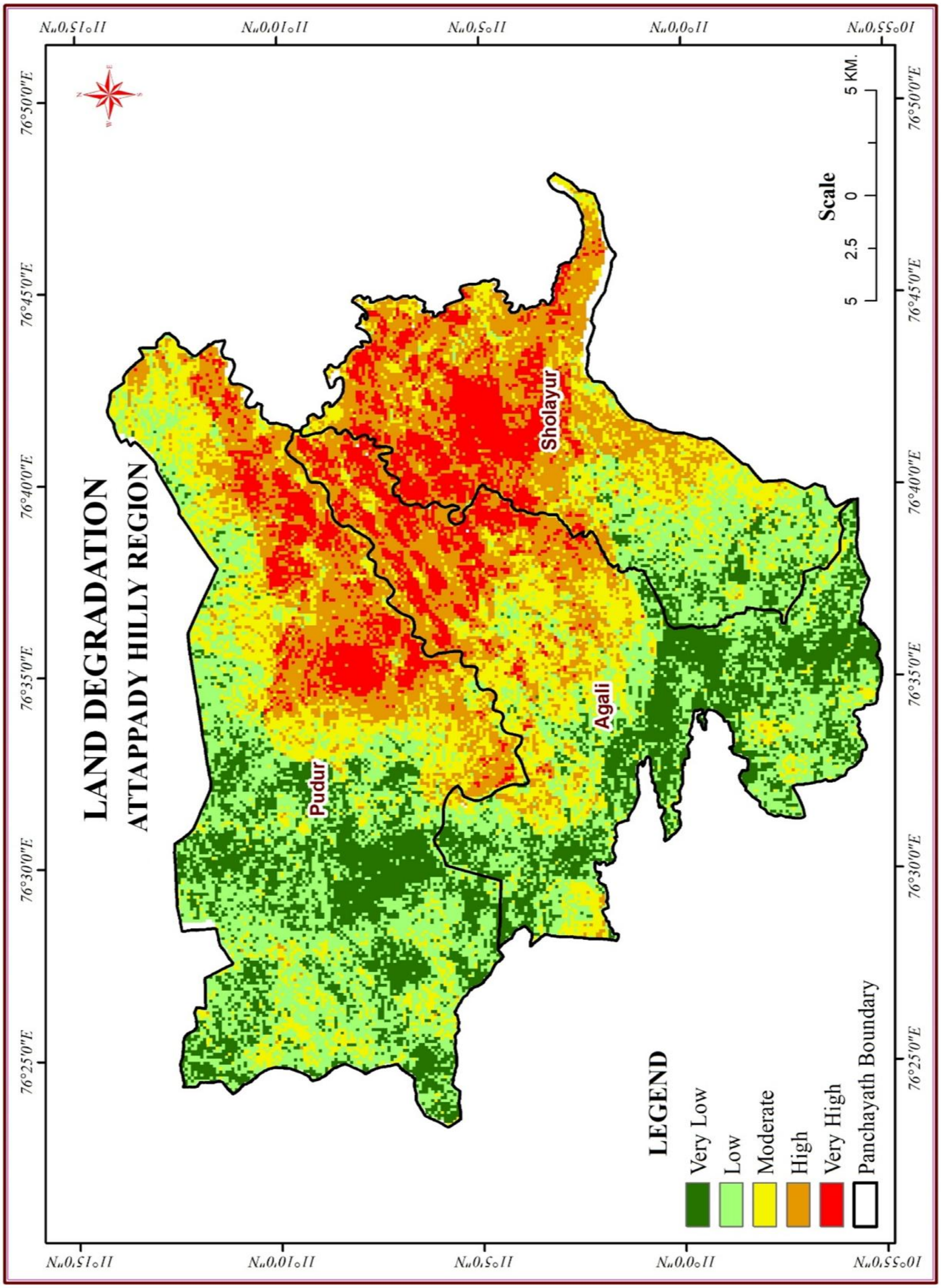
Sl.No	Land Degradation	Area in Km^2	Area in %
1	Very Low	127.13	15.58
2	Low	221.34	27.12
3	Moderate	227.85	27.92
4	High	147.32	18.05
5	Very High	92.58	11.34
	Total	**816.22**	**100**

Source: Prepared by Researcher

To assess land degradation in the region, the Multi-Influencing Factor Technique (MIF) is applied, utilizing 11 variables that are closely associated with land degradation delineation and climate. The resulting land degradation map (Fig 6.16) categorizes the land into five levels of degradation:

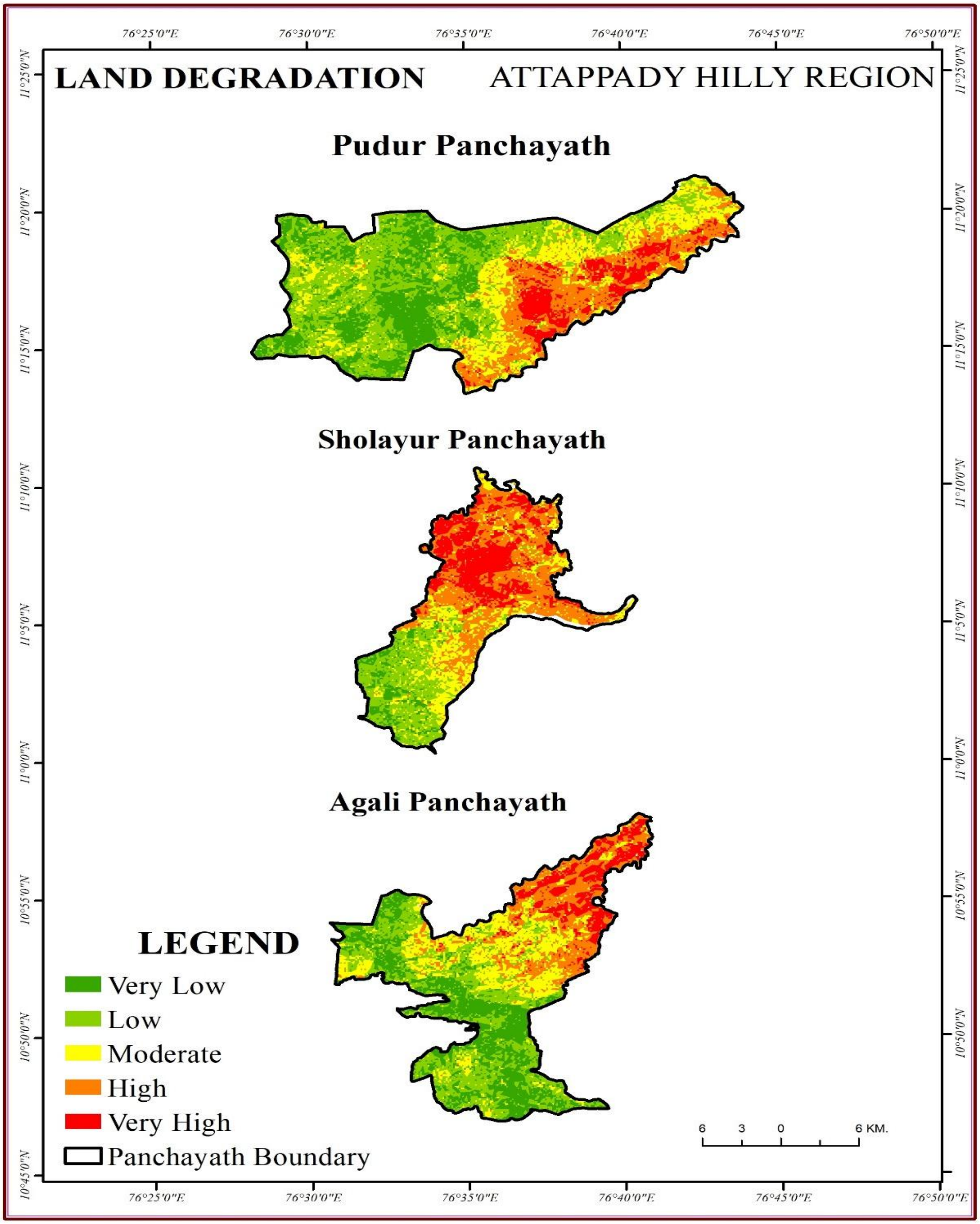
A) Very Low Land Degradation (15.58%): A relatively small but significant portion of Attappady's land remains in excellent condition, with very low degradation levels. These areas maintain high soil quality, adequate water retention capacity, and good agricultural productivity.

Such regions are crucial for biodiversity conservation, sustainable agriculture, and maintaining ecosystem services. B*)* Low Land Degradation (27.12%): These areas still support diverse land uses and show relatively good land quality and productivity. Although not severely degraded, they require proper land management practices to prevent deterioration. With appropriate conservation strategies, these areas could serve as models for sustainable land use and restoration efforts. C)Moderate Land Degradation (27.92%): A significant portion of Attappady falls into the moderate degradation category (table 6.15). These areas are showing signs of soil erosion, reduced fertility, and lower agricultural productivity. There is an urgent need for intervention to mitigate further degradation, such as promoting soil conservation techniques, reforestation, and agroforestry practices. D) High Land Degradation (18.05%): These areas are severely degraded, with a noticeable reduction in agricultural productivity and a higher risk of soil erosion. The degradation in these regions is driven by factors like overgrazing, deforestation, and unsustainable agricultural practices. Restoration efforts will require substantial investment in soil reclamation, water management, and sustainable land use planning. E) Very High Land Degradation (11.34%): This category represents the most critically degraded areas in Attappady. These regions are characterized by severe soil erosion, reduced water retention capacity, loss of soil organic matter, and the deterioration of soil structure. The degradation in these areas is alarming, as it leads to desertification, edaphic drought (soil moisture deficit), and a dramatic decline in agricultural productivity. Immediate intervention, including large-scale soil conservation, watershed management, and reforestation, is necessary to prevent irreversible damage. From the study of land degradation level, it is clear that the eastern part of Attappady, being a rain shadow region, is under the grip of the severe land degradation when compared to the western part. Therefore, climatic factors play a very important role in the formation land degradation in Attappady.



Source: Prepared by Researcher

Fig. 6.17: Land Degradation Map of the Attappady Hilly Region



Source: Prepared by Researcher

Fig.6.18: Panchayat wise Land Degradation Map of the Attappady Hilly Region

6.6 Impact of Land Degradation in the Attappady Hilly Region

Land degradation in Attappady has profound socio-economic and environmental impacts. The region's high level of degradation is particularly concerning in the rain shadow areas, where reduced rainfall and higher temperatures exacerbate water deficits. The resulting increase in evaporative demand further strains water resources, compounding the already limited water availability. During intense rainfall events, the consequences of land degradation become even more pronounced. Decreased soil infiltration and the formation of gullies lead to faster runoff, which intensifies flooding and magnifies peak river flows. These floods disrupt agricultural activities and cause soil erosion, leading to long-term productivity losses. The study indicates that the majority of Attappady's rain shadow region faces very high to high degradation, signaling that with proper conservation measures, it is still possible to restore these areas. However, the regions categorized as high and very high degradation require urgent attention. If left unaddressed, these areas could face irreversible ecological and socio-economic damage.

Deforestation in the catchment areas has led to the drying up of perennial rivers and the disappearance of natural springs. Water quality has deteriorated significantly, causing severe water shortages during summer. This scarcity has resulted in water-related diseases, poor health, and even starvation among the tribal population. With no access to water or fodder, many are forced to sell their cattle, further impacting their livelihoods. Additionally, extensive tree felling and improper farming practices, such as tilling slopes with bullock carts have worsened soil erosion, increased runoff, and depleted groundwater levels. In eastern Attappady, brick-making activities strip away the thin topsoil, leaving the land even more vulnerable to natural hazards.

The socio-economic impacts of these changes are profound and far-reaching. Climate change and environmental degradation have disrupted livelihoods, causing income loss, reduced well-being, and even led to premature deaths. These effects are not evenly distributed, with marginalized communities bearing the brunt of the crisis (Ribot, 2010). The situation in Attappady highlights the urgent need for sustainable practices and better resource management to restore the land and protect the lives of those who depend on it.

The consequences of land degradation in Attappady is not limited to environmental decline; they also lead to socio-economic marginalization. Many indigenous farmers have abandoned traditional farming practices due to the economic non-viability of agriculture in degraded lands. As a result, a significant portion of the tribal population has shifted to low-paying, unskilled labor, leading to increased poverty and a loss of cultural heritage tied to agriculture. The degradation of natural resources has not only undermined local food security but also exacerbated social inequities, with tribal communities suffering from extreme marginalization. Efforts to combat land degradation should, therefore, be integrated with social development programs that focus on restoring agricultural productivity, promoting alternative livelihoods, and empowering local communities through capacity-building and education.

In recent years, land use changes in the Attappady region have led to widespread deforestation, which is having a significant impact on the environment. Forests are crucial for maintaining ecological balance, and they are widely considered the most sustainable land use system (Agus, 2004). However, the clearing of forests, especially in the higher altitudes of Attappady, has made the area more vulnerable to the consequences of the rain shadow effect. This phenomenon, where the Western Ghats block rain, already makes the region prone to water scarcity, and deforestation only worsens the situation. By reducing the natural vegetation cover, the region becomes more prone to floods downstream, as the protective forest cover that once helped regulate water flow is removed (Meyer et al., 1992). In addition to the direct effects on flooding, land use changes have also led to a decline in water quality. Intensive farming practices in the area increase soil erosion, raise sediment levels in water sources, and lead to the leaching of harmful chemicals like pesticides and fertilizers into rivers, groundwater, and streams (Foley et al., 2005). The impact on water availability and flow is even more pronounced in areas affected by the rain shadow effect, where water resources are already limited. This is a classic example of how changes in land uses such as deforestation—can disrupt natural water cycles and lead to long-term environmental damage (Meyer et al., 1992).

Land use activities in Attappady are also contributing to the broader issue of climate change. As land cover changes, especially through urbanization, the region becomes more vulnerable to shifting climate patterns (Seto et al., 2009). Urbanization, along with deforestation and agricultural expansion, is altering the natural balance of carbon in the atmosphere. This shift has a direct impact on local climate conditions, creating feedback loops that worsen both land degradation and climate change (Dale, 1997). The conversion of evergreen forests and grasslands into agricultural land, particularly in the rain shadow areas, is a key driver of these changes. Such land conversion creates an imbalance in the local climate, acting as both a heat source and a moisture sink (Bounoua et al., 2004). When natural vegetation is cleared for farming, large amounts of carbon stored in plants and soils are released into the atmosphere, contributing to global warming (Houghton, 1994). Studies have shown that up to 90% of the carbon originally stored in vegetation and about 25% in the soil can be lost during land conversion. The conversion of land to pastures may release less carbon than cropland. Practices like burning forests to make way for grazing land still release harmful gases like carbon monoxide, methane, and nitrous oxide, along with CO_2. In Attappady's rain shadow areas, these changes in land cover significantly alter the region's energy and water balance and accelerates the process of land degradation.

6.7 Conclusion

Land degradation has become a critical global issue that threatens food security, ecosystem balance, and rural livelihoods, particularly in hilly regions. It results from a complex interplay of natural and socio-economic factors, necessitating comprehensive assessment and management strategies. Understanding the causes, impacts, and assessment methods is essential for effective intervention. The study on the impact of the rain shadow phenomenon on land degradation in Attappady highlights the intricate interplay between climatic, geographical, and human-induced factors that contribute to the region's environmental challenges. Attappady, situated in the rain shadow region of the Western Ghats, experiences significant climatic variability, with the western part receiving abundant rainfall and the eastern part facing arid conditions due to the rain shadow effect. This climatic disparity has profound implications for land degradation, soil health, water availability, and vegetation cover, ultimately affecting the livelihoods of the local population, particularly the indigenous tribal communities.

Land degradation in Attappady, a tribal-dominated region in Kerala, highlights the complex interplay of natural and anthropogenic factors, including recurring droughts, deficient rainfall, and unsustainable land use practices. The application of geoinformatics, specifically the Multi-Influencing Factor (MIF) technique which includes Slope, relief, rainfall, groundwater, soil, TWI, Drainage Density, Road Density, Land use Land cover, and vegetation condition, are the major parameters considered for the delineation of land degradation. The study revealed varying levels of degradation across the region, with 46.97% of the area facing moderate to high degradation. These areas are marked by soil erosion, reduced fertility, and diminished agricultural productivity, necessitating urgent interventions such as soil conservation, reforestation, and sustainable land use strategies. The findings also underline the socio-economic impacts of land degradation, particularly among indigenous communities who face declining agricultural viability, loss of traditional livelihoods, and worsening poverty. Many tribal farmers have abandoned traditional farming practices, shifting to low-paying labor, which has further entrenched poverty and disrupted cultural practices tied to the land. The degradation of natural resources has also exacerbated health issues, with water scarcity and poor soil quality contributing to malnutrition and disease. Analysis of land use and land cover changes from 1970 to 2024 further underscores significant shifts in land utilization patterns in both the wet and rain shadow regions of Attappady. The rain shadow area experienced an alarming reduction in forest cover and an increase in barren and urbanized land, exacerbating ecological and climatic challenges. Conversely, plantation activities expanded, offering potential but limited ecological benefits. The study underscores the urgent need for sustainable land management practices to mitigate land degradation and restore the ecological balance in Attappady. Interventions such as reforestation, soil conservation, water resource management, and the promotion of sustainable agricultural practices are critical to reversing the degradation trends. A comprehensive approach, combining advanced geospatial analysis with community-based interventions, is pivotal in restoring degraded lands, conserving biodiversity, and enhancing the resilience of vulnerable communities. Additionally, empowering local communities through education, capacity-building, and alternative livelihood opportunities can help alleviate the socio-economic impacts of land degradation.

CHAPTER 7

LAND DEGRADATION DRIVEN SOIL QUALITY DETERIORATION OF ATTAPPADY HILLY REGION

CHAPTER 7

LAND DEGRADATION DRIVEN SOIL QUALITY DETERIORATION OF ATTAPPADY HILLY REGION

7.1 Introduction

Soil quality serves as the basis for both food security and environmental sustainability. Soil quality is a concept that integrates soil's physical and chemical factors into a framework for soil resource evaluation (Karlen D L et al., 1997). Soil health defined by the NRCS (2012) as "the soil's ongoing ability to function as a dynamic living system that supports plants, animals, and humans". This concept closely aligns with the concept of soil quality, first introduced in the 1990s as "the soil's capacity to sustain productivity, maintain environmental balance, and promote plant and animal health within ecosystem boundaries" (Bouma, 2002). Soil quality is concerned with some measure of property or function of soil (Carter et al., 1997). Healthy soils enhance average crop yields while buffering against climate-induced yield fluctuations (Qiao et al., 2022). Conversely, soil degradation worsens climate-related production losses, threatening long-term food supply, particularly in staple crops like cereals (Qiao et al., 2022). Soil degradation may be defined as the permanent or temporary lowering of the soil's productive capacity (Syers J K et al., 1997). To optimise production and implement soil management interventions, understanding the state of the soil quality is fundamental (Abdu et al., 2023). The interdependence of agriculture and soil quality is vital for sustainable food security and environmental resilience. Safeguarding soil quality is thus essential to ensure future generations remain well-nourished and ecologically secure (Papendick et al., 1992).

Land degradation significantly impacts soil quality, affecting agricultural productivity and environmental health. Land degradation significantly impacts soil quality, which is crucial for maintaining ecosystem services and agricultural productivity. Soil degradation reduces the capacity of soils to support life and regulate essential ecosystem services like water regulation and nutrient cycling. This is accelerated by land conversion from forests and grasslands to intensive agriculture, which depletes soil organic matter and contributes to climate change (Sprunger, 2023). Low Soil Quality Index (SQI) values indicate significant land degradation, while higher values reflect better soil quality, emphasizing the need for effective management strategies to combat degradation and enhance soil health (Nursita, 2020). The rain shadow effect in Attappady hilly region can exacerbate land degradation due to insufficient moisture for vegetation. The degradation process in rain shadow regions, primarily driven by soil erosion due to lack of moisture, land use changes, and poor management practices, leads to the deterioration of soil's physical, chemical and biological properties. The adverse effects of rain shadow reflect on soil quality, necessitating integrated soil management strategies to combat degradation and enhance agricultural productivity (Yeneneh et al., 2024). The following paragraph examines the impact of rain shadow effects on the soil quality in the hilly region of Attappady. To reveal hidden facts that deteriorate soil health, the physical and chemical properties of soil from different geographical locations were assessed.

7.2 Conceptual Understanding of Land Degradation and its Impacts on Soil Properties

The rain shadow effect also significantly influences soil quality by altering precipitation patterns, which in turn affects soil moisture and nutrient availability. This phenomenon occurs when mountains block the passage of rain-producing weather systems, casting a "shadow" of dryness behind them. The resulting arid conditions can lead to distinct soil characteristics compared to regions with more abundant rainfall. Reduced soil moisture can limit plant growth and soil microbial activity, which are crucial for maintaining soil fertility and structure. Arid conditions induced by the rain shadow effect can exacerbate soil erosion, as less vegetation cover leads to increased vulnerability to wind and water erosion

(Sarapatka; Bendar, 2022). Soil erosion negatively impacts soil quality by removing the nutrient-rich topsoil, which is essential for crop production and environmental health (Sarapatka; Bendar, 2022). High-quality soils, which are less prevalent in rain shadow regions, are crucial for sustaining agricultural productivity and resilience to climate change (Qiao et al., 2022). The rain shadow effect greatly affects soil quality, impacting agricultural productivity, biodiversity, and overall ecosystem health. Soil quality is determined by its ability to support plant and animal life, maintain water quality, and promote health, influenced by factors like texture, structure, and nutrient content. In rain shadow areas, decreased moisture availability can alter soil properties, potentially leading to increased salinity and changes in pH, which can shift plant communities towards drought-resistant species. This shift further affects soil quality through changes in organic matter and root structures. Regions experiencing rain shadow effects, such as parts of the Western Ghats, and the Himalayas, demonstrate distinct ecological differences due to this phenomenon. Moreover, the rain shadow effect heightens soil erosion risk due to diminished vegetation, leading to increased runoff and sediment loss, which can degrade soil and affect agriculture and aquatic ecosystems (Adam et al., 2018).

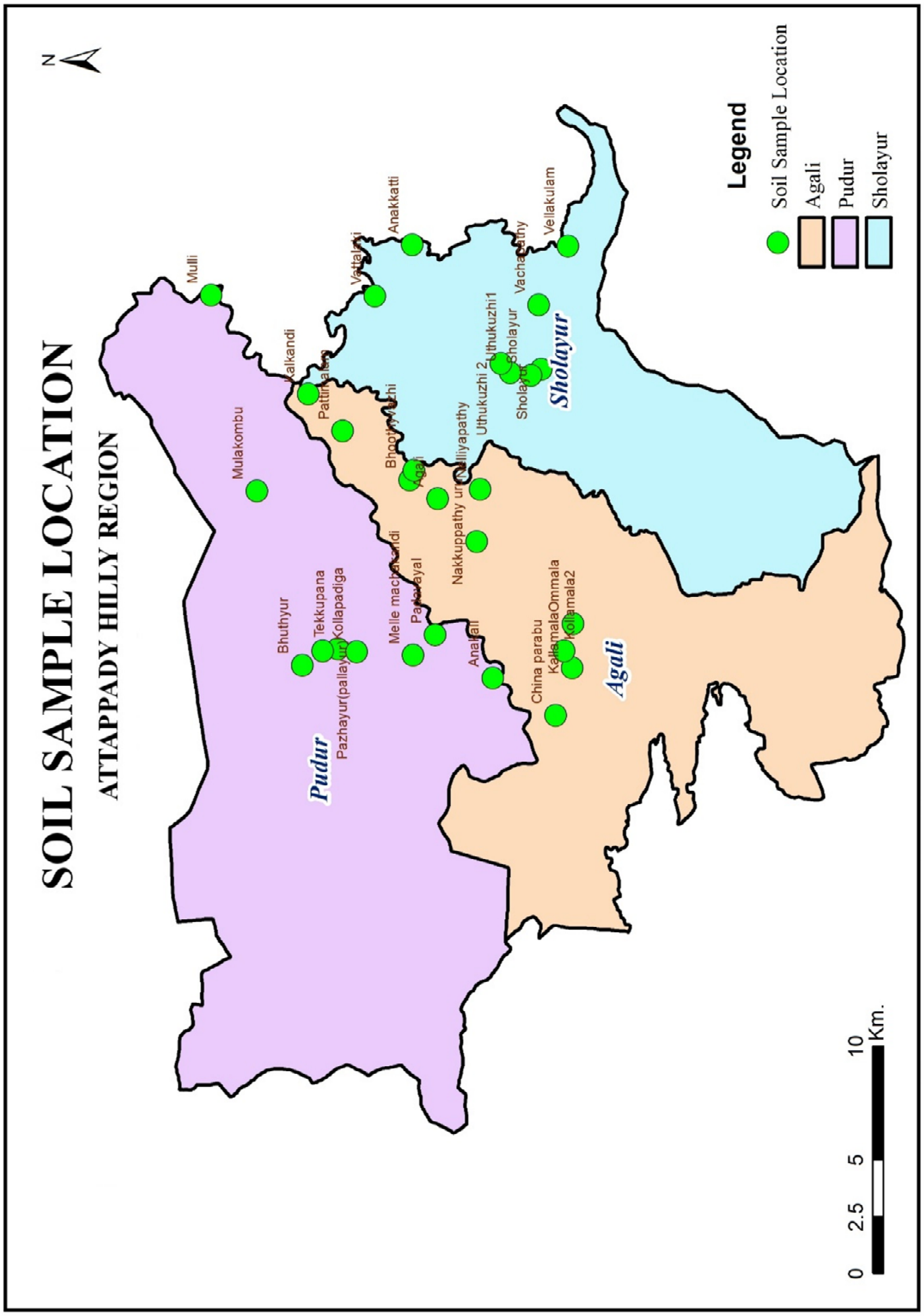
Different land uses have a marked influence on the quality of the surface soils (Burton S et al., 1989). Land use change and land conversion can also cause soil degradation. Soil fertility decline is the key factor in soil degradation and is probably the major cause of declining crop yields. The severity of soil degradation depends on the sensitivity of individual elements in the ecosystem to anthropogenic and natural disturbances (Okou F et al., 2014). Plant, litter and stone are the main ecological factors affecting soil degradation; they protect the soil, and their decrease leads to an increase in degradation. In the context of soil degradation, a decline in soil fertility is primarily interpreted as the depletion of organic matter and plant nutrients (Syers J K et al., 1997). Vegetative cover influences soil quality because it contributes the required organic matter to the soil. Thus, forest degradation and conversion of forested lands to agriculture may lead to changes in soil properties and soil fertility losses (Burton S et al., 1989; Dawoe E K et al., 2014). Soil's chemical and physical properties are significantly impacted by the conversion of forests to agricultural land use, and this may result in the alteration of many ecological processes (Hajabbasi M A et al., 1997; Sharma P et al., 2004; Zeng D H et al., 2009). Deforestation and the subsequent agricultural practices and urban development may inevitably increase soil bulk density and soil compaction (Hajabbasi M A et al., 1997; Brye K R et al., 2005; Dawoe E K et al., 2014; Yones K et al., 2014; Teferi E et al., 2016). Changes in land use could lead to a shift or gradual degradation of vegetation, which in turn could affect both quality and quantity of soil organic matter (Zhang P et al., 2006). Changes in organic carbon input and carbon mineralization are the main ways by which land use change affects Soil Organic Carbon (SOC) (Guo L B et al., 2002). SOC represents a key indicator for soil quality (Dawoe E K et al., 2014) especially after land cover change (Zeng D H et al., 2009). A main factor in the deterioration of soil properties is the conversion of forest and pasture lands into cultivated lands resulting in the reduction of SOC (Zeng D H et al., 2009; Sommer R et al., 2011; Yones K et al., 2012; Qiu L et al., 2012; Teferi E, et al., 2016). The decline in SOC stocks after forest land conversion to agricultural fields is most likely the result of carbon break down through oxidation following land clearing (Dawoe E K et al., 2014).

The total nitrogen (N) stocks are higher in the forest lands than in the croplands (Dawoe E K et al., 2014). Total N content decreases as the forest land is converted into other purposes as urban, cultivated and pastures (Hajabbasi M A et al., 1997; Zeng D H et al., 2009; Yones K et al., 2012). Forest land conversion has an impact on the available phosphorous (P) content too. Total P concentrations decrease when forest and grasslands are converted into cultivated land (Zeng D H et al., 2009; Dawoe E K et al., 2014). The total Microbial Biomass is also affected by land use change and land conversion. Land clearing degrades soil microbial biomass, and the total microbial biomass is closely related to the changes in SOC and total N (Langley T S J et al., 2005; Dawoe E K et al., 2014). There is a significant difference in soil texture following land use changes and this can be attributed to the loss of finer particles that follows vegetation loss (Yones K et al., 2012). Deforestation can also cause a significant decrease in soil aggregate stability among different land uses. Another important soil quality parameter is the cation exchange capacity (CEC). CEC depends on the SOM and clay amount, and the average CEC is always higher in forest lands compared to other land uses (Yones K et al., 2012). The average CEC may decrease when natural productive forest is converted into agriculture (Burton S et al., 1989). Like CEC, Soil Microbial Respiration (SMR) is also an important soil quality factor (Yones K et al., 2012). SMR reflect the overall activity of the microbial population (Zhang P et al., 2006). Soils under well protected natural vegetation maintain high microbial activity and microbial respiration. Similarly, the forested and the deforested sites have the highest and the lowest potassium (K) contents respectively (Hajabbasi M A et al., 1997). Therefore, it can be concluded that the land use change and land conversion can significantly affect various soil quality parameters and hence can cause land degradation.

7.3 Methodology of Soil Quality Assessment

Soil samples were collected from the degraded areas of Attappady hilly region which is derived from the MIF techniques. This method helped to identify the intensity of degradation. These selected sample locations were then combined with land use data to make sure that samples were taken from different land use types of agriculture, plantation, fallow land, scrub, and built-up areas (table 7.1).

The selected sample points were saved as location points in QGIS. These points were exported to the Q Field application. With the help of Q Field and GPS, samples were



Source: Prepared by Researcher

Fig. 7.1: Soil Sample Location in the Attappady Hilly Region

collected directly from the identified degraded spots in the field. Totally 28 samples were collected from the field, viz., 3 samples collected from agriculture field, 4 from cultivable land, 1 from barren land, 4 from scrubs, 9 from fallow land, 6 from plantations and 1 from built up areas from 40–60 cm depth (Fig.7.1). From each land use land cover areas, samples were collected from the respective soil depths and were preserved in one kg polythene bags and were emptied and spread out on plastic trays. Coarse concentrations, rock pebbles, pieces of roots, leaves and other composed organic matter were removed. Large lumps of moist soils were broken by hands. The samples were air dried and were mixed and harmonized. After air drying, the soil samples were crushed gently in mortar and pestle and then sieved though a 2 mm sieve. Soil samples were then analysed for various physio-chemical attributes like pH, EC, Boron, Mg, Potassium etc., by standard methods.

Table 7.1: Soil Quality Methodology Table

Total Samples	28
Number of Samples in each land use	7 Samples from Agricultural land, 1 Sample from Barren land, 4 samples from Scrub, 9 samples from Fallow land, 6 samples from plantations and 1 from Built-up.
Methods	Sites selected based on land degradation information, and points exported to Q Field for GPS-guided sampling; soil collected at 40–60 cm, air-dried, sieved.
Soil Quality Parameter	pH, Electrical Conductivity (EC), Nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg), Copper (Cu), Iron (Fe), Zinc (Zn), Manganese (Mn), Boron (B), Sul fur (S)
Software & Instrument Used	QGIS, Q Field, Carmin GPS, SPSS, & Google Co lab
Analysis	Soil Quality Index calculated based on Principal Component Analysis with Eigenvalues, PCA Correlation analysis and Interpolation

Source: Prepared by Researcher

After preparing the samples, they were tested for 13 soil quality parameters. These included both physical and chemical properties such as pH, electrical conductivity (EC), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), and micronutrients like iron (Fe), copper (Cu), zinc (Zn), manganese (Mn), and boron (B). Standard lab procedures were used for testing each of these. To calculate the Soil Quality Index (SQI), Principal Component Analysis (PCA) and Correlation Analysis were used. These statistical methods helped to reduce the number of variables and identify the most important soil indicators. Parameters with strong influence were selected from each component. Each selected component was given a weight based on its importance. Finally, the weighted values were added together to calculate the SQI for each sample site. This index helped to understand the soil health status across the rain shadow region of Attappady.

7.4 Assessment of Soil pH in the Attappady Hilly Region

Soil pH is the negative logarithm of the hydrogen ion activity (Foth H D, 1990). The degree of acidity or alkalinity is considered a master variable that affects nearly all soil properties – chemical, physical and biological (Brady N et al., 1996) and is one of the most important properties involved in plant growth (Foth H D, 1990). It is an indicator of soil quality because of its sensitivity to change (Langley T S J et al., 2005). It is an important factor that influence the availability of nutrients to plants, as well as various soil chemical and biological processes. The pH scale ranges from 0 to 14, with 7 considered neutral. Values below 7 indicate acidic conditions, while values above 7 indicate alkaline conditions.

Government of India Ministry of Agriculture and Farmers Welfare initiated soil health card scheme across India on village level by collecting soil samples from field level since 2014-2015. Soil Health Cards (SHCs) Scheme introduced in the year 2014-15, is a massive programme of soil sampling, testing and generation of SHCs was launched to assist State Governments to issue soil health cards to all farmers in the country. As per its guidelines the soil pH ranges are given below (Table 7.2) and in this report pH analysis made using the same data and techniques.

Table 7.2: Limits of pH Concentration in Soil

Class	pH
Strongly acidic	<4.5
Moderately acidic	4.5 – 5.5
Slightly acidic	>5.5 – 6.5
Normal	>6.5 – 7.5
Slightly alkaline	>7.5 – 8.5
Moderately alkaline (Sodic)	>8.5 – 9.5
Strongly alkaline (Highly Sodic)	> 9.5

Source: BIS (Bureau of Indian Standards)

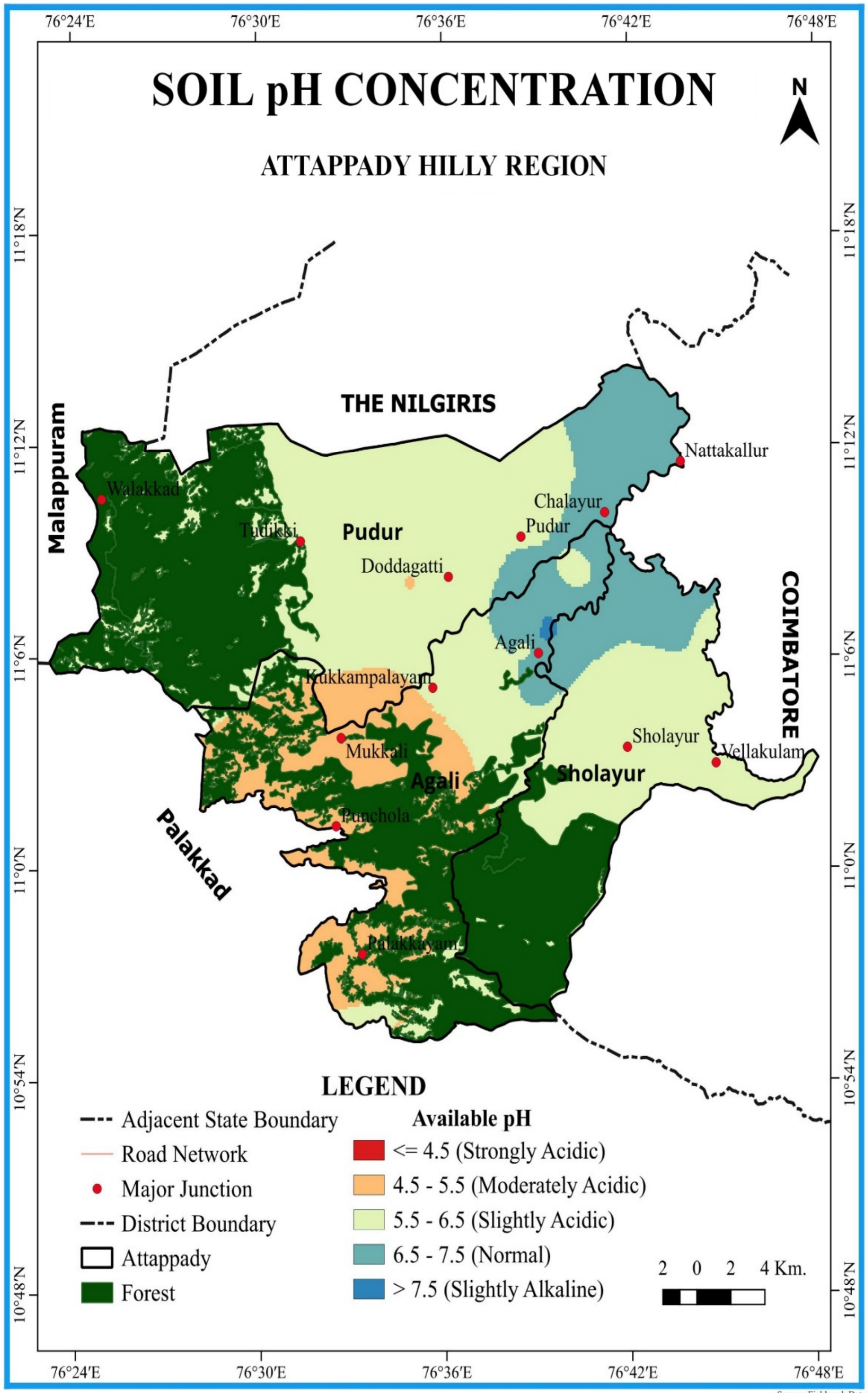
Table 7.3: Distribution of soil reaction (pH) in the Attappady Hilly Region

Class	Area in Ha	Area in %
1. Strongly acidic (< 4.5)	3.58	0.01
2. Moderately acidic (4.5 - 5.5)	2,801.55	3.76
3. Slightly acidic (>5.5 - 6.5)	14,085.86	18.9
4. Normal (>6.5 - 7.5)	5,455.67	7.32
5. Slightly alkaline (>7.5 - 8.5)	63.82	0.09
6.Misc.(Forest, Habitations, ROC, Water bodies)	52,101.52	69.92
Total	**74,512**	**100**

Source: KFRI (Kerala Forest Research Institute)

7.5 Presence of Electrical Conductivity (EC) in the Attappady Hilly Region

Electrical Conductivity is an indispensable parameter in soil fertility as it helps in understanding the soil's ability to transmit nutrients and water. The soil moisture, mineral contents and temperature are the influencing factors of EC. Measuring of soil EC aids in evaluating the levels of soil salinity and nutrient content, which enables to make knowledgeable choices on soil management applications such as irrigation and fertilization. The EC with too high or too low values, are detrimental to plant growth. For instance, too low soil EC indicates nutrient deficiencies while, very high soil salinity or EC can result in salt stress, which causes imbalance of water in plants and obstructs nutrient intake.



Source: Prepared by Researcher

Fig. 7.2: Soil pH Concentration in the Attappady Hilly Region

The Ministry of Agriculture and Farmers Welfare, Integrated Nutrient Management (INM Division) Government of India, in its Soil Health Cards (SHCs) programme defined Electrical Conductivity as follows:

Table 7.4: Limits of Electrical Conductivity (EC) in the soil of the Attappady Hilly Region

Class	**EC (dS/m) in 1:2.5 extract at 25^{0}C**	**Electro-conductivity of soil saturated extract ECe at 25^o C (dS/m)**
Non saline	0 -1.68	0-2
Low salinity	1.68-3.36	2-4
Mild salinity	3.36-6.72	4-8
High salinity	6.72-13.44	8-16
Sever salinity	> 13.44	>16

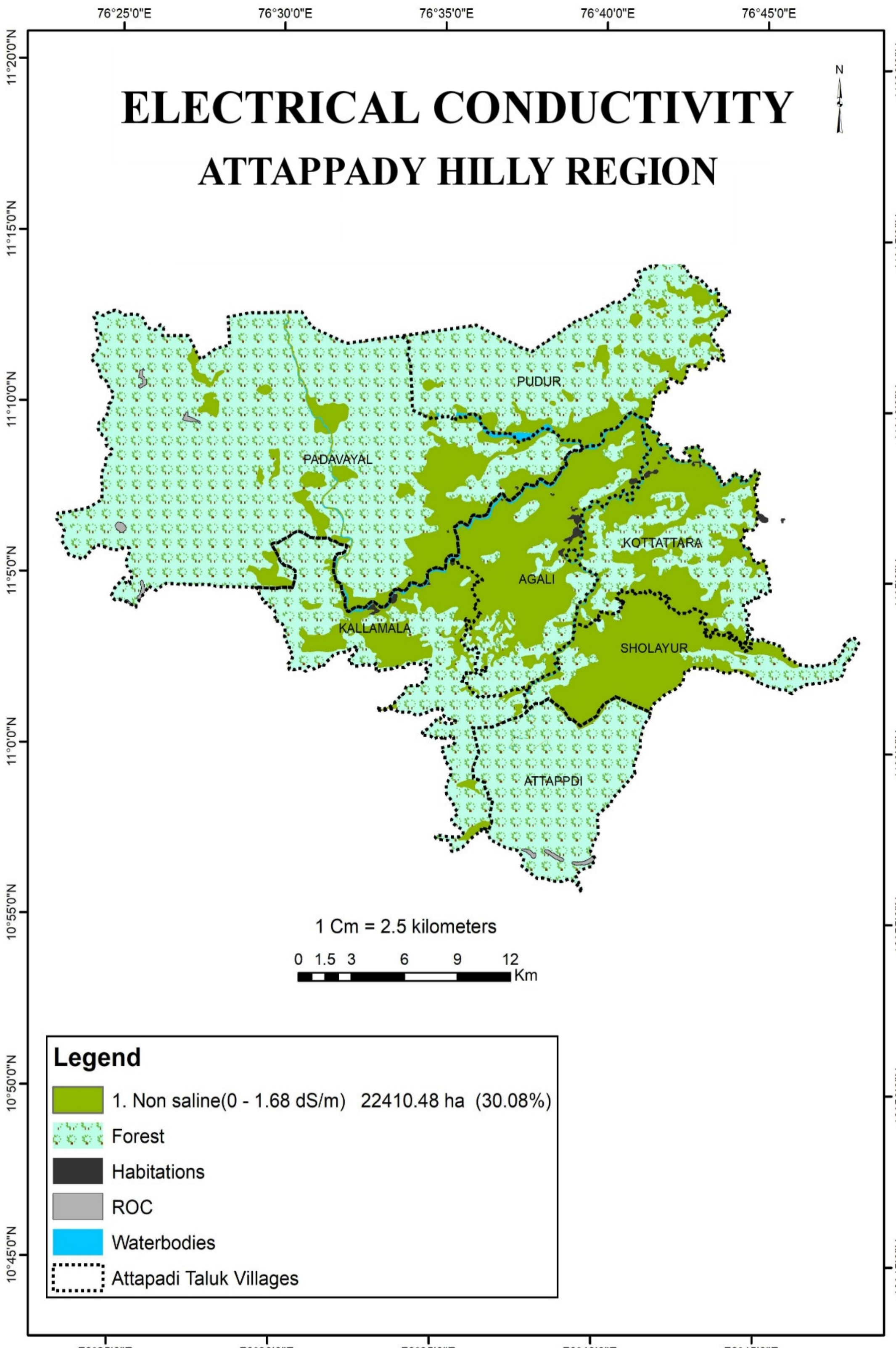
Source: BIS (Bureau of Indian Standards)

Table 7.5: Area of Electrical Conductivity (EC) Distribution in the Attappady Hilly Region

Class	Area in Hectare	Area in Percentage
1. Non - saline (0 - 1.68 dS/m)	22410.48	30.08
2. Misc. (Forest, habitations, Waterbodies)	52101.52	69.92
Total	**74512**	**100**

Source: BIS (Bureau of Indian Standards)

In a total area of 74512 ha. of Attappady region, 22410.48 ha. (30.08%) of soils are non-saline (0-1.68 dS/m) which is a favourable condition for soil fertility and 52101.52 ha (69.92%) comes under miscellaneous region including forest, habitations and water bodies (table 7.4). Systematic monitoring of soil salinity with remedial measures may leads to healthier plant growth, enhanced crop yields and sustainable practices of agriculture in gap region. Even though, only a few fractions of gap area show low saline soils, it tends to be very low in future, hence monitoring and managing for an ideal balance of salts and nutrients in the region is vital. Appropriate irrigation practices, for example using low salt content water and avoiding of overwatering can be maintained. Also, to ensure healthy root development and preventing salt accumulation adequate drainage is very essential. In addition, making the soil rich with organic matter can improve the soil structure and decrease the risk of soil bulk density (compaction) which helps in enhancing plant nutrient availability



Source: Prepared by Researcher

Fig. 7.3: Electrical Conductivity in the Attappady Hilly Region

and overall soil fertility. The table 7.4 below shows the distribution of EC in Attappady taluk region in area and percentage (Fig. 7.5).

7.6 Concentration of Boron (B) in the soils of the Attappady Hilly Region

Boron (B) is an inorganic micro-nutrient which is vital for the normal growth and increase the quality of crops. Boron supports in regulating the transference of sugar in plants. It plays crucial role in cell divisions and seed development. Boron (B) has important function in the plant life cycle hence its deficiency as well as toxicity i.e. its presence in excess amount causes abnormalities in several metabolic and anatomical systems. A deficit in this soil nutrient causes abnormalities in several metabolic and anatomical systems. Plants that are deficient in boron also experience inhibitory effects on their growth, meristem death, and decreased fertility in both their vegetative and reproductive stages.

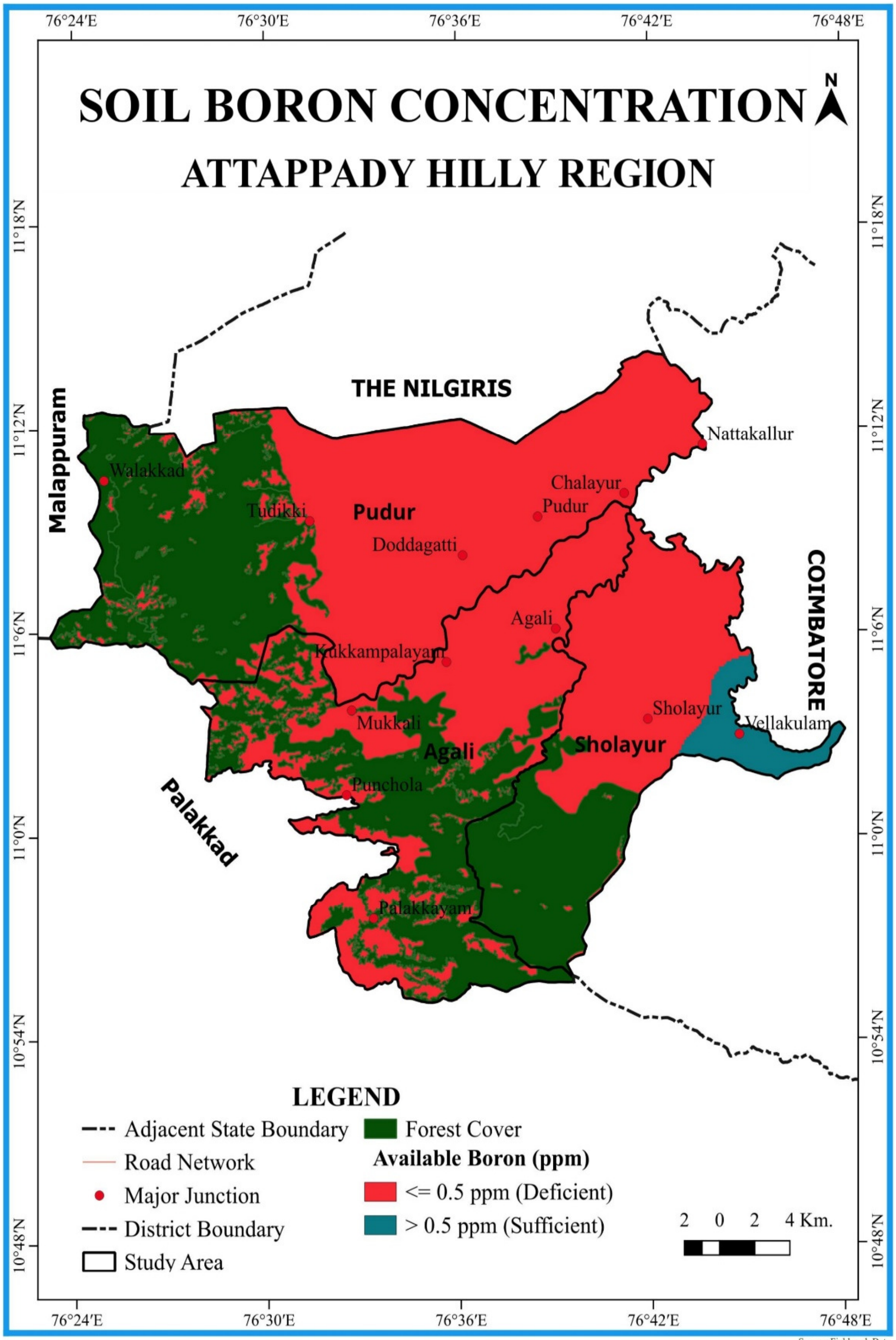
As per the Soil Health Cards (SHCs) scheme of Ministry of Agriculture and Farmers Welfare, under Integrated Nutrient Management (INM Division), Government of India the available Boron (B) concentration has been classified as follows (table 7.6);

Table 7.6: Limits of Boron Concentration in the soil of the Attappady Hilly Region

Category	**Boron (B) ppm**
Deficient	<0.5
Sufficient	>0.5

Source: BIS (Bureau of Indian Standards)

It is evident that the available boron in Attappady taluk region comes under deficient category (less than 0.5 ppm), falls under an area of 22339.44 ha. (29.98 %) out of 74512 ha (table 7.7). Of the total area of interest, sufficient category (>0.5) covers 71.04 ha (0.1%) and the miscellaneous region including forest, water bodies and habitations covers 52101.52 ha (Fig 7.2). Boron fertilizers such as solubor, boric acid and borax can be supplemented to deficient soils according to crop needs based on soil test results. While deep watering will



Source: Prepared by Researcher

Fig. 7.4: Soil Boron concentration in the Attappady Hilly Region

relieve heavy boron soil concentrations by leaching the nutrient away from the roots. The distribution of boron in Attappady hilly region is shown in Fig. 7.4.

Table 7.7: Area of Boron concentrations in the Attappady Hilly Region

Class	**Area (ha)**	**Area in %**
Low	22366.86	30.02%
Medium	41.62	0.06%

Source: KFRI (Kerala forest Research Institute)

7.7 Concentration of Nitrogen (N) in the soils of the Attappady Hilly Region

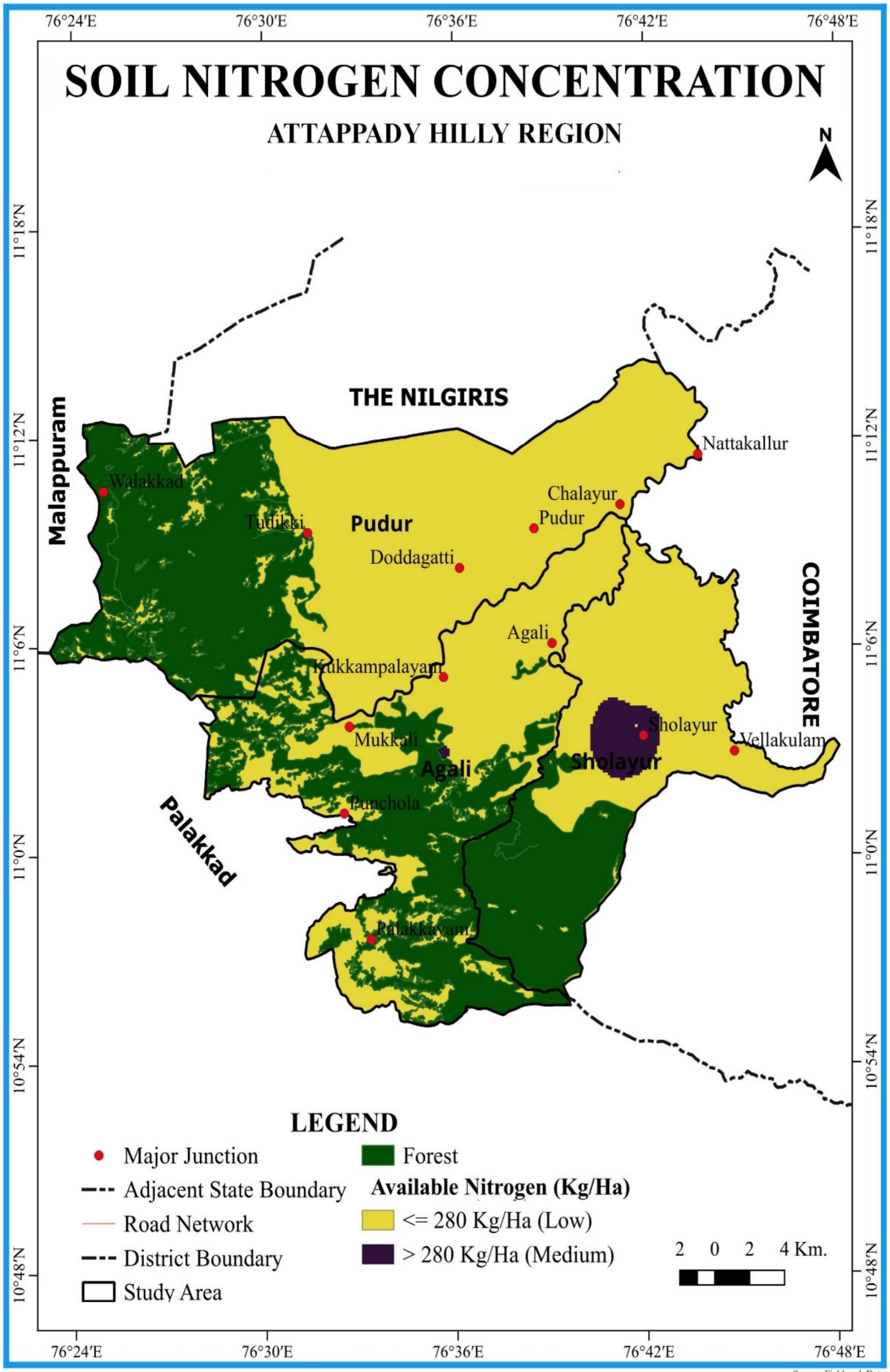
Nitrogen levels vary, with the highest at 510.54 kg/ha in Sholayur and the lowest at 137.98 kg/ha in Bhoothyvazhi. Ideal nitrogen levels range from 200 to 400 kg/ha for agriculture. Areas like Sholayur with higher nitrogen levels may support robust plant growth, while low-nitrogen areas like Bhoothyvazhi (137.98 kg/ha) (table 7.8) may face limitations in agricultural productivity. Nitrogen is essential for foliage and root development, so deficiencies could limit crop yields.

Table 7.8: Available Nitrogen (N) in the Attappady Hilly Region

Legend	**Area in hectares**	**Area in %**
1. Deficient (<0.5 ppm)	22339.44	29.98
2. Sufficient (>0.5ppm)	71.04	0.1
2.Misc.	52101.52	69.91
Total	**74512**	**100**

Source: BIS (Bureau of Indian Standards)

In Attappady, the nitrogen levels in soil show significant deficiencies, with low nitrogen content (<280 kg/ha) observed in 30% of the area and medium levels (280–560 kg/ha) being rare at just 0.06%. This deficiency is prominent in barren lands such as Bhuthyur (193.18 kg/ha) and uncultivated zones like Pazhayur (179.38 kg/ha), where limited organic matter and microbial activity restrict nitrogen availability (Fig 7.5). Even agricultural areas like



Source:Prepared by Researcher

Fig.7.5: Soil Nitrogen Concentration in the Attappady Hilly Region

Padavayal (220.77 kg/ha) exhibit low nitrogen levels, likely due to nutrient depletion from continuous cultivation without adequate replenishment. The rain shadow effect in Attappady further exacerbates this issue, as reduced rainfall diminishes natural nitrogen fixation and plant biomass, contributing to soil degradation. This interplay between nitrogen scarcity, land use patterns, and the region's climatic conditions highlights the urgent need for sustainable soil management practices to address declining fertility and support agricultural productivity.

7.8 Concentration of Phosphorus (P) in the soils of the Attappady Hilly Region

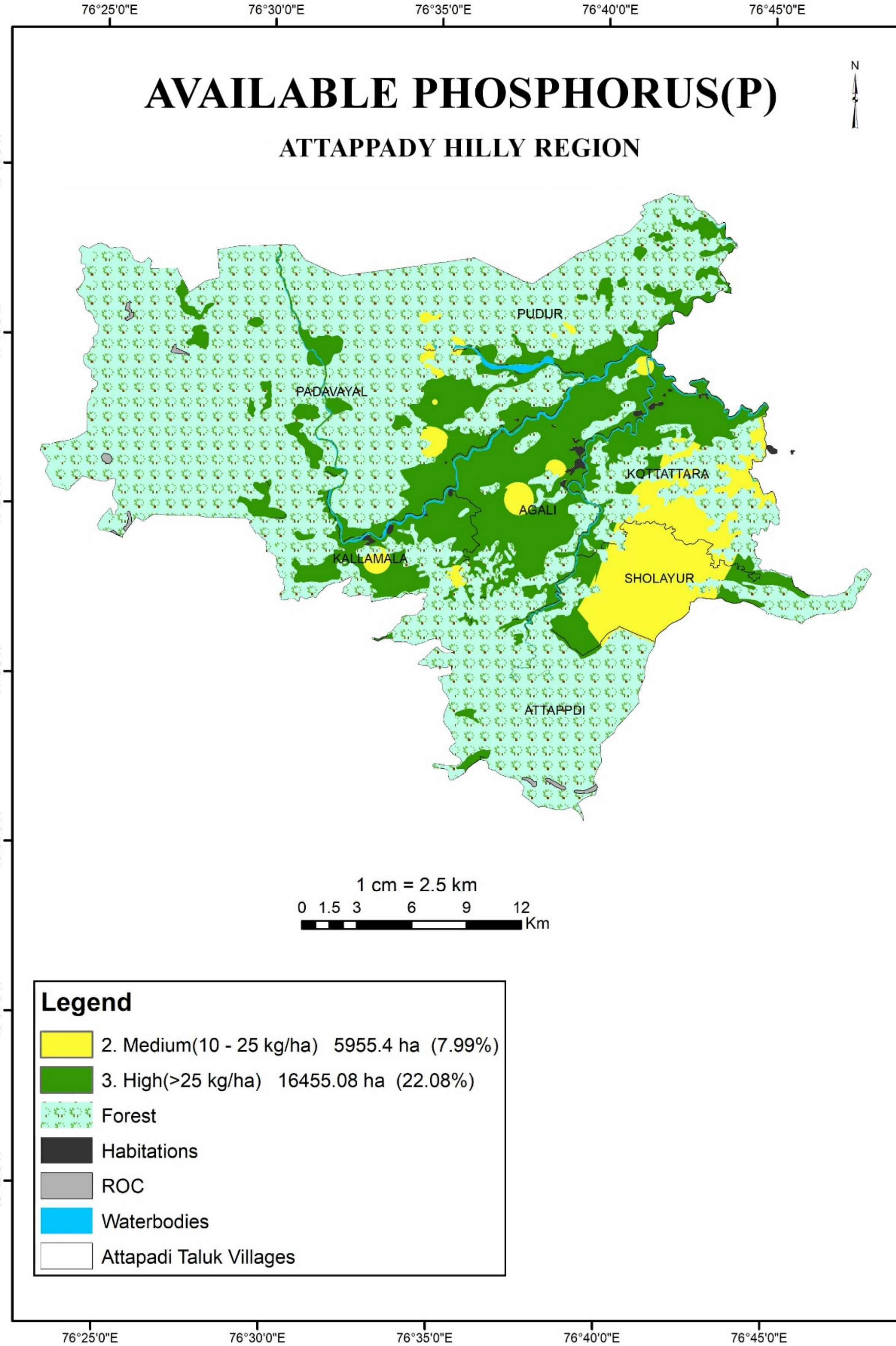
Phosphorus content ranges from 11.08 kg/ha (Sholayur) to 152.75 kg/ha (Kallamala). Optimal phosphorus levels range from 25 to 50 kg/ha (table 7.9). In areas like Kallamala, high phosphorus availability supports root development and flowering, improving plant health. In contrast, areas like Sholayur, with low phosphorus, might face limitations in crop productivity, especially for fruit and seed-producing plants.

Table 7.9: Available Phosphorus (P) in the Attappady Hilly Region

Class	Class (kg/ha)	Area (ha)	Area in Percentage
Medium	10 – 25	5955.4	7.99%
High	>25	16455.08	22.08%

Source: BIS (Bureau of Indian Standards)

Phosphorus is a crucial macronutrient in soil, essential for plant growth, energy transfer, and root development. In Attappady, medium phosphorus levels (10–25 kg/ha) are observed in 8% of the area, while high levels (>25 kg/ha) account for 22%. Elevated phosphorus levels are found in agricultural areas like Tekkupana (57.31 kg/ha) and plantain-growing regions such as Kallamala (152.75 kg/ha), likely due to fertilizer application. In contrast, barren and uncultivated lands, such as Bhuthyur (13 kg/ha) and Pazhayur (13.55 kg/ha), exhibit low phosphorus levels, indicating limited organic matter and nutrient input (Fig.7.6). The rain shadow effect in Attappady exacerbates soil degradation, as reduced rainfall limits phosphorus mobility and its availability to plants. While high phosphorus content can enhance crop productivity, excessive levels risk runoff-induced water pollution, contributing



Source:Prepared by Researcher

Fig.7.6: Soil Phosphorus Concentration in the Attappady Hilly Region

to eutrophication. Sustainable soil management practices, including balanced fertilization, erosion control, and organic amendments, are essential to maintain soil health and mitigate the adverse effects of phosphorus imbalance.

7.9 Concentration of Potassium (K) in the soils of the Attappady Hilly Region

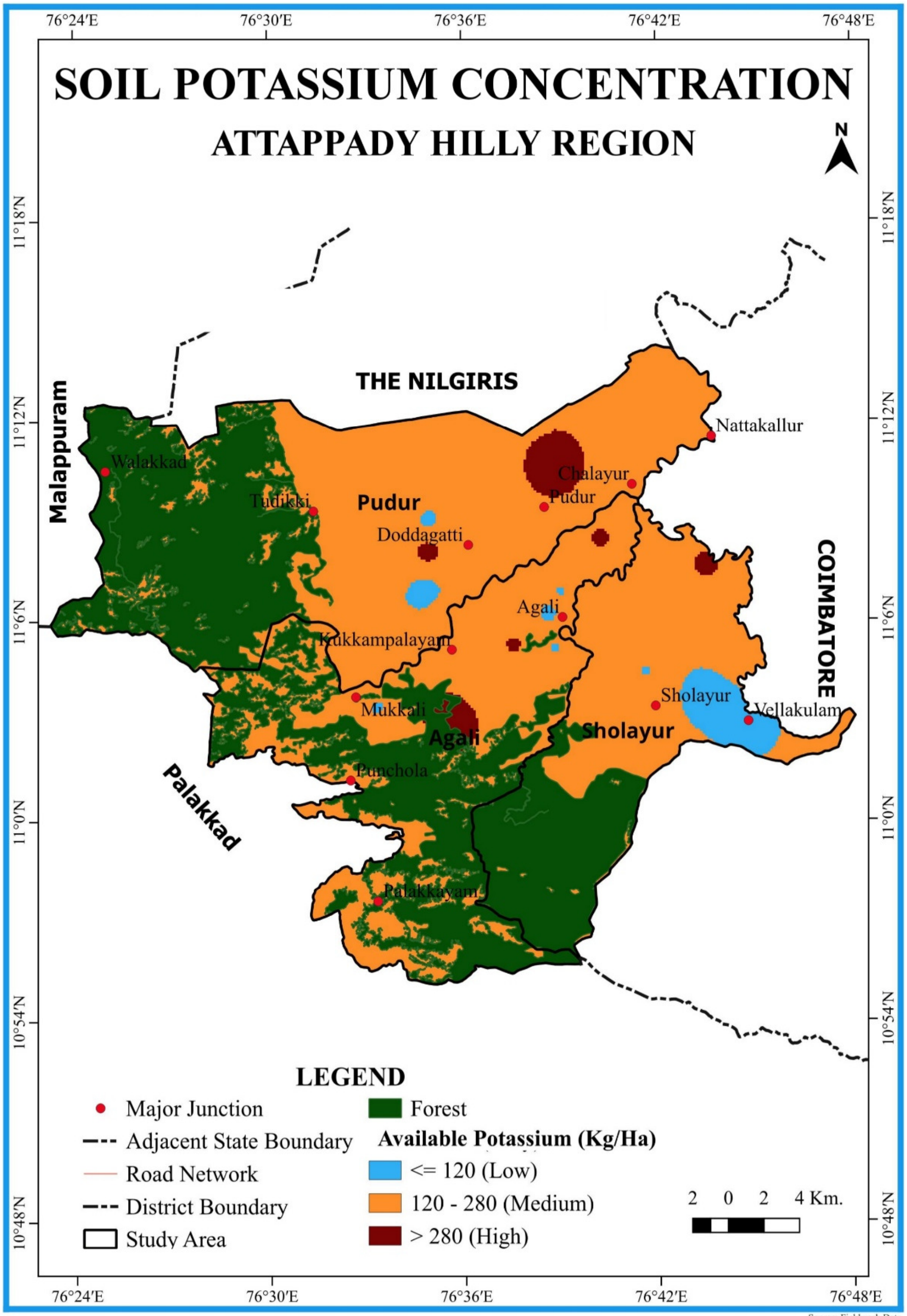
Potassium levels vary widely, from 45.92 kg/ha (Melle Machakandi) to 367.36 kg/ha (Kollamala). Potassium levels between 150 to 300 kg/ha are generally considered sufficient (table 7.10). Higher potassium levels, like those in Kollamala, enhance plants' resistance to drought and diseases, essential in the rain shadow region. Low potassium levels, as seen in Melle Machakandi, can result in poor water regulation and reduced plant resilience, especially in drier conditions (Fig 7.7).

Table 7.10: Available Potassium (K) in the Attappady Hilly Region

Class	Class (kg/ha)	Area(ha)	Area in Percentage
Low	<120	1149.4	1.54%
Medium	120 – 280	20636.98	27.7%
High	>280	624.1	0.84%

Source: BIS (Bureau of Indian Standards)

Potassium (K) is an essential macronutrient in soil, crucial for plant processes such as water regulation, enzyme activation, and photosynthesis. In Attappady, low potassium levels (<120 kg/ha) are minimal, accounting for 1.54% of the area, while medium levels (120–280 kg/ha) are more common at 27%, and high levels (>280 kg/ha) are observed in 0.8% of the region. Elevated potassium levels are typically found in intensively cultivated areas such as Kollapadiga (369.6 kg/ha), where fertilizer application is frequent. In contrast, uncultivated or scrubland areas like Melle Machakandi (45.92 kg/ha) exhibit low potassium levels, reflecting limited nutrient input. The rain shadow effect in Attappady contributes to land degradation by reducing rainfall, which impairs potassium mobility and availability to plants. While adequate potassium enhances crop productivity and resilience, excessive levels may disrupt nutrient balance, and low levels can limit plant growth. Sustainable soil management



Source:Prepared by Researcher

Fig.7.7: Soil Potassium concentration in the Attappady Hilly Region

practices, such as balanced fertilization, organic amendments, and erosion control, are vital to maintaining soil health and mitigating nutrient deficiencies.

7.10 Concentration of Copper (Cu) in the soils of the Attappady Hilly Region

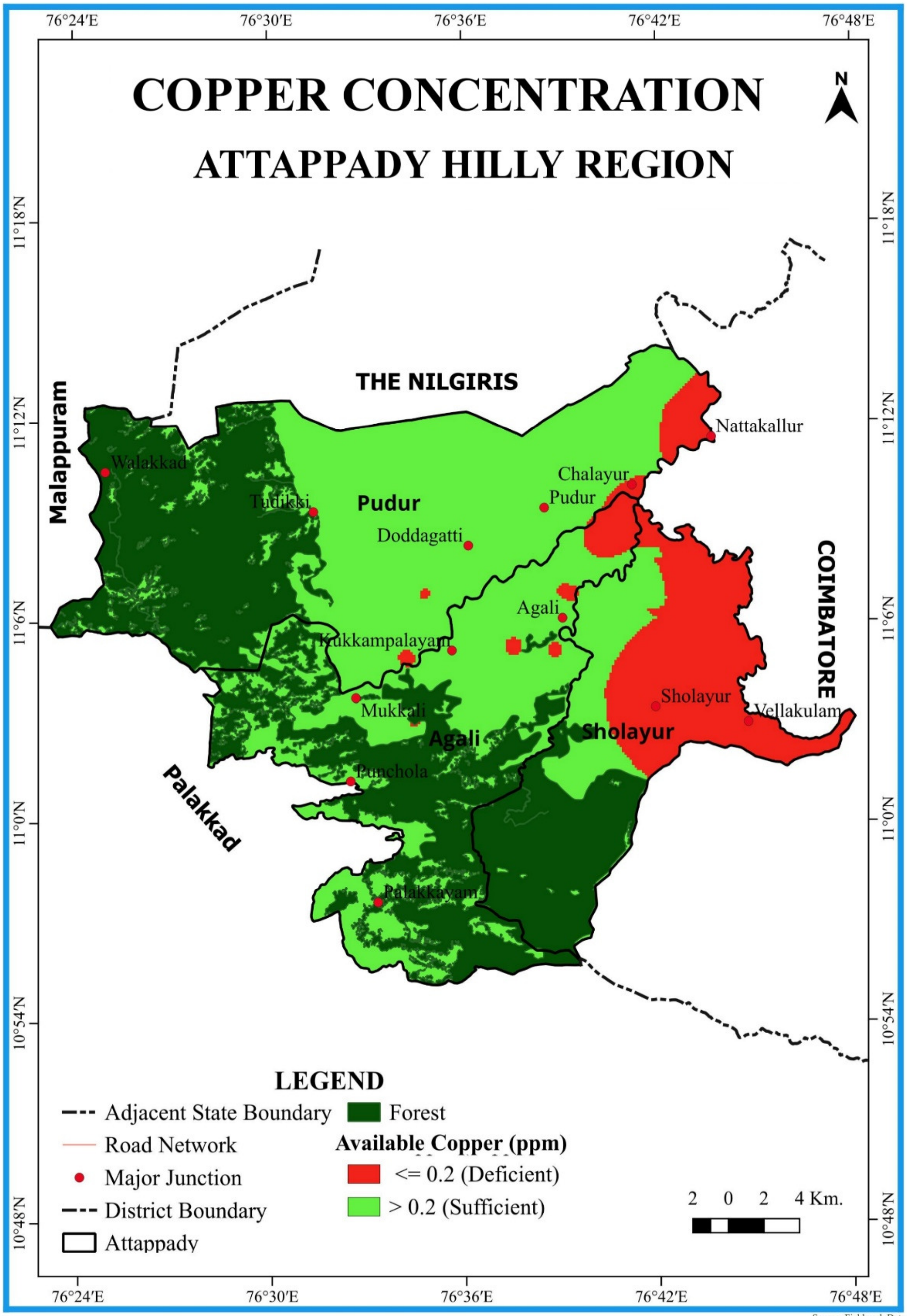
Copper content in soil plays a crucial role in determining soil quality and its suitability for agricultural and ecological functions. Copper is an essential micronutrient for plant growth, involved in enzymatic processes, photosynthesis, and disease resistance. While adequate copper levels support healthy plant development and microbial activity, excessive copper can be toxic, disrupting soil microbial communities and causing phytotoxicity, which can harm plant health. Conversely, insufficient copper levels can lead to plant deficiencies, affecting growth and yield. To address copper imbalances, strategies such as targeted copper supplementation, regular soil testing, and the use of organic amendments like compost can help maintain optimal levels. Rainfall deficiency can influence copper content in soil, as reduced precipitation may limit leaching, leading to localized accumulations, or conversely, restrict plant availability due to reduced organic matter.

Table 7.11: Available Copper (Cu) in the Attappady Hilly Region

Class	Class ppm)	Area (ha)	Area in Percentage
Deficient	<0.2	4060.54	5.45 %
Sufficient	0>.2	18349.94	24.63 %

Source: BIS (Bureau of Indian Standards)

In the Attappady region, 5.45% of soils exhibit copper deficiency (<0.2 ppm), while 25% have sufficient copper levels (table 7.11). This variation reflects differences in land use and geographical conditions. Agricultural lands, such as those in Padavayal and Tekkupana, tend to have higher copper content due to cultivation practices and potential fertilizer application, whereas barren lands or areas with sparse vegetation, such as Bhuthyur, often show lower copper levels, exacerbated by erosion and lack of organic matter. The rain shadow effect in Attappady contributes to reduced vegetation cover and soil degradation, further impacting



Source: Prepared by Researcher

Fig.7.8: Soil Copper concentration in the Attappady Hilly Region

copper availability. Addressing copper deficiencies in such rain-shadowed regions requires a combination of sustainable agricultural practices, reforestation, and soil conservation measures to enhance organic matter and stabilize nutrient cycles (Fig.7.8).

7.11 Concentration of Zinc (Zn) in the soils of the Attappady Hilly Region

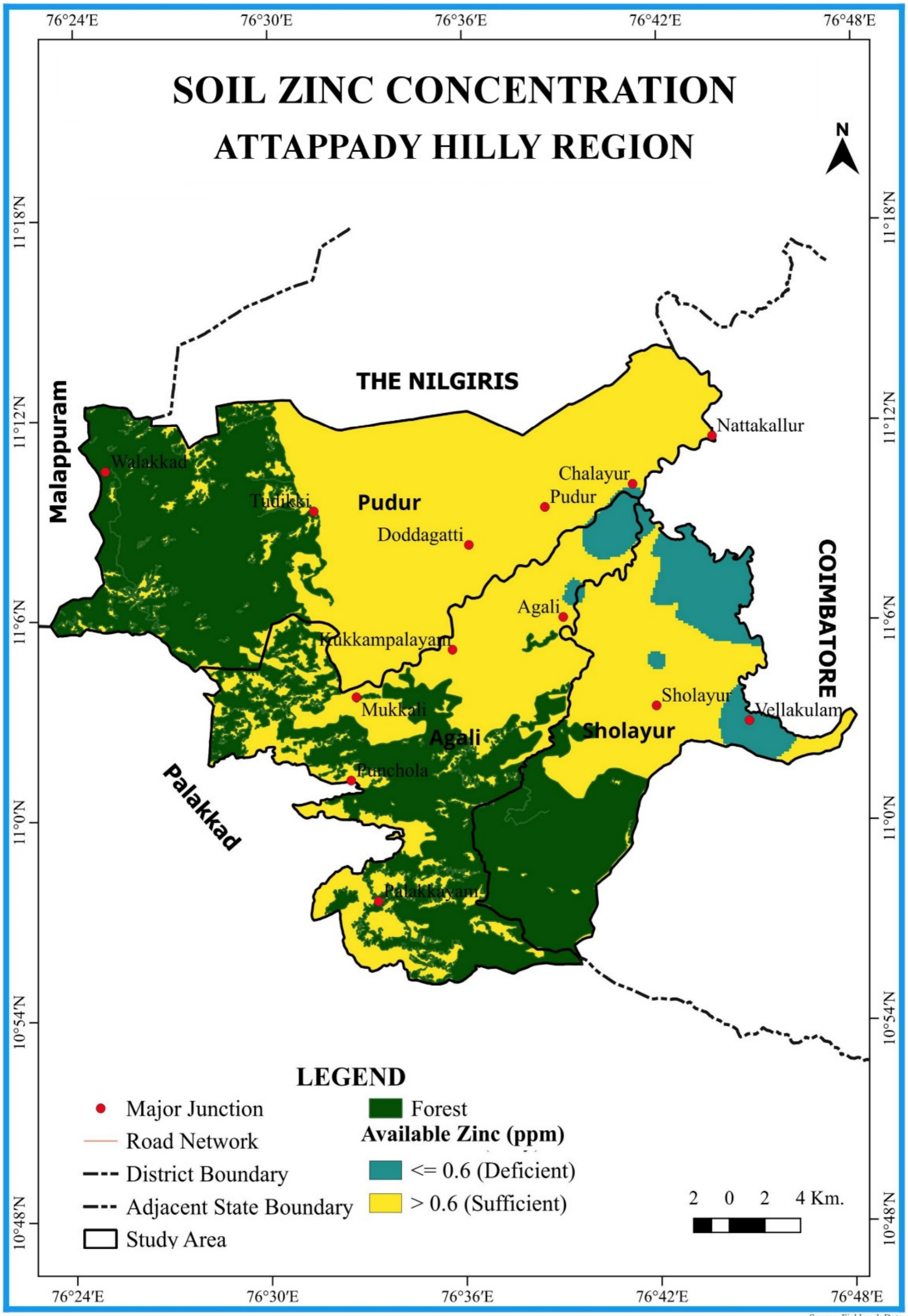
Zinc content in soil is a critical factor in soil quality and plant health, as zinc is an essential micronutrient involved in chlorophyll synthesis, respiration, and enzymatic functions. Adequate zinc levels enhance plant growth, improve resistance to stress, and support soil microbial activity. However, excessive zinc can lead to toxicity, affecting plant roots and microbial ecosystems, while insufficient zinc results in deficiencies such as chlorosis, especially in calcareous or alkaline soils. Mitigating zinc imbalances involves soil testing, using zinc chelates or organic amendments, and managing soil pH to improve availability. Rainfall deficiency can influence soil zinc levels, as reduced precipitation can limit the leaching of zinc but also hinder its availability due to decreased organic matter and microbial activity.

Table 7.12: Available Zinc (Zn) in the Attappady Hilly Region

Class	Class (ppm)	Area (ha)	Area in Percentage
Deficient	<0.6	2593.64	3.48 %
Sufficient	>0.6	19816.84	26.6 %

Source: BIS (Bureau of Indian Standards)

In the Attappady region, only 0.77% of soils exhibit zinc deficiency (<4.5 ppm), while 29% have sufficient levels (>4.5 ppm) (table 7.10). Agricultural areas, such as Padavayal and Tekkupana, typically show higher zinc content due to better management practices and organic inputs, while barren lands like Bhuthyur or areas with sparse vegetation are more prone to lower zinc availability (Fig:7.9). The rain shadow effect in Attappady exacerbates soil degradation and limits vegetation cover, impacting the zinc cycle in the soil. To address



Source:Prepared by Researcher

Fig. 7.9: Soil Zinc concentration in the Attappady Hilly Region

these challenges, sustainable land use practices, reforestation, and the incorporation of organic matter are essential to maintain balanced zinc levels and mitigate the effects of soil degradation and rainfall deficiency.

7.12 Concentration of Sulphur (S) in the soils of the Attappady Hilly Region

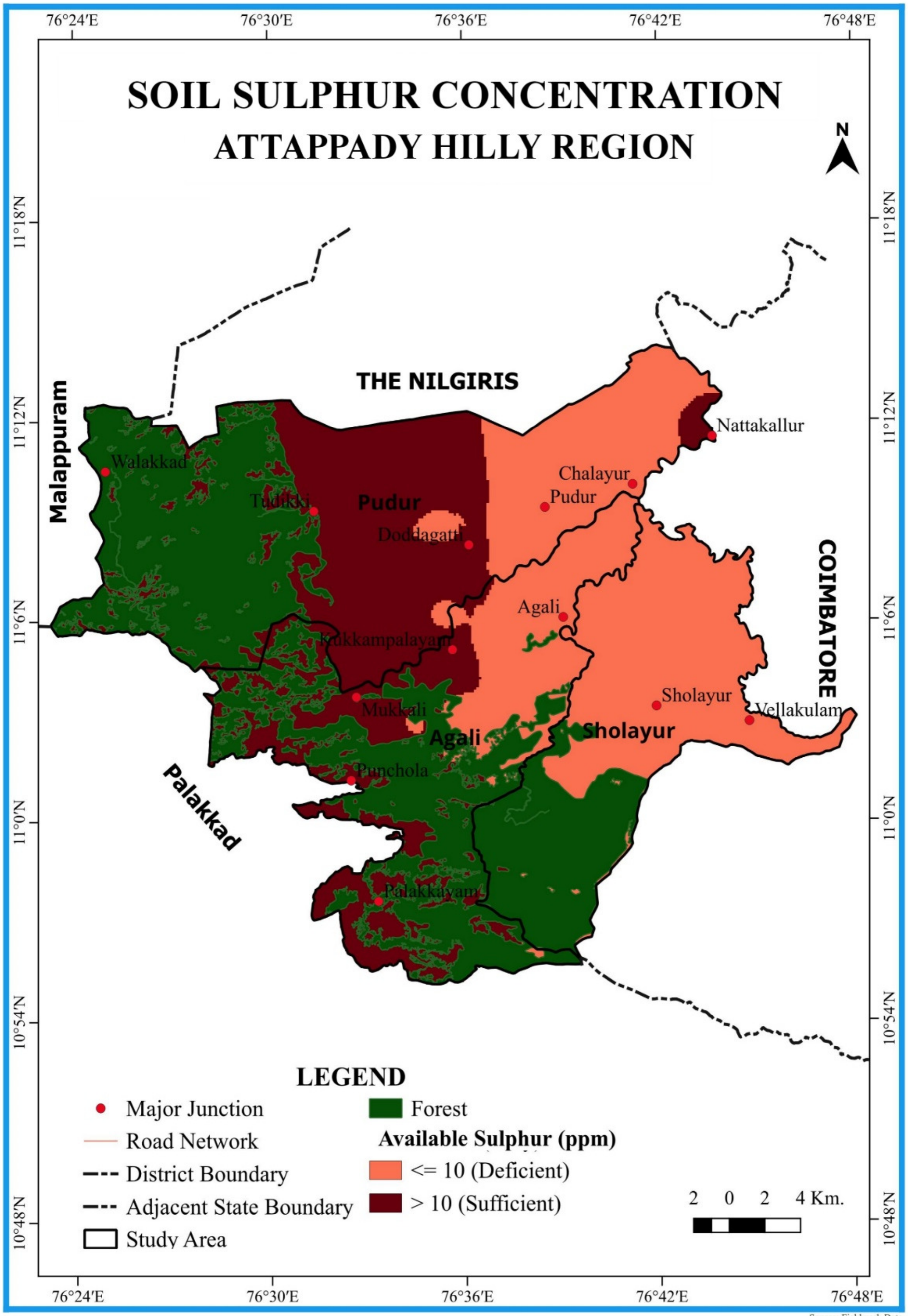
Sulphur content in soil is a critical determinant of soil quality and plant health, as sulphur is an essential macronutrient involved in protein synthesis, enzyme activation, and chlorophyll formation. Adequate sulphur levels enhance crop yield, improve quality, and support soil microbial activity. However, excessive sulphur can lead to soil acidification, negatively impacting soil structure, microbial communities, and plant growth, while sulphur deficiency can cause yellowing of leaves (chlorosis) and stunted growth in plants. Addressing sulphur imbalances requires soil testing and strategies like the application of sulphur fertilizers, organic amendments, and crop rotation with sulphur-accumulating plants. Rainfall deficiency can influence sulphur availability, as reduced precipitation limits organic matter decomposition and microbial activity, which are critical for sulphur cycling in soil.

Table 7.13: Available Sulphur (S) in the Attappady Hilly Region

Class	Class (ppm)	Area (ha)	Area in Percentage
Deficient	<10.0	16080.08	21.58 %
Sufficient	>10.0	6330.4	8.5 %

Source: BIS (Bureau of Indian Standards)

In the Attappady region, 22% of soils are deficient in sulphur (<10 ppm), while only 9% have sufficient levels (>10 ppm) (table 7.11). Agricultural lands, such as Padavayal and Tekkupana, generally exhibit higher sulphur levels due to fertilizer inputs and better organic matter management. In contrast, barren lands like Bhuthyur or areas with minimal vegetation suffer from low sulphur content due to soil erosion, lack of organic matter, and poor microbial activity. The rain shadow effect in Attappady exacerbates these issues, as limited



Source: Prepared by Researcher

Fig.7.10: Soil Sulphur concentration in the Attappady Hilly Region

rainfall reduces vegetation cover and impairs nutrient cycling, contributing to land degradation. To improve sulphur content and combat land degradation, sustainable practices such as organic matter incorporation, afforestation, and soil conservation are essential, especially in rain-shadowed regions like Attappady (Fig:7.10).

7.13 Concentration of Iron (Fe) in the soils of the Attappady Hilly Region

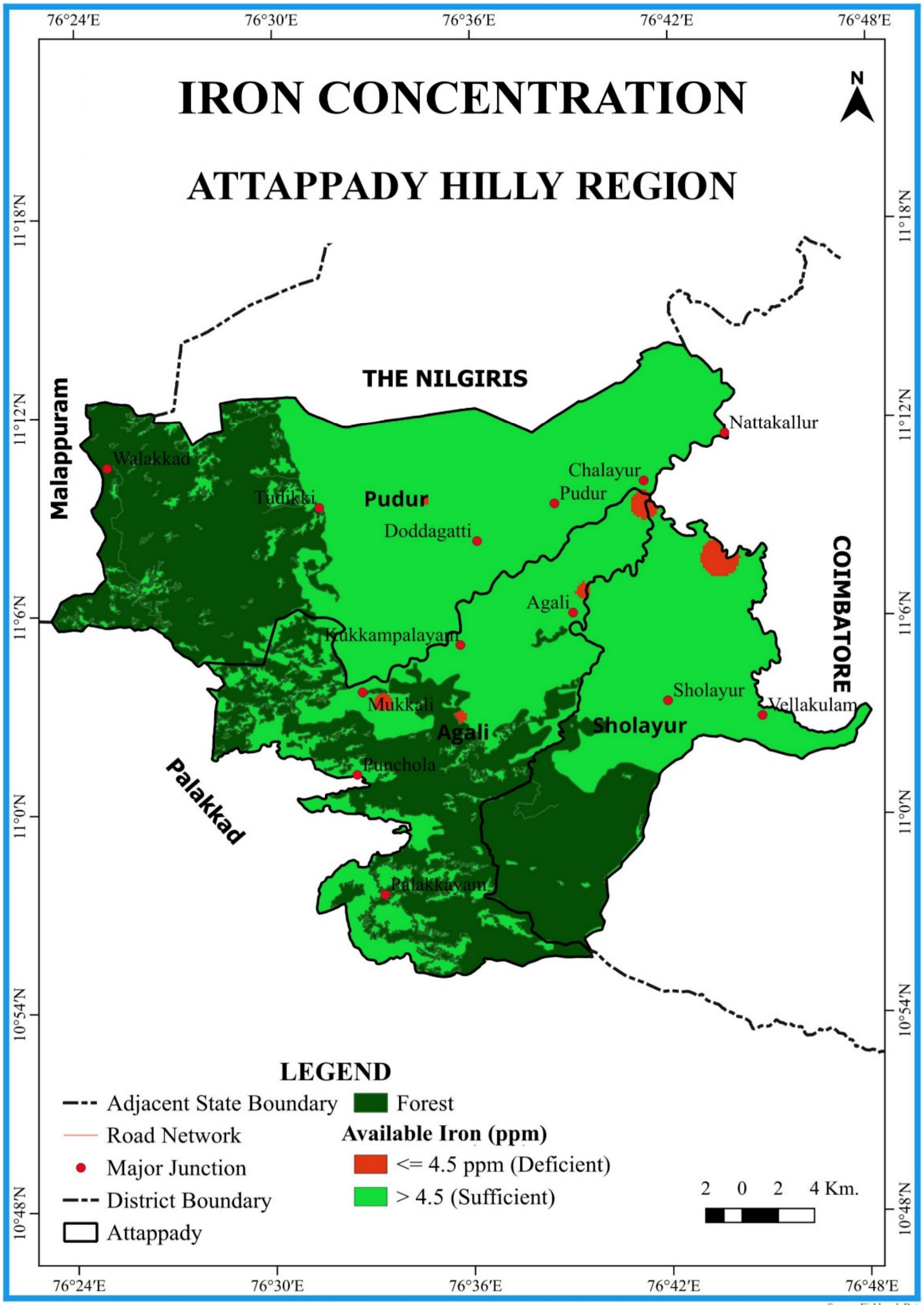
Iron content in soil is a crucial factor in determining soil quality and plant health, as iron is an essential micronutrient involved in chlorophyll synthesis, respiration, and various enzymatic processes. Adequate iron levels in soil promote healthy plant growth, increase resistance to stress, and support microbial activity. However, excessive iron can lead to toxicity, negatively affecting plant roots, reducing crop productivity, and disrupting soil microbial communities. On the other hand, iron deficiency can cause chlorosis (yellowing of leaves), stunted growth, and reduced photosynthetic efficiency, particularly in calcareous or alkaline soils. To mitigate iron imbalances, soil testing, the application of iron chelates, organic amendments, and proper pH management are effective strategies. Rainfall deficiency can influence iron availability, as reduced precipitation may limit leaching, leading to localized iron accumulations, or restrict plant uptake due to decreased organic matter and microbial activity.

Table 7.14: Available Iron (Fe) in the Attappady Hilly Region

Class	Class (ppm)	Area (ha)	Area in Percentage
Deficient	<4.5	576.54	0.77 %
Sufficient	>4.5	21833.94	29.3 %

Source: BIS (Bureau of Indian Standards)

In the Attappady region, 0.77% of soils exhibit iron deficiency (<4.5 ppm), while 29% have sufficient levels (>4.5 ppm) (table 7.12). Agricultural lands, such as those in Padavayal and Tekkupana, generally display higher iron content due to management practices and organic



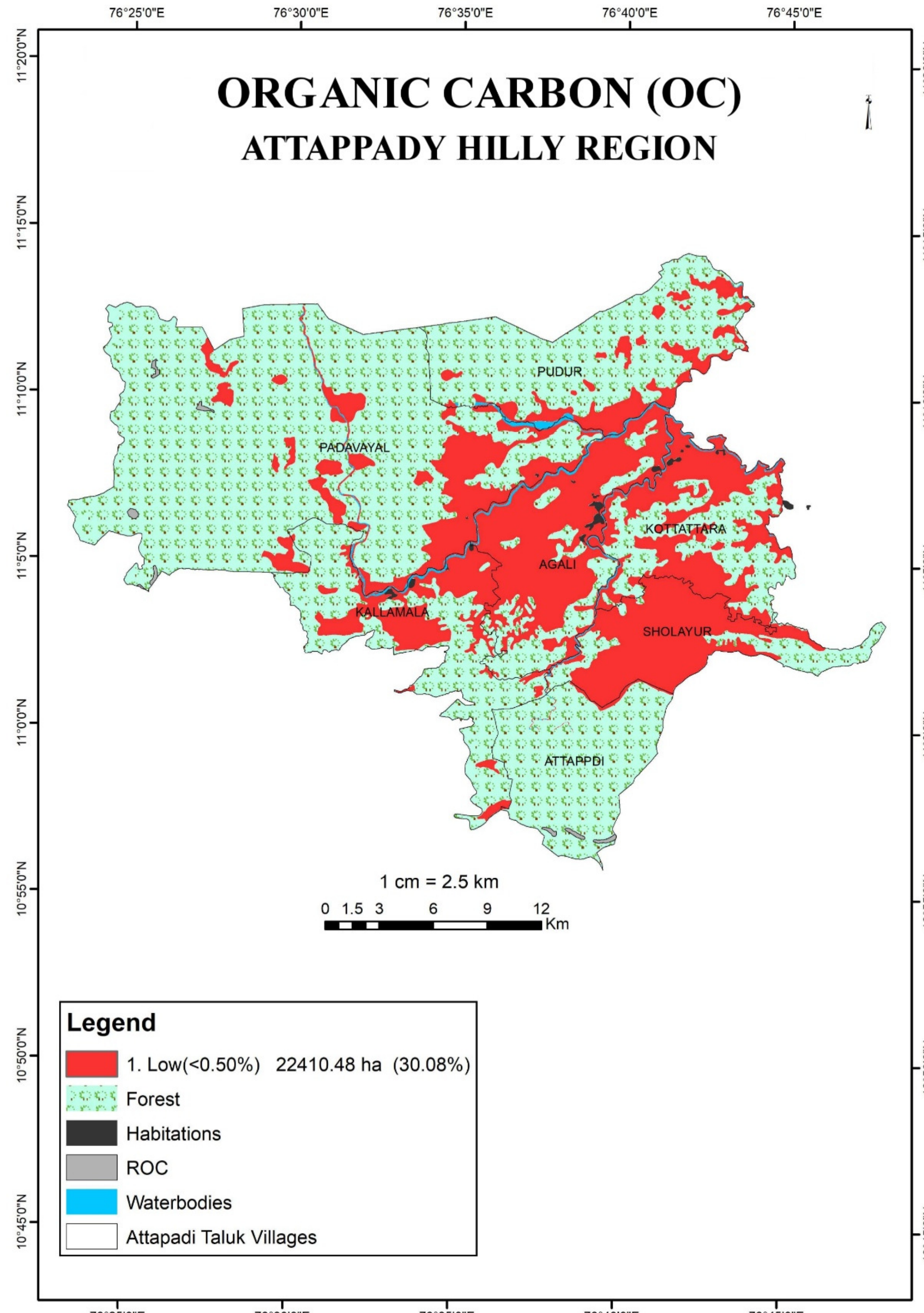
Source:Prepared by Researcher

Fig.7.11: Soil Iron concentration in the Attappady Hilly Region

inputs. In contrast, barren lands or sparsely vegetated areas like Bhuthyur often have lower iron availability due to erosion, minimal organic matter, and degraded soil conditions. The rain shadow effect further exacerbates these issues in Attappady by reducing vegetation cover and limiting the nutrient cycle, thereby contributing to soil degradation (Fig 7.11). To address these challenges, sustainable land management practices, reforestation, and the incorporation of organic matter are vital for maintaining balanced iron levels and mitigating the impacts of land degradation and rainfall deficiency in this region.

7.14 Concentration of Organic Carbon (OC) in the soils of the Attappady Hilly Region

The organic carbon is a measure of organic matter in the soil components. It makes up about 2 to 10% of most of the soil mass and plays a significant part in the physical, chemical and biological operations in the agricultural soils. The OC has the capacity of retaining plant nutrients, soil structure, soil moisture and so on (Jincy, 2019). Organic carbon content in soil is a vital determinant of soil quality and fertility, as it significantly influences the physical, chemical, and biological properties of the soil. High organic carbon content enhances soil fertility by improving the availability of essential nutrients like nitrogen, phosphorus, and potassium, while also increasing water retention capacity and fostering soil aggregation, which reduces erosion and compaction. Furthermore, it supports microbial biodiversity, which is crucial for soil health and ecosystem functions. However, excessive organic carbon levels can have drawbacks, including nutrient imbalances, reduced availability of nutrients to plants, potential greenhouse gas emissions during decomposition, and nutrient leaching in high-rainfall areas. Strategies to manage and optimize organic carbon include incorporating cover crops, applying organic amendments like compost, practicing conservation tillage, and maintaining diverse crop rotations to sustain soil organic matter. Additionally, organic carbon levels can be linked to rainfall patterns, as areas with deficient rainfall often have lower organic matter due to reduced vegetation and microbial activity.



Source: Prepared by Researcher

Fig. 7.12: Soil Organic carbon in the Attappady Hilly Region

In the Attappady region, 30.08% of soils exhibit low organic carbon content (<0.50%), which is influenced by factors such as land use, vegetation cover, and the rain shadow effect (Fig 7.12). Degraded lands with minimal vegetation or barren areas tend to have significantly reduced organic carbon, exacerbating land degradation in this rain-shadowed zone.

7.15 Concentration of Manganese (Mn) in the soils of the Attappady Hilly Region

Manganese (Mn) is an essential micronutrient in soil, critical for plant physiological processes such as photosynthesis, nitrogen assimilation, and enzyme activation. In Attappady, sufficient manganese levels (>2.0 ppm) are present in 30.08% of the area, predominantly in cultivated regions such as Padavayal (5.44 ppm) and Pazhayur (83.85 ppm), where soil organic matter and microbial activity enhance manganese availability. Conversely, barren and scrublands like Bhoothyvazhi (58.03 ppm) and Uthukuzhi (71.09 ppm) show uneven manganese distribution, likely due to limited organic matter and inconsistent mineral cycling (Fig 7.13). Rainfall deficiency in the region, exacerbated by the rain shadow effect, impacts manganese solubility and availability. While adequate manganese supports plant growth and nutrient uptake, excessive levels can cause toxicity, affecting plant health and soil microbial balance. Sustainable practices such as organic amendments, balanced fertilization, and erosion control are vital to maintain optimal manganese levels and address the challenges posed by land degradation and climatic variations.

7.16 Concentration of Calcium (Ca) in the soils of the Attappady Hilly Region

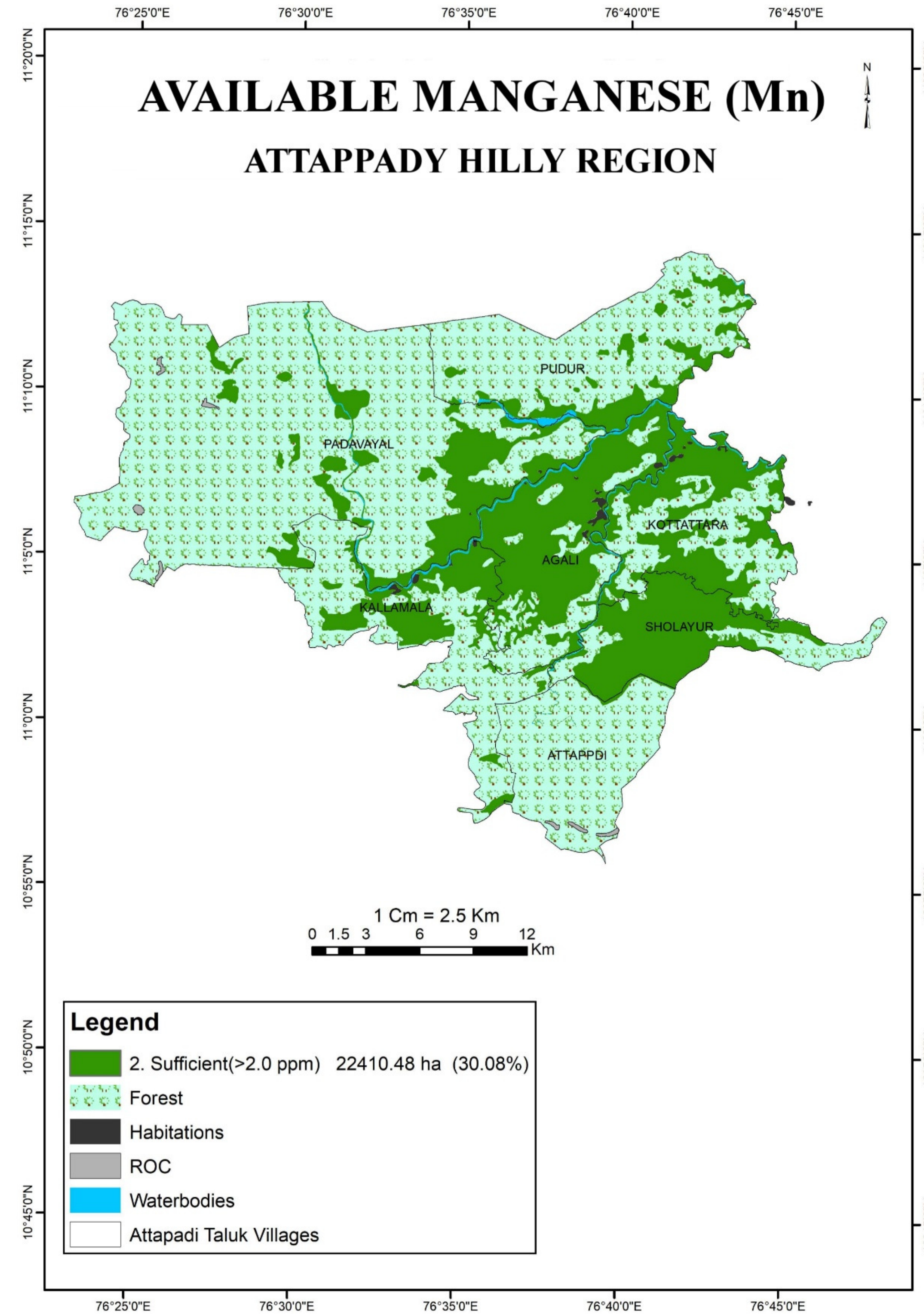
Calcium is an essential secondary macronutrient in soil, playing a crucial role in agricultural productivity and ecosystem health. It improves soil structure by enhancing aggregate formation, which increases water infiltration, retention, and aeration. Calcium aids in the neutralization of soil acidity, reducing toxicity from excess hydrogen ions and promoting a balanced pH for optimal nutrient availability. Furthermore, it supports plant growth by improving root and leaf development and facilitating the uptake of vital nutrients such as nitrogen, potassium, and magnesium. However, excessive calcium levels can lead to soil alkalinity, which may inhibit the availability of micronutrients like iron, zinc, and manganese, and can negatively impact certain crops adapted to acidic soils. Mitigating calcium imbalances involves practices such as using gypsum or lime amendments to manage deficiencies or applying organic matter and balanced fertilizers to counteract excess calcium. Rainfall deficiency and the rain shadow effect, as seen in areas like Attappady, can significantly influence calcium levels by limiting leaching processes, leading to accumulation in some regions and depletion in others, further contributing to land degradation.

Table 7.15: Available calcium (Ca) in the Attappady Hilly Region

Class	Class (ppm)	Area (ha)	Area in Percentage
Optimum Level	<1600 ppm	77746	94
High Calcium	>1600 ppm	5196	6

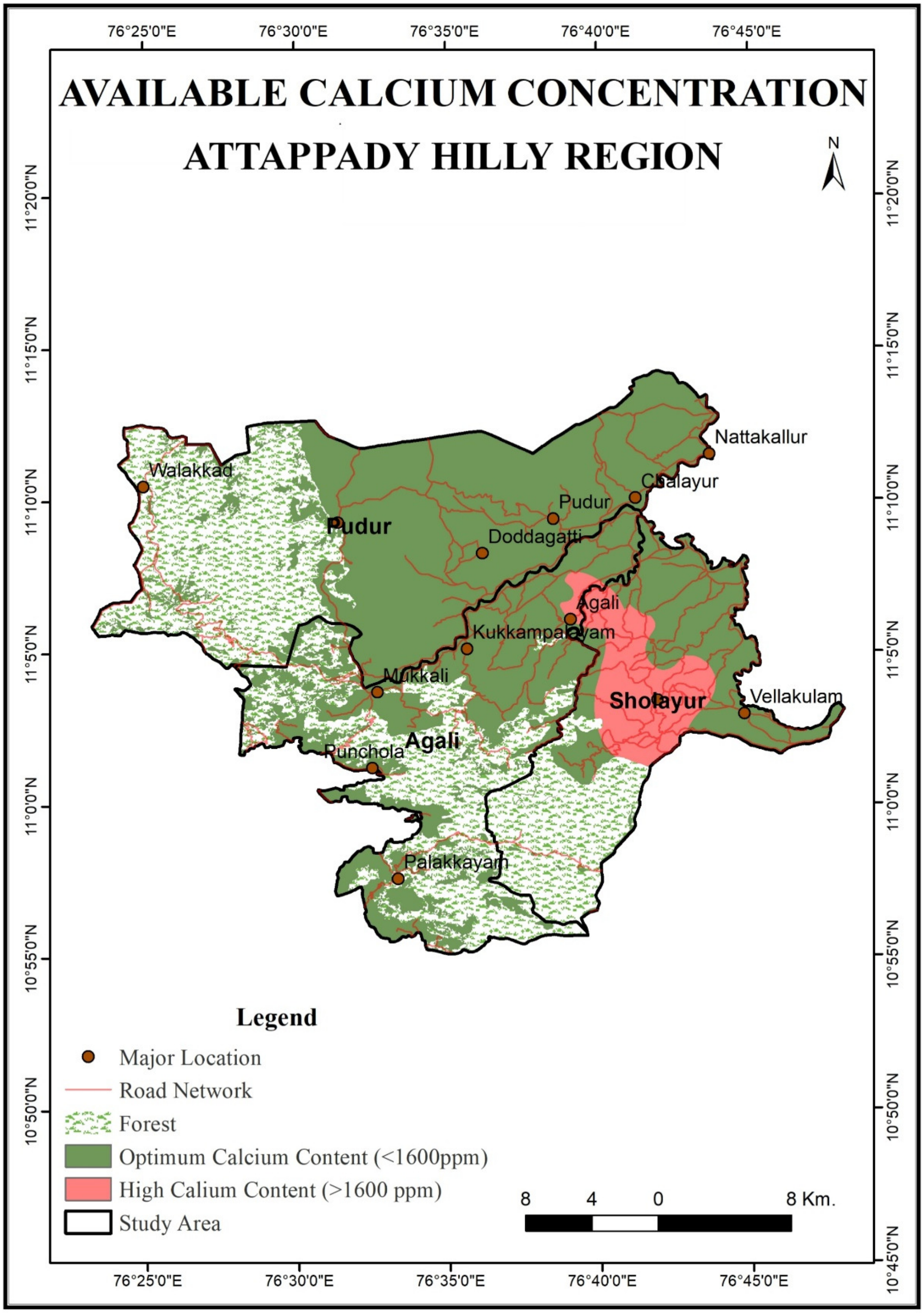
Source: BIS (Bureau of Indian Standards)

In Attappady, calcium (Ca) content in soil plays a significant role in determining soil quality and its suitability for agriculture. The study reveals that 94% of soil samples have calcium levels below the optimum threshold of 1600 ppm, indicating moderate fertility, while 6% exceed this threshold, potentially leading to nutrient imbalances (Fig.7.14). High calcium levels, as observed in locations like Bhoothvazhi built-up area (3136.75 ppm) and Sholayur (2011.38 ppm), are often linked to non-agricultural or degraded lands, reflecting limited leaching due to the rain shadow effect. Conversely, areas such as Nelliyapathy (789.13 ppm) and Mulli (620.25 ppm) exhibit lower calcium levels, likely influenced by moderate crop activity and rainfall facilitating nutrient utilization (table 7.13). Rainfall deficiency in the rain shadow region contributes to calcium accumulation, while heavy rains in other areas might deplete calcium through leaching. This dynamics highlight the interplay between calcium content, land use, and environmental factors, with high calcium levels correlating with land



Source: Prepared by Researcher

Fig.7.13: Soil Manganese concentration in the Attappady Hilly Region



Source:Prepared by Researcher

Fig.7.14: Soil Calcium concentration in the Attappady Hilly Region

degradation and limited agricultural productivity. Addressing these imbalances through soil management practices is essential to maintain soil health and ecosystem stability.

7.17 Concentration of Magnesium (Mg) in the soils of the Attappady Hilly Region

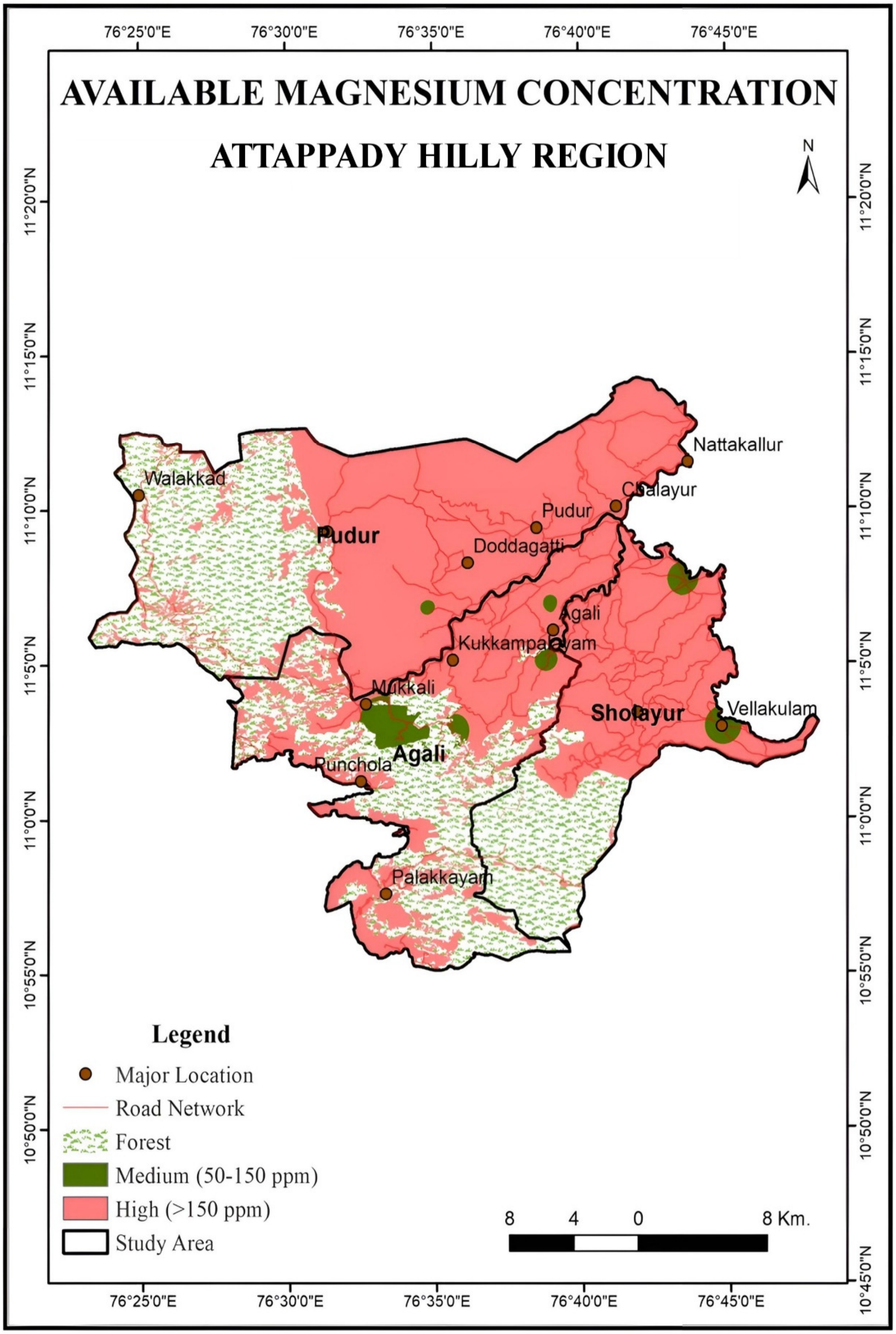
Magnesium is a vital secondary macronutrient in soil, essential for plant growth and ecosystem health. It is a key component of chlorophyll, playing a central role in photosynthesis, and it supports enzyme activation, energy transfer, and nutrient transport within plants. Magnesium also contributes to soil structure by promoting aggregate stability and improving cation exchange capacity. However, excessive magnesium levels can lead to soil compaction and poor drainage, while deficiencies can result in reduced chlorophyll production, stunted growth, and yellowing of leaves. Addressing magnesium imbalances involves practices such as applying dolomitic lime to correct deficiencies or using gypsum to displace excess magnesium. The availability of magnesium in soil is often influenced by factors like soil pH, organic matter content, and climatic conditions, particularly rainfall patterns.

Table 7.16: Available magnesium (Mg) in the Attappady Hilly Region

Class	Class (ppm)	Area (ha)	Area in Percentage
Moderate	50-150ppm	437	3
High	>150 ppm	80309	97

Source: BIS (Bureau of Indian Standards)

In Attappady, 97% of the soil samples have high magnesium levels (>150 ppm), while only 3% fall within the moderate range (50–150 ppm). Excess magnesium was particularly notable in locations such as Sholayur (611.58 ppm) and Padavayal (561.64 ppm), associated with non-agricultural or sparsely cultivated lands, indicating a correlation with the rain shadow effect and limited leaching (Fig.7.15). Conversely, areas like Vellakulam (75.83 ppm) and Kallamala (65.38 ppm) exhibit moderate levels, likely due to better crop activity and



Source:Prepared by Researcher

Fig.7.15: Soil Magnesium Concentration in the Attappady Hilly Region

balanced rainfall that supports magnesium utilization. While adequate magnesium levels improve photosynthesis, enzyme activation, and soil structure, excessive amounts can lead to soil compaction, reduced permeability, and nutrient imbalances, hindering plant growth. Rainfall deficiency exacerbates magnesium accumulation by limiting leaching, while heavy rains in certain regions may facilitate its depletion. Mitigating excess magnesium involves using calcium-rich amendments like gypsum to balance cation ratios or incorporating organic matter to improve soil structure. The observed high magnesium levels across Attappady, particularly in degraded lands, underscore the interplay between rainfall patterns, land use, and soil health, emphasizing the need to modify soil management practices to restore agricultural productivity and ecosystem stability.

7.18 Soil Quality Index (SQI) of the Attappady Hilly Region

Since soil quality cannot be measured directly, it is estimated using related soil properties and represented as the Soil Quality Index (SQI) (Abdu et al., 2023). The SQI is a composite metric that evaluates soil health by integrating various soil characteristics, offering a holistic view of soil quality essential for sustaining plant growth, water retention, and human needs (Jumiun et al., 2024; Nursita, 2020). Its main function is to provide a clear and thorough evaluation of soil conditions, aiding policymakers and land managers in making informed decisions about soil conservation and sustainable use (Shoumik et al., 2024; Adjekukor & O, 2024).

The SQI is a key instrument for evaluating soil health and functionality under different land uses and environmental settings. By combining multiple soil parameters such as pH, organic matter, phosphorus, potassium, and electrical conductivity it delivers a detailed assessment of soil quality, supporting sustainable agriculture and land management (Lat et al., 2024; Coelho et al., 2024). Depending on the study, additional indicators like soil texture, nitrogen levels, and microbial activity may be included to better represent soil health (Shoumik et al., 2024; Jumiun et al., 2024).

However, while the SQI is a valuable tool, it is important to account for the dynamic relationship between soil quality and environmental factors, such as climate change, which can alter soil conditions over time (Ennaji et al., 2024). In this research, the SQI was computed using 13 soil quality parameters collected from 28 locations in rain-shadow regions. Principal Component Analysis (PCA)-based SQI values were generated in R Studio using the SQICAL application, developed by Nishant Sinha in 2023.

7.19 Importance of Principal Component Analysis in Soil Quality Index Calculations

A statistics-based approach employing Principal Component Analysis (PCA) is widely used to estimate the Soil Quality Index (SQI) (Li et al., 2018; Mukherjee & Lal, 2014). This method enhances objectivity by utilizing statistical techniques such as multiple correlation, factor analysis, and variance decomposition, minimizing bias and redundancy through the selection of a Minimum Data Set (MDS) (Podwika et al., 2020). The PCA model incorporates all original observations of soil parameters, where Principal Components (PCs) with high eigenvalues capture the greatest variance in the dataset. Typically, only the "highly weighted" variables those with the strongest influence are retained in the MDS. These variables are defined as those with the highest factor loadings within a given PC or those within 10% of the highest loading value under the same PC (Podwika et al., 2020; Tesfahunegn, 2014). If multiple variables are retained under a single PC, a multivariate correlation matrix assesses their relationships. Parameters with strong correlations ($r > 0.70$) undergo further screening, where only the variable with the highest factor loading is kept in the MDS to prevent redundancy. However, if multiple uncorrelated variables with high loadings remain, a normalized PCA is applied (Podwika et al., 2020; Tesfahunegn, 2014). Each PC explains a portion of the total variance in the dataset. The weightage of a PC is determined by dividing its explained variance by the cumulative variance of all selected PCs (Podwika et al., 2020; Mukherjee & Lal, 2014). This PCA-based approach has been successfully applied in numerous soil quality studies, demonstrating its robustness across diverse environmental conditions.

7.20 Methodology of Principal Component Analysis in the Soil Quality Analysis of the Attappady Hilly Region

PCA is used to reduce large datasets into a smaller set of variables, known as the minimum data set (MDS), which are most indicative of soil quality. For instance, in Tieling County, China, PCA identified key indicators such as total potassium, clay, and soil organic matter, which were crucial for evaluating topsoil quality (Abdel-Fattah et al., 2021) (Abdu et al., 2023). PCA helps in calculating the SQI by assigning weights to selected indicators, which are then used to assess soil quality. In El-Fayoum, Egypt, PCA was used to determine relative weights and soil indicators, leading to the classification of soil into different quality zones (Qian et al., 2023). Studies have compared PCA with other methods like network analysis (NTA) and found that while PCA is effective, NTA can sometimes provide better differentiation of soil quality under different land uses (*Soil Quality Evaluation Based on A Minimum Data Set (MDS) A Case Study of Tieling County, Northeast China*, 2023).

The table 7.15 and table 7.16 presents the p-values at which correlations between 13 soil quality parameters pH, electrical conductivity (Ec), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), copper (Cu), iron (Fe), zinc (Zn), manganese (Mn), boron (B), and sulfur (S) are statistically significant, based on data collected from 28 locations in the rainshadow areas of Attappady, Palakkad district, for the purpose of calculating Principal Component Analysis (PCA) to determine the Soil Quality Index. A p-value less than 0.05 typically indicates a statistically significant correlation, meaning there is less than a 5% chance that the observed relationship occurred by random chance. In this table, several correlations stand out: for instance, pH shows a significant correlation with N (p=0.11) and P (p=0.47), but not with other parameters like Ca (p=0.04) or Mg (p=0.79), suggesting that pH variations may influence nitrogen and phosphorus levels to some extent, though the significance is borderline for N. Nitrogen (N) exhibits significant correlations with P (p=0.33), K (p=0.57), and Fe (p=0.58), indicating potential interdependencies among these nutrients in the soil. Potassium (K) and calcium (Ca) show a strong significant correlation (p=0.32), as do calcium and magnesium (p=0.00), highlighting a close relationship between these cations, likely due to their shared chemical behaviour in soil. Trace elements like copper (Cu) and iron (Fe) also show a significant correlation (p=0.55), suggesting possible interactions in their availability or uptake. However, many pairs, such as Ec with most parameters (all NA) and Mg with Mn (p=0.55), show no significant correlation, indicating that these parameters may vary independently in this region. Overall, the table reveals a complex web of relationships among soil quality parameters in Attappady, with significant correlations providing insights into nutrient interactions that can guide the PCA and subsequent Soil Quality Index calculation, while non-significant correlations suggest independent behaviour of certain parameters in this rain shadow ecosystem.

Table 7.17: Correlation Coefficient

	pH	Ec	N	P	K	Ca	Mg	Cu	Fe	Zn	Mn	B	S
pH	1.00	NA	-0.31	-0.14	-0.21	0.39	-0.05	-0.27	-0.25	-0.02	-0.01	-0.01	-0.33
Ec	NA	1.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
N	-0.31	NA	1.00	-0.19	0.11	0.25	0.49	0.05	0.11	0.01	-0.21	-0.10	0.01
P	-0.14	NA	-0.19	1.00	-0.02	-0.32	-0.35	-0.20	0.11	0.31	0.07	0.05	-0.12
K	-0.21	NA	0.11	-0.02	1.00	-0.19	0.01	-0.02	-0.26	-0.09	0.01	-0.19	-0.13
Ca	0.39	NA	0.25	-0.32	-0.19	1.00	0.70	-0.01	0.18	-0.04	-0.14	-0.20	-0.18
Mg	-0.05	NA	0.49	-0.35	0.01	0.70	1.00	0.16	0.33	0.13	-0.19	-0.20	0.01
Cu	-0.27	NA	0.05	-0.20	-0.02	-0.01	0.16	1.00	0.12	0.20	0.12	-0.10	0.25
Fe	-0.25	NA	0.11	0.11	-0.26	0.18	0.33	0.12	1.00	0.40	-0.02	-0.14	-0.29
Zn	-0.02	NA	0.01	0.31	-0.09	-0.04	0.13	0.20	0.40	1.00	-0.06	-0.21	-0.03
Mn	-0.01	NA	-0.21	0.07	0.01	-0.14	-0.19	0.12	-0.02	-0.06	1.00	-0.05	0.00
B	-0.01	NA	-0.10	0.05	-0.19	-0.20	-0.20	-0.10	-0.14	-0.21	-0.05	1.00	-0.09
S	-0.33	NA	0.01	-0.12	-0.13	-0.18	0.01	0.25	-0.29	-0.03	0.00	-0.09	1.00

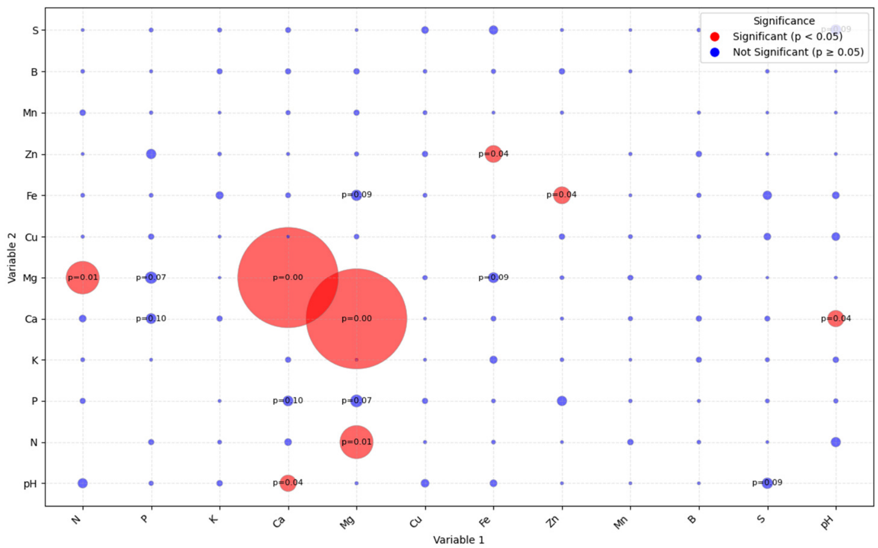
Source: Prepared by Researcher

Table 7.18: Value at which Correlation is Significant

	pH	Ec	N	P	K	Ca	Mg	Cu	Fe	Zn	Mn	B	S
pH	NA	NA	0.11	0.47	0.29	0.04	0.79	0.16	0.20	0.93	0.94	0.97	0.09
Ec	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
N	0.11	NA	NA	0.33	0.57	0.20	0.01	0.81	0.58	0.94	0.29	0.62	0.96
P	0.47	NA	0.33	NA	0.91	0.10	0.07	0.32	0.58	0.11	0.71	0.81	0.56
K	0.29	NA	0.57	0.91	NA	0.32	0.97	0.92	0.18	0.65	0.97	0.33	0.52
Ca	0.04	NA	0.20	0.10	0.32	NA	0.00	0.95	0.37	0.83	0.48	0.32	0.36
Mg	0.79	NA	0.01	0.07	0.97	0.00	NA	0.40	0.09	0.50	0.33	0.30	0.96
Cu	0.16	NA	0.81	0.32	0.92	0.95	0.40	NA	0.55	0.31	0.55	0.62	0.21
Fe	0.20	NA	0.58	0.58	0.18	0.37	0.09	0.55	NA	0.04	0.92	0.47	0.14
Zn	0.93	NA	0.94	0.11	0.65	0.83	0.50	0.31	0.04	NA	0.76	0.29	0.87
Mn	0.94	NA	0.29	0.71	0.97	0.48	0.33	0.55	0.92	0.76	NA	0.79	1.00
B	0.97	NA	0.62	0.81	0.33	0.32	0.30	0.62	0.47	0.29	0.79	NA	0.66
S	0.09	NA	0.96	0.56	0.52	0.36	0.96	0.21	0.14	0.87	1.00	0.66	NA

Source: Prepared by Researcher

The table 7.17 provided, though not explicitly shown, appears to be a Principal Component Analysis (PCA) output generated from a dataset comprising 13 soil quality parameters collected across 28 locations in the rain shadow areas of Attappady, Palakkad district. The PCA is a critical step in calculating the Soil Quality Index (SQI) for this region, reducing the dimensionality of the data while retaining significant variability to identify key soil quality indicators. The p-value in this context indicates the statistical significance of the correlations between these soil parameters and the principal components (PCs), typically considered significant at a threshold like $p < 0.05$ or $p < 0.01$, depending on the study's rigor. A low p-value suggests that the correlations between certain soil parameters (e.g., pH, organic carbon, nutrient levels) and the PCs are not due to random chance, highlighting their importance in explaining soil quality variations in Attappady's unique rain shadow environment. For instance, parameters with high factor loadings and significant p-values in the dominant PCs (those with eigenvalues > 1) likely reflect critical soil properties influenced by the region's arid conditions, such as water retention or nutrient availability, which are vital for agriculture in this drought-prone area. Conversely, parameters with non-significant p-values (e.g., $p > 0.05$) may indicate weaker or less consistent relationships with soil quality, potentially due to spatial heterogeneity across the 28 sampled locations. This interpretation underscores how the PCA table helps to distil complex soil data into meaningful components for SQI computation, tailored to Attappady's ecological challenges.



Source:Prepared by Researcher

Fig. 7.16: Correlation Significance Bubble Chart

Table 7.19: Principal Component Analysis Table Where Eigen Value is >1

	EigenValue	variancePercent	CumulativeVariancePercent
1	2.45	20.43	20.43
2	1.84	15.36	35.79
3	1.68	14.03	49.83
4	1.28	10.71	60.53
5	1.17	9.76	70.3

Source: Prepared by Researcher

Table 7.20: Weight Values of Respective Principal Components

	data
1	0.29
2	0.22
3	0.2
4	0.15
5	0.14

Source: Prepared by Researcher

The table 7.18 provided displays the weight values for the respective Principal Components (PCs) derived from a Principal Component Analysis (PCA) conducted on a dataset of 13 soil quality parameters collected from 28 locations in the Rain shadow areas of Attappady, Palakkad district, as part of calculating the Soil Quality Index (SQI) for the region. The weights assigned to the PCs reflect their relative contribution to explaining the variance in soil quality data, with PC1 having the highest weight of 0.29, followed by PC2 at 0.22, PC3 at 0.20, PC4 at 0.15, and PC5 at 0.14. These weights indicate that PC1 accounts for the largest proportion of variability (29%) in the soil quality parameters, likely capturing the most dominant soil characteristics, such as organic matter or pH, which are critical in the arid, rain shadow conditions of Attappady where water and nutrient availability are often limited. PC2 and PC3, with weights of 0.22 and 0.20 respectively, also contribute significantly, suggesting they represent other important but secondary factors, possibly related to soil texture or micronutrient levels, which further explain the variability across the 28 locations. The lower weights of PC4 (0.15) and PC5 (0.14) imply that these components capture less influential aspects of soil quality, potentially minor variations in less impactful parameters. Since the user previously mentioned the significance of correlations (p-values) in the PCA, these weights likely correspond to PCs where correlations between soil parameters and the components were statistically significant (e.g., $p < 0.05$), ensuring that only meaningful relationships are considered in the SQI calculation. Overall, this table highlights the hierarchical importance of the PCs in summarizing soil quality dynamics in Attappady, with the higher-weighted PCs being the most critical for understanding and addressing soil health challenges in this drought-prone region.

Table 7.21: Variable Selection (+/- of 10% of Max)

Principal_Component	Column	Variable	Column_For_Scoring	Value
Dim.2	2	pH	1	0.81
Dim.3	3	P	4	0.56
Dim.4	4	K	5	0.67
Dim.1	1	Mg	7	0.9
Dim.3	3	Fe	9	0.62
Dim.3	3	Zn	10	0.6
Dim.5	5	B	12	0.7

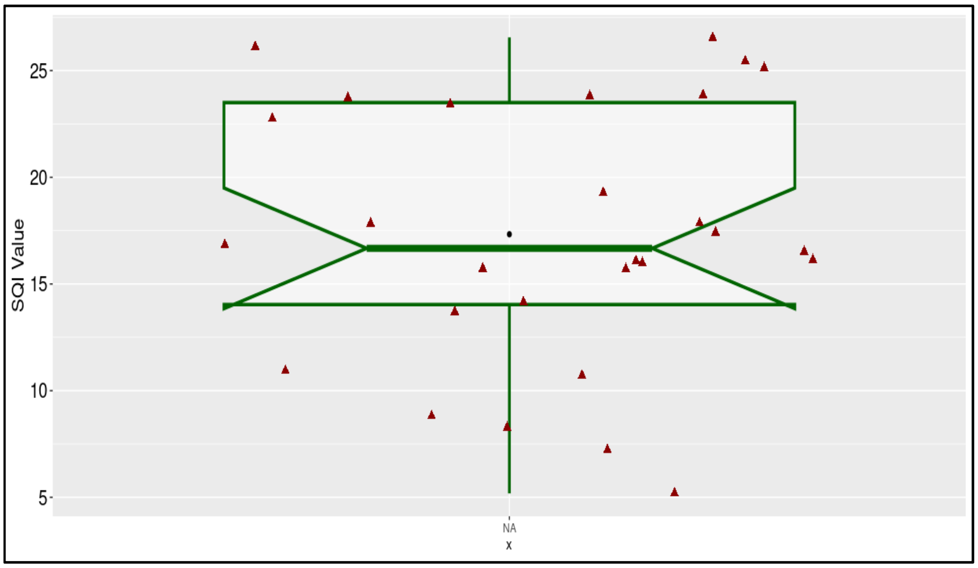
Source: Prepared by Researcher

The table (table 7.19) presents the results of variable selection for Principal Components (PCs) derived from a Principal Component Analysis (PCA) conducted on a dataset of 13 soil quality parameters collected from 28 locations in the rain shadow areas of Attappady, Palakkad district, as part of calculating the Soil Quality Index (SQI). The selection criterion, indicated as "+/- 10% of Max," suggests that variables were chosen based on their factor loadings, retaining those within 10% of the maximum loading value for each PC to identify the most influential soil parameters. The table lists the PCs (Dim.1 to Dim.5), the column numbers, the selected variables, the column numbers for scoring, and their corresponding loading values. For Dim.1, magnesium (Mg) has the highest loading at 0.9, indicating it strongly influences this component, likely reflecting its critical role in soil fertility in Attappady's arid conditions. Dim.2 highlights pH with a loading of 0.81, suggesting that soil acidity or alkalinity is a key factor in this component, which is vital for nutrient availability in rain shadow soils. Dim.3 identifies phosphorus (P), iron (Fe), and zinc (Zn) with loadings of

0.56, 0.62, and 0.6 respectively, pointing to the importance of these nutrients in explaining soil quality variations, possibly due to their impact on plant growth in nutrient-scarce environments. Dim.4 selects potassium (K) with a loading of 0.67, underscoring its relevance for soil health in this region, where potassium deficiency can limit crop productivity. Finally, Dim.5 identifies boron (B) with a loading of 0.7, indicating its role in this component, potentially linked to specific micronutrient dynamics in Attappady's soils. These selected variables, with their significant loadings, are likely those with statistically significant correlations (e.g., $p < 0.05$) as per the user's earlier mention of p-values, ensuring they meaningfully contribute to the SQI by capturing the most impactful soil quality factors in this drought-prone area.

7.21 Analysis of the Soil Quality Index at the Attappady Hilly Region

The graph (Fig 7.17) displays the Soil Quality Index (SQI) values for 28 locations in the rain shadow areas of Attappady, Palakkad district, plotted as a notched box plot with individual data points represented by red triangles. The SQI values, calculated using Principal Component Analysis (PCA) based on 13 soil quality parameters, range from approximately 5 to 25 on the y-axis. The box plot provides a visual summary of the distribution of SQI values across these locations. The median SQI value, indicated by the thick black line within the box, appears to be around 15, suggesting that half of the locations have an SQI below this value and half above. The interquartile range (IQR), represented by the box, spans roughly from 12 to 18, indicating that the middle 50% of the SQI values fall within this range, reflecting moderate variability in soil quality across Attappady. The notches around the median, which are narrow, suggest that the median SQI is statistically significant and not highly variable, implying a relatively consistent central tendency in soil quality. The whiskers extend to the minimum and maximum values within 1.5 times the IQR, showing the full range of SQI values from about 5 to 25. Notably, there are no outliers beyond the whiskers, indicating that all SQI values fall within an expected range without extreme deviations. The spread of the red triangles shows that while some locations have relatively low SQI values (around 5), likely indicating poorer soil quality due to factors like low nutrient availability or poor pH in this arid region, others have higher SQI values (up to 25), suggesting better soil conditions possibly due to higher levels of key parameters like magnesium or phosphorus, as identified in the earlier PCA variable selection. Overall, the graph reveals a diverse but not extreme range of soil quality in Attappady, with most locations clustering around a moderate SQI, reflecting the challenges of maintaining soil health in a rain shadow environment.



Source: Prepared by Researcher

Fig.7.17: Soil Quality Index of the Attappady Hilly Region

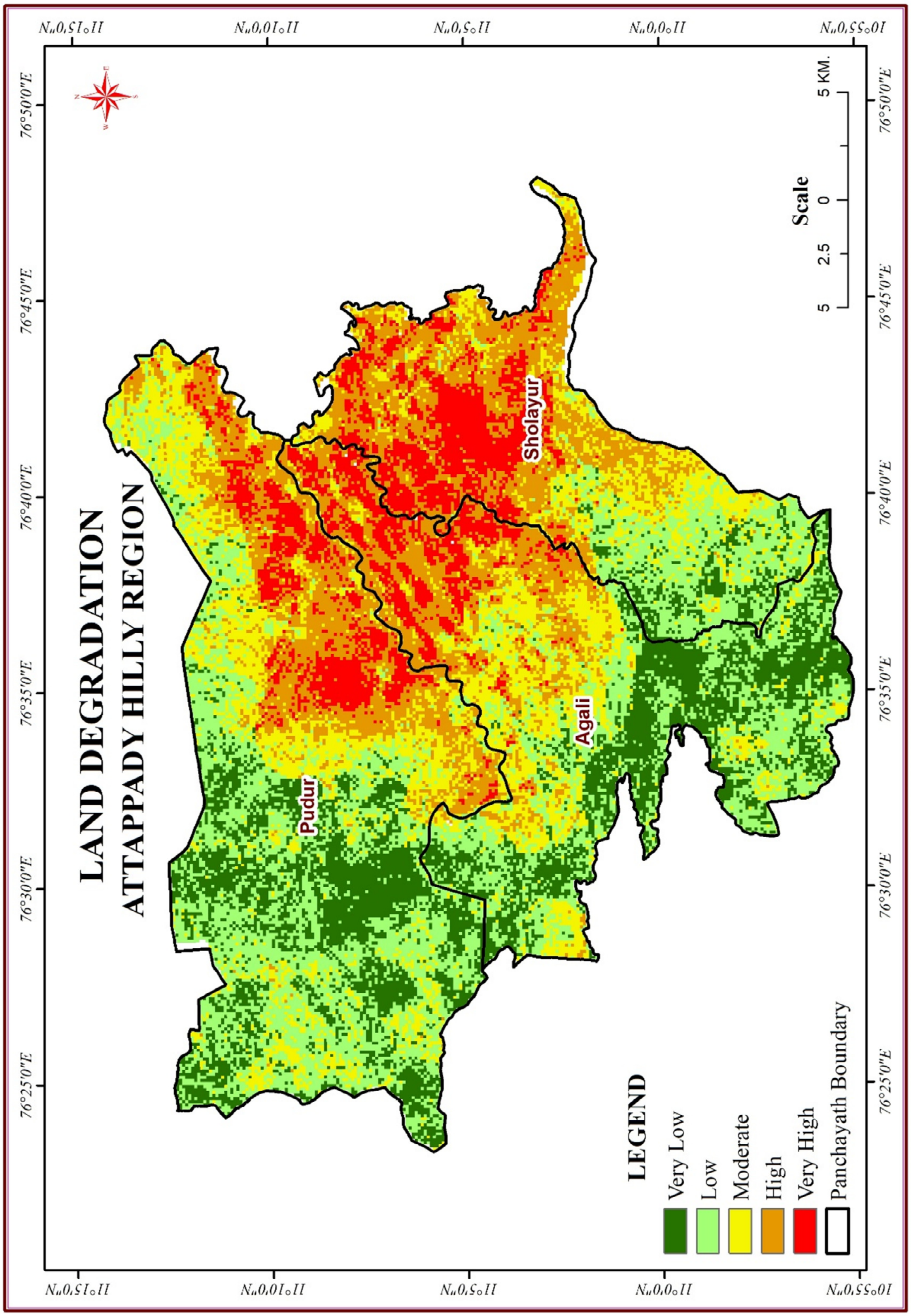
Table 7.22: Soil Quality Index of the Attappady Hilly Region

Sl.No	SQI Value	Area in Km^2	Area in %
1	Very Poor	21.31	2.57
2	Poor	109.20	13.16
3	Moderate	120.71	14.55
4	Good	531.08	64.03
5	Excellent	46.93	5.65

Source: Prepared by Researcher

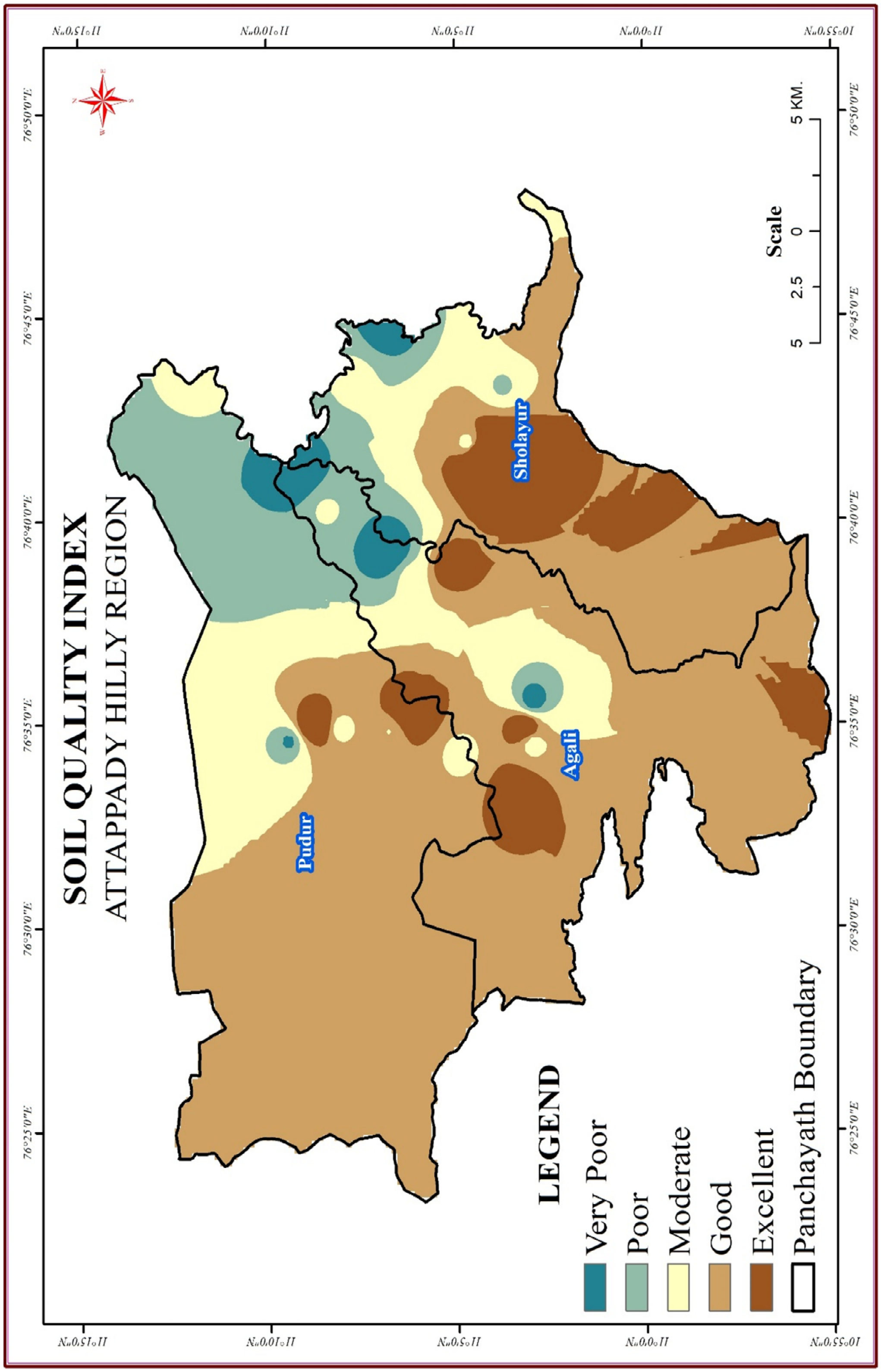
The Soil Quality Index (SQI) map for Attappady Taluk, derived from Principal Component Analysis of 13 soil quality parameters across 28 samples (Appendix.4), reveals significant spatial variation in soil quality, which is further interpreted by area statistics (table 7.20). The map (Fig 7.18) categorizes soil quality into five classes: Very Poor, Poor, Moderate, Good, and Excellent. Area-wise, the good category dominates, covering 531.08 km² (64.03% of the total 829.23 km²), primarily around Pudur in the northwest, indicating that the majority of the taluk has soil suitable for agriculture, as supported by SQI 19.29. The excellent category, with high SQI values of 26.56, spans 46.93 km² (5.65%), mostly near Pudur, reflecting optimal conditions with balanced nutrients and neutral pH. Moderate soil quality covers 120.71 km² (14.55%), seen around Agali and parts of Sholayur, with samples like Sample 5 (15.97) showing average fertility but often limited by low phosphorus and micronutrients. Poor soil quality occupies 109.20 km² (13.16%), in light brown around Sholayur and Agali, with samples like Sample 21 (14.14) indicating deficiencies in potassium and micronutrients. The very poor category, with the lowest SQI values like Sample 13 (5.19), covers just 21.31 km² (2.57%), concentrated in dark brown patches around Sholayur and Agali, where high pH and severe nutrient deficiencies pose significant challenges. Overall, while most of Attappady Taluk benefits from good soil quality, targeted interventions like nutrient supplementation and pH adjustment are crucial for the 15.73% of the area (very poor and poor) to enhance agricultural productivity, particularly in Sholayur and Agali.

In Attappadi taluk, the health of the land and the quality of its soil are deeply intertwined, as revealed by the maps (Fig 7.19 and Fig 7.20) and data (table 7.21). Where the soil struggles classified as very poor (16 % of the area) the land bears the scars of high degradation (29%), with erosion and loss of fertility leaving it vulnerable. Meanwhile, moderately healthy soils (15%) face moderate degradation (28%), holding on but still at risk.



Source: Prepared by Researcher

Fig.7.18: Land Degradation Map of the Attappady Hilly Region



Source: Prepared by Researcher

Fig.7.19: Soil Quality Index Map of the Attappady Hilly Region

The brighter spots are areas with good soil quality (70%), where the land remains more resilient, suffering only low degradation (43%). But nature hasn't made it easy for Attappadi. Enveloped in the rain shadow of the Western Ghats, the region is starved of rainfall, with dry winds stripping moisture from the land. This harsh reality makes it harder for the soil to recover, leaving it brittle and less fertile. Without enough water, vegetation struggles to grow, exposing the earth to further damage. The rain shadow effect silently worsens the cycle where soil quality dips, degradation follows.

Table 7.23: Soil Quality Index and Land Degradation for the Attappady Hilly Region

Sl.No	SQI Index	Land Degradation
1	Very Poor Soil Quality (2.57%)	Very High Land Degradation (11.34%)
2	Poor Soil Quality (13.16%)	High Land Degradation (18.05%)
3	Moderate Soil Quality (14.55%)	Moderate Land Degradation (27.92%)
4	Good Soil Quality (64.03%)	Low Land Degradation (27.92%)
5	Excellent Good Soil Quality (5.65%)	Very Low Land Degradation (15.58%)

Source: Prepared by Researcher

7.22 Conclusion

Soil quality is a fundamental pillar of agricultural productivity and environmental health, reflecting the intricate balance of physical, chemical, and biological properties that sustain ecosystems. In Attappady, a rain-shadow region of Kerala, soil degradation has emerged as a critical challenge due to climatic constraints and unsustainable land use practices. The Western Ghats block monsoon rains, creating arid conditions that reduce soil moisture, accelerate erosion, and deplete vital nutrients. This study evaluated soil quality across 28 locations, analyzing key indicators such as pH, electrical conductivity (EC), macronutrients (nitrogen, phosphorus, potassium), micronutrients (zinc, boron, iron), and organic carbon. The findings reveal a clear link between land degradation and declining soil health, with human activities like deforestation and intensive farming accelerate the region's vulnerability.

The methodology in this analysis combined field sampling with laboratory analysis to assess soil properties, followed by Principal Component Analysis (PCA) to compute the Soil Quality Index (SQI). The SQI, derived from 13 weighted parameters, categorized soils into five classes: very poor (5–10), poor (10–15), moderate (15–20), good (20–25), and excellent (>25). Results showed significant spatial variation, with western Attappady (e.g., Padavayal) exhibiting moderate-to-good SQI due to better nutrient retention and organic matter, while eastern zones (e.g., Bhuthyur) scored poorly due to severe deficiencies and high alkalinity. The SQI effectively captured the impact of land degradation, with lower values correlating strongly with erosion, compaction, and loss of microbial activity.

Land degradation in Attappady is both a cause and consequence of poor soil quality. The rain-shadow effect reduces vegetation cover, leaving soils exposed to wind and water erosion, while unsustainable agriculture depletes nutrients and organic carbon. Areas with very poor SQI (17% of the region) coincided with high degradation (28%), where soil structure and fertility were critically compromised. Conversely, regions with good SQI (64%) showed lower degradation, emphasizing the protective role of healthy soils. The PCA-based SQI model highlighted magnesium (Mg), pH, and phosphorus (P) as dominant factors, suggesting these parameters should be prioritized in restoration efforts.

The analysis also envisaged the urgent need for targeted soil conservation strategies in rain-shadow regions of Attappady. Practices such as organic amendments, agroforestry, and precision nutrient management could restore degraded soils, while government initiatives like the Soil Health Card Scheme can help monitor progress. By addressing the root causes of land degradation erosion, nutrient depletion, and poor land use Attappady can enhance its agricultural resilience and long-term sustainability.

CHAPTER 8

LIVELIHOOD DYNAMICS AND CHALLENGES OF THE RAIN SHADOW AFFECTED AREAS AT THE ATTAPPADY HILLY REGION

CHAPTER 8

LIVELIHOOD DYNAMICS AND CHALLENGES OF THE RAIN SHADOW AFFECTED AREAS AT THE ATTAPPADY HILLY REGION

8.1 Introduction

Rural livelihoods are increasingly challenged by the dual threats of land degradation and climate change. In arid and semiarid areas, land degradation results mainly from climate variations and human activity (Archer & Schimel 1995 and Tucker &. Nicholson 1997). Climate change can intensify existing land degradation processes and often leads to a loss of soil organic carbon, which negatively impacts both land productivity and its function as a carbon sink. Globally, rural livelihoods are increasingly confronted by the land degradation and climate change. The land degradation is believed to be severe where climate change will bring higher temperatures and shifts in rainfall. (Maia Call et.al 2020). In arid and semiarid areas, land degradation results mainly from climate variations and human activity (Archer &Schimel 1995 and Tucker &. Nicholson 1997). The livelihood conditions of the people of Attappady are tightly linked to its climatic and environmental factors. This part evaluates the livelihood scenario of the people of the rain shadow effected region through direct field level study. Attappady hilly region straddling the ecological divide between the region of orographic precipitation to the west and the rain shadow to the east. The rain shadow effect significantly influences rural livelihoods, especially in areas where agriculture is the main economic activity. In these regions, rural populations are often heavily dependent on rain-fed agriculture, making them vulnerable to climate variability. This variability, particularly changes in rainfall patterns creates most pervasive stresses on rural communities of this region. Reduced rainfall leads to a decrease in soil moisture content, which in turn results in lower crop yields and reduced net revenues for farmers. The effects of diminished rainfall can be particularly severe, as the majority of rural populations in these areas rely on agriculture for their livelihood. As a consequence, lower crop yields and economic losses increase household vulnerability, making the region's farmers more susceptible to food shortages and economic hardship. The current chapter address the perception level and awareness of the native communities in the Attappady hilly region about rain shadow induced livelihood issues. Perhaps first-hand information about the intensity and severity of the disaster of the affected people is a pivotal component in the success and failure of the implementation remedial measures. Hence following sessions provide a clear picture about the adverse effects faced by people of Attappady hilly region due to the rain shadow induced land degradation and also give the insights about their adaptive measures.

8.2 Conceptual Understanding of Livelihood and Climate Induced Land Degradation of the Attappady Hilly Region

Rain shadow areas, characterized by reduced rainfall due to mountains blocking moisture-laden winds, can significantly contribute to significant reduction of the productive capacity of land. The climate in these regions strongly influences vegetation type, biomass, and biodiversity. High temperatures and low precipitation in drylands reduce organic matter production and accelerate its oxidation. Low organic matter leads to poor soil aggregation and stability, making these areas highly vulnerable to wind and water erosion (Sivakumar & Stefanski, 2007). The scarcity of rainfall in rain shadow regions often results in poor soil structure, reduced vegetation cover, and increased erosion potential (Sabová et al., 2022; Ratan & Priya, 2021). Rainfall patterns play a critical role in driving soil erosion, particularly water erosion, which affects soil properties and infiltration rates (Yujie et al., 2019). Moreover, rapid population growth and in-migration in this region have further exacerbated land degradation, which has forced indigenous communities to diversify their livelihoods, often resulting in socio-economic marginalization (Manikkandan & Kurian, 2016).As climate exerts a strong influence over the soil, crops, vegetation type, biomass and diversity especially in the area having low rainfall and high temperature region, it also leads to poor organic matter production (Sivakumar &Stefanski 2007). Climate change affects the productive capacity of the land and leads to land degradation (Henry 2007)

Land degradation is a complex process resulting from both anthropogenic activities and climatic factors. It is a process of decreasing land productivity, and deteriorating the characteristic of usable land, converting suitable land to unsuitable and unfertile land for humankind and destroying the soil ecosystem, (Hill et al. 2005, Naseer and Pandey 2018). It means that a significant reduction of the productive capacity of land (Zhihui Li et.al 2014) and is a complex process which involves both the natural ecosystem and the socioeconomic system and become a critical issue at local, regional, and global scales (Kosmas et al., 2014) especially in the developing countries like India. In agricultural communities, land degradation further heightens the vulnerability of farmers, making it more difficult for them to maintain food security. The negative impacts of land degradation are difficult to quantify, as they involve multiple interrelated factors, but they often lead to a significant decline in the overall productivity of natural resources. Studying land degradation in Attappady, is crucial for understanding its effects on rural livelihoods. Also, climate change has exacerbated land degradation along the mountain gradient in Attappady, and further accelerating the loss of soil organic carbon, which diminishes soil quality and productivity of this region. (Manikandan et al., 2016). The degradation of land led to a decline in agricultural productivity in Attappady. Traditional food crops of the region are being replaced by cash crops, which has resulted in nutritional insecurity among the tribal populations. The economic pressures resulting from reduced agricultural productivity often led to changes in land use. The conversion of land for agriculture, coupled with the loss of forest cover, leads to increased vulnerability to erosion and landslides. The degradation of land in Attappady has profound socioeconomic implications for local communities. Many residents rely on agriculture for their livelihoods, and declining soil health directly affects their income and food security (Kemalo Abdulmalik and Israel Zewide, 2021). As the capacity of the land to support traditional agricultural practices diminishes, communities may face increased poverty, increased malnutrition among tribal populations which culminated in infant deaths, and migration pressures as individuals seek alternative livelihoods elsewhere (Manikandan, 2016). The land degradation further exacerbates social inequalities and increased difficulties in accessing resources, education, and healthcare again entrenching poverty within these communities.

In Attappady land degradation is an imperceptible process and more people are not aware that their land is degrading. Climate change over the Attappady mountain gradient has had severe impacts on land degradation. The deforestation, shifting cultivation, and loss of fertile land have resulted in soil moisture stress, water stress, and ecological degradation. This degradation has made a pressing issue on extreme socio-economic marginalization of the indigenous people in Attappady. The rain shadow effect, along with land degradation, poses a serious threat to rural communities, impacting both their livelihoods and long-term sustainability. The combination of reduced rainfall and land degradation makes these communities highly vulnerable to food insecurity and economic instability (Gina Ziervogel and Rebecca Calder, 2003). The main objective of this study is to analyse people's perception and knowledge on the impact of rain shadow induced land degradation on agricultural land productivity and their livelihood status. People perception refers to the way in which something is regarded, understood and interpreted by people. Perception strongly influences how farmers deal with climate induced risks and opportunities (Adger 2009) and also influence whether and to what extent farmers perceive climate change and its impact on local agriculture (Deressa et al. 2011). The farming experience of a subsistence farmer and their accumulated knowledge of the environment especially, changes in climatic conditions also affects their perception level

(Juana et al. 2013). It is essential for the use of local community knowledge in elucidating the root causes and effects of land degradation from local community knowledge and adopting strategies for designing and promoting sustainable land management practices. (Tesfaye Samuel Saguye 2017). This study attempted to analysis the perception of the people on the impact of rain shadow induced land degradation on agricultural land productivity and on socio-economic condition of the people who are mainly dependent on rainfed agriculture in the rain shadow region of the Attappady of Palakkad District.

8.3 Materials and Method of the Study of the Attappady Hilly Region

This study was carried out in the three panchayats, namely Agali, Pudur and Sholayur of the Attappady taluk. The main objective of this study is to analyze the perception of people on the impact of rain shadow induced land degradation on agricultural land productivity decline, and its effects on people's livelihood. The relevant data to this study were collected from the field survey by using various primary data collection techniques and tools. The primary data covered the demographic, socioeconomic, climatic, land degradational and agricultural attributes of the study area. The data also include the information about farmers' perception on the impact of rain shadow induced land degradation hazard on agricultural land productivity. Survey questionnaires, focus group discussion, interviews and field observation methods were employed in this study. Household-level data were collected through an open and close-ended survey questionnaire and covered detailed information of demographic and socio-economic characteristics, agriculture status, and impact of rain shadow effects on land degradation and agriculture, people's perceptions and attitudes on the impacts of rain shadow induced land degradation on agricultural productivity and yield. The questionnaire was pre-tested by administering it to selected fifty respondents. On the basis of the results obtained from the pretest, necessary modifications were made on the questionnaire and interviews were also carried out to substantiate the responses acquired using the questionnaire. The primary data from the field survey were supplemented with data obtained from secondary sources.

This study used a multistage sampling procedure to select household samples. In the first stage, the study area was classified into three panchayats, namely Agali, Pudur and Scholayur and in the second stage, from each panchayat, samples were selected by proportionate simple random sampling method to represent the people's perception on the impact of rain shadow induced land degradation on the agricultural land productivity and livelihood aspects of the study area. For the grass root level examination, 384 households, including marginal, small and larger famers are randomly drawn from three panchayats on the basis of probability proportional to size (PPS) sampling procedure. Out of the 384 households, 209 (54.4%) samples collected from Agali panchayat which includes 100 samples from ST, 30 from SC, 56 from OBC and 23 samples from General category. From Pudur panchayat, 73 (19%) samples were collected for the study which includes 41 samples from ST, 8 from SC, 22 from OBC and 2 samples from General category. In the Sholayur panchayat, samples size was 102 (26.6%) which included 38 samples from ST, 25 from SC, 29 from OBC and 10 samples from General category. The samples details are given in the table No.8.1 and figure No.8.1. The sample size of the study was based on Cochran sample size determination method. (Cochran 1977). The sample size calculation steps are given below;

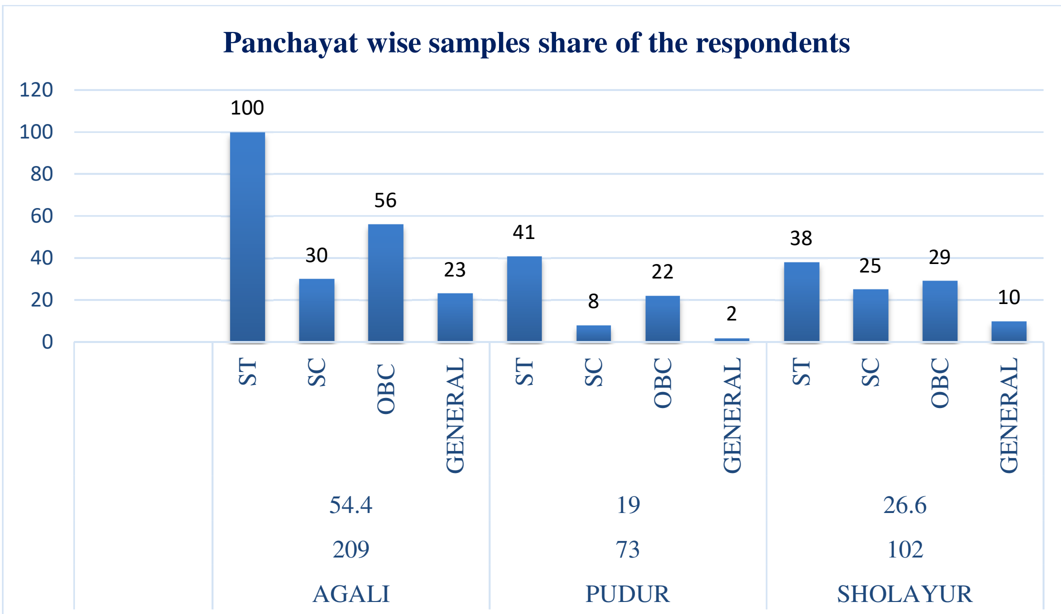
$$no = z^{2}\,{}^{pq}/_{e^2}$$

p=0-.5 and hence q =1-0.5= 0.5; e=0.05; z=1.96

So, no = $(1.96)^2$ (0.5) (0.5) / $(0.05)^2$ =384.16 = 384

Source: Cochran (1977)

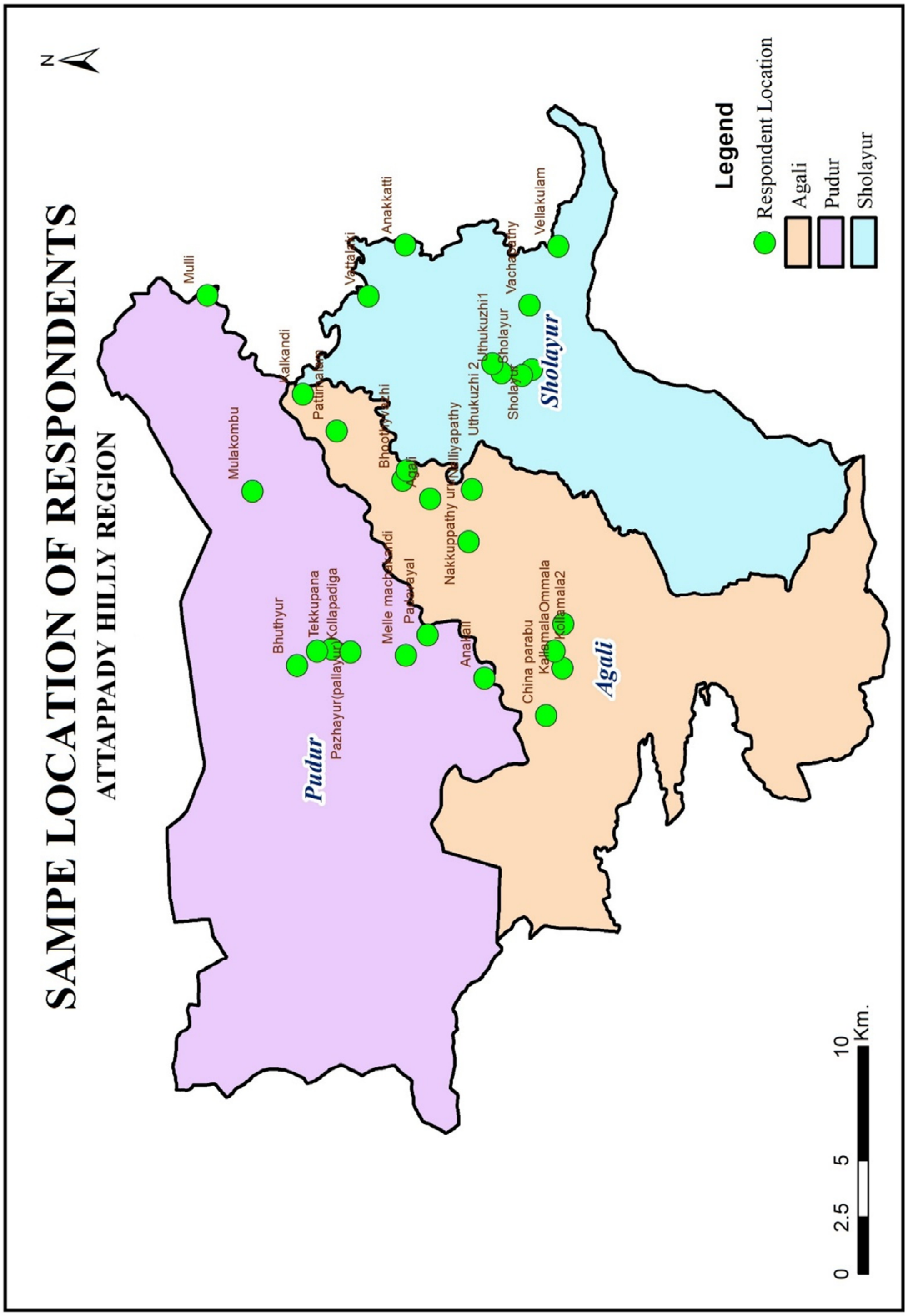
where, *n0* is the sample size, *z* is the selected critical value of desired confidence level, *p* is the estimated proportion of an attribute that is present in the population, $q\ p = -1$ and *e* is the desired level of precision. p = 0.5 and hence q =1-0.5 = 0.5; e = 0.05; z =1.96, the sample size, therefore, 384. The study employed a combination of both descriptive and inferential statistics to analyze data collected from the respondents. Trun statistical analysis, data was coded and entered into SPSS version 26.



Source: Prepared by Researcher

Fig. 8.1: Panchayat wise Sample share of the respondents of Attappady Hilly Region

Focus Group Discussions: The Focus Group Discussions (FGD) are conducted in order to get some in-detail information on people's perceptions and attitudes on the impacts of rain shadow induced land degradation on agricultural productivity and yield and their consequences. In this study, prior to the household survey, six focus group discussions were conducted, each group consist six people consists of male and females who were selected randomly from the study area. The selection of the people for focused group discussion was based on more than twenty years of the farming experience. The discussion with male and female were mostly done in the afternoon due to their time of availability. The goal of the FGD in this study is to examine the vital role of the topo climate and its impact on the livelihood of the common people through



Source: Prepared by Researcher

Fig. 8.2: Sample location of respondents of the Attappady Hilly Region

Table 8.1: Panchayat Wise Sample Share of the respondents of the Attappady Hilly Region

Panchayat	Samples	%	Category	Samples	Farming Land size (Acres)						
					Marginal Farmer		Small farmer			Large farmer	Not cultivating
					1	2	3	4	5	6	
AGALI	209	54.4	ST	100	11	15	30	2	0	0	42
			SC	30	2	1	5	0	0	0	22
			OBC	56	6	7	25	6	1	4	7
			GENERAL	23	1	0	6	9	4	3	0
PUDUR	73	19.0	ST	41	7	18	5	1	0	0	10
			SC	8	1	4	1	0	0	0	2
			OBC	22	4	10	5	2	1	0	0
			GENERAL	2	0	0	0	1	1	0	0
SHOLAYUR	102	26.6	ST	38	10	5	16	2	0	0	5
			SC	25	7	12	3	3	0	0	0
			OBC	29	4	11	10	0	0	2	2
			GENERAL	10	1	2	5	0	0	2	0
TOTAL	**384**	**100**									

Source: Prepared by Researcher

with their cropping strategies. The first and second focused group discussions were conducted from Agali, three and fourth group discussions from Pudur and fifth and sixth focus group discussions were conducted from Sholayur panchayat respectively.

Steps followed for focused group discussion were

- ❖ Identifying the type of respondents required as per the study based on their farming experience (minimum 20 years)
- ❖ Investigator has been acted as moderator of the discussion
- ❖ Investigator presented the aim and purpose of discussion to the groups
- ❖ Conducted focused group discussion
- ❖ Transcribed, analysed and interpreted responses.

Here the researcher also used a checklist of topics to guide the group discussion in an orderly and effective way. These qualitative techniques helped to acquire useful and detailed information, which would have been difficult to collect through the interview schedule. Focused group discussion with people of Attappady (2024)

Field Observation: Field Observation are conducted through transect walk with the local communities in order to get some in-detail information about the impact of rain shadow effect on land degradation and primary activities. They were conducted twice in a year, before the S.W monsoon period (April and May) and after S.W monsoon period (November and December) for three years from 2021 to 2024. In each field observation, collected detail information about nature of rainfall pattern and temperature distribution, influence of the physical barriers (hills) on climate, types of the natural vegetation, soil quality change, land use changes, source of water for agriculture, nature of agricultural practices, types of crops grown, crop conversion and farm soil conservation measures in order to ensure the validity of information obtained from the farmers and non-farmers through interview schedule and focused group discussion. This helped to capture more information that were not clearly obtained from the interview. Therefore, field observations ensured that the validity of information obtained from the farmers and non-farmers through interview schedule and focused group discussion are correct and true. Information is obtained through field observation to understand the land use changes, soil types and general vegetation type of the study area. More new building construction are found in eastern part of Attappady and also sand and gravel soil types are common. Moreover, common vegetation types in eastern Attappady are the scrubs and grass.

8.4 Demographic Attributes of Respondents of the Attappady Hilly Region

As per the 2011 census report, (table 8.2) Attappadi taluk has a total population of 64,318 where 32,035 are males and 32,283 are females. This taluk has scheduled tribal population of 27,627 (43% of total population) where 13,708 were males and 13,919 were females. The tribal population of the valley mostly consists of Muduga, Irula, Kurumba tribal people and a section of settlers from other districts of Kerala and Tamilnadu also settled in Attappady. The total SC population is 3054(4.75%), and other settlers are 33637 (52.29%). The population of children in the age group of 0-6 was 7,009 (10.9%) among which 3,551 are boys and 3,458 are girls. The total number of literates in Attappadi is 43,021 with an overall literacy rate of 75% which is lower than the state average of 94%. Male literacy stands at 80.2% and Female literacy at 70%. The total number of households in Attappay were 16,865 as per 2011census.

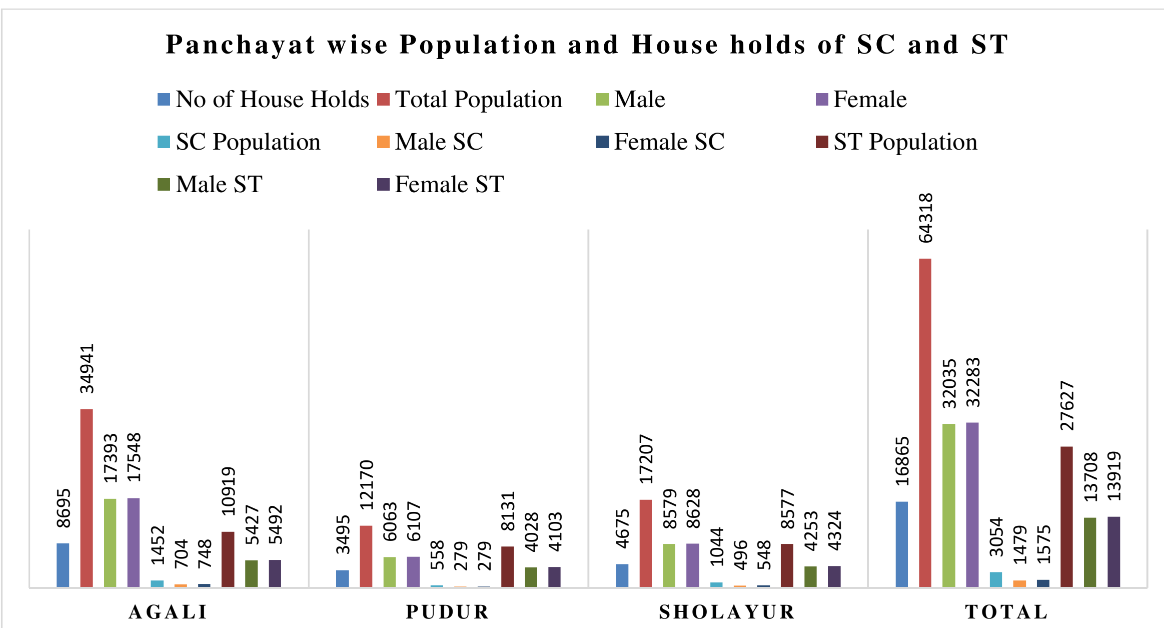
There are nearly 192 tribal hamlets in Attappady. The three tribes in Attappady are Irula, Muduga and Kurumba (table 8.3). Irula are the largest tribe in Attappady. The Mudugas have the highest rate of literacy and Kurumbas tribal community are the most primitive and they are still living in the interior forest area. The literacy rate of tribes in Attappady is only 40%. A vast majority are below poverty-line. Each tribe has its own dialect for communication. Tribal hamlets are scattered in all the three panchayats of Attappady viz. Agali, Pudur and Sholayur.

Agali and Pudur panchayaths contain more or less the same number of hamlets. lrulas dominate in all panchayaths. The Kurumbas reside only in Pudur and Sholayur panchayath. (GOI – 2011, Census of India)

Table 8.2: Panchayat wise Population and Households of SC &ST of the Attappady Hilly Region

Panchayats	No of House Holds	Total Population	Male	Female	SC Population	Male SC	Female SC	ST Population	Male ST	Female ST
Agali	8695	34941	17393	17548	1452	704	748	10919	5427	5492
Pudur	3495	12170	6063	6107	558	279	279	8131	4028	4103
Sholayur	4675	17207	8579	8628	1044	496	548	8577	4253	4324
Total	**16865**	**64318**	**32035**	**32283**	**3054**	**1479**	**1575**	**27627**	**13708**	**13919**

Source: Panchayat Department, Govt. of Kerala Census 2011



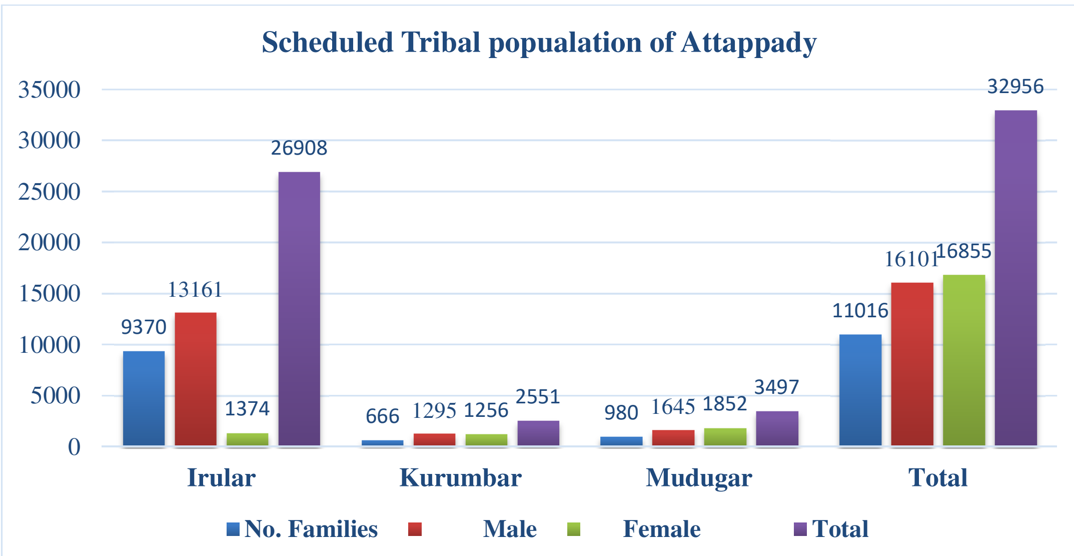
Source: Panchayat Department, Govt. of Kerala Census 2011

Fig. 8.3: Panchayat wise Population and Households of SC &ST of the Attappady Hilly Region

Table 8.3: Scheduled Tribal population of the Attappady Hilly Region

Community	No. Families	Male	Female	Total
Irular	9370	13161	1374	26908
Kurumbar	666	1295	1256	2551
Mudugar	980	1645	1852	3497
Total	11016	16101	16855	32956

Source: 2011 census



Source: 2011 census

Fig 8.4: Scheduled Tribal population of the Attappady Hilly Region

8.5 Demographic history of the Attappady Hilly Region

The population growth and demographic change were more in the hilly regions of Attappady for the last couple of decades. There was a massive migration from Travancore to hilly areas of Malabar during period 1940-50. The major reason for the migration of farmers from Travancore to Malabar were the rapidly increasing population and the resultant pressure on cultivable land in Travancore. This process of migration also brought migrants in large numbers to Attappady from Travancore. The demographic structure of Attappady has changed after the 1950s mainly due to uncontrolled influx of population from others district of Kerala

(Ernakulam, Idukki, Kottayam, Alappuzha and Thiruvananthapuram) and Tamil Nadu (Coimbatore). As a consequence, demographics of Attappady totally changed and turned to be unfavourable to tribals. During 1940s, the tribal population of Attappady is estimated to have been around 10,000 and the non-tribal population just a few hundred. According to the 1951 census, the proportion of non-tribal population to total population was just 9.68%. The sudden increase in migration to Attappady reduced the tribals from a majority group in 1951 to a minority group by 1991 (velluva 1999). In 1951, 90.27 percent of the total population was tribal people in Attappady. but, the percentage of tribal people in the total population rapidly declined and have just around 44 percent in 2011census and this is referred to as demographic change (Velluva 2006: 18) because it is a shift from the dominance of the tribal population to the predominance of non-tribal population during the period 1951–2001 by a section of settlers migration from other districts of Kerala and Tamil Nadu to Attappady in search of livelihood activities. This demographic change has adversely affected the self-sufficient, self-sustained, need-based, self-organised, self-managed characteristics of tribal economy and society and its traditional agricultural practice, tribal councils, indigenous knowledge and power dynamics of tribes in Attappady (AHADS Status Report 2010). This population pressure reduced most of the tribal lands and population growth due to migration from other districts of Kerala and Tamil Nadu had a direct impact on land use change and land degradation of Attappady (Manikkandan 2016). The main economic activity of people of Attappady is agriculture and its allied activities. The climatic variations and decrease of soil quality have led to multiplier effects on life and livelihood activities of the people. The better understanding of local people's perceptions on the impact of rain shadow induced land degradation on agricultural land productivity in the rain shadow region of the Attappady will provide better insights and information of the relationship between rain shadow induced land degradation and agricultural land productivity. Therefore, this study addressing the following empirical information (i) people' perception on rain shadow effect of the study area (ii) people s' perception on the climatic variability by rain shadow effect and with agricultural practice and livelihood strategies (iii) people' perception on the impact of rain shadow induced land degradation and their issues.

8.6 Socio-economic and Demographic Attributes of Respondents of the Attappady Hilly Region

The details of the socio-economic and demographic attributes of respondents of the survey are given in table No.8.4.

Table 8.4: Socio-economic and Demographic Attributes of respondents of the Attappady Hilly Region

VARIABLE	INDICATORS	FREQUENCY	PERCENTAGE
Panchayat	Agali	**209**	54.4
	Pudur	**73**	19
	Sholayur	**102**	26
Gender	Male	302	78.6
	Female	82	21.4
Age	40-50	13	3.3
	50-60	276	71.8
	60-70	95	24.8
House hold size (No. Persons.)	2-4	20	5.2
	4-6	292	76.0
	Above 6	72	18.8
Education	Illiterate	47	12.2
	1-4	139	36.19
	5-10	180	46.98
	+ 2	10	2.6
	Degree	8	2.1
Residence status	Native	235	61.2
	Migrant	149	38.8
Category	ST	179	46.6
	SC	63	16.4
	OBC	107	27.9
	GENERAL	35	9.1
Income status	BPL	241	62.8
	APL	143	37.2

Source**:** Prepared by Researcher

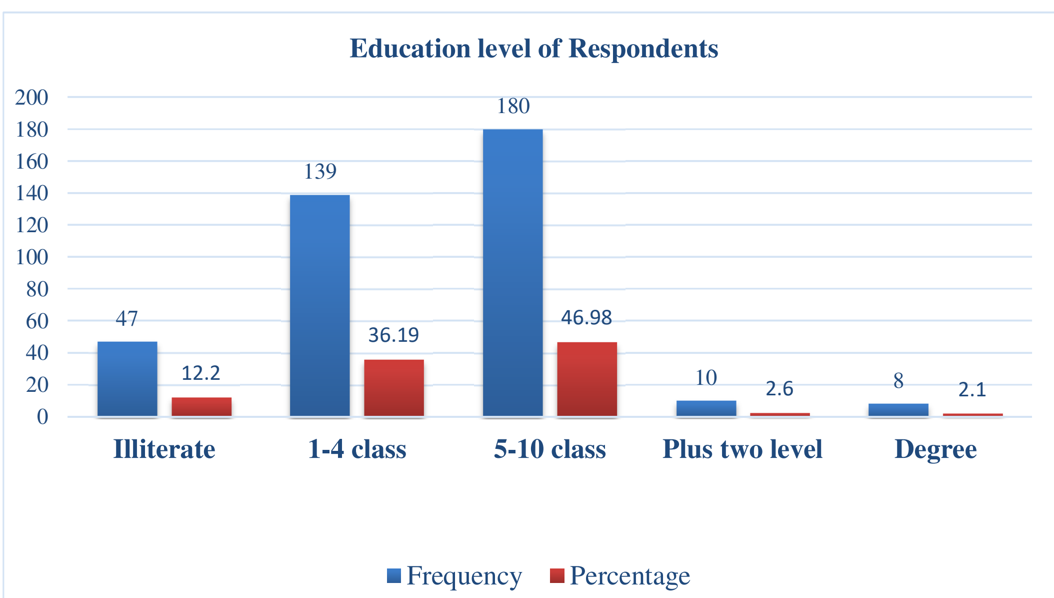
The socio-economic and demographic attributes like gender, age, and category etc. of respondents of the survey are given in table No.8.4. The total sample size of the household of the study was 384. Out of which 209 (54.4%) samples from Agali panchayat,102 (26%) from Sholayur and remaining 73 (19%) from Pudur panchayat based on proportionate simple random sampling method. Among the 384 people surveyed, 78.6% respondents were male and nearly 21.4% were females. While analyzing the table 71.8% of the respondent are between the age group of 50- to 60-years, they form the majority with 384 respondents. 24.8% of the respondents are between the age group of 60 to70 age and 3.3% of the respondent between the age group of 40 to 50. In term of education status most of the respondents (83.09%) were below 10th class education, 12.2% were illiterate and only 4.7% were above + 2 level education. The majority of the respondents (61.2%) were native people (indigenous in the area) and but 38.8% respondents were migrant from other districts of the Kerala and from Tamil Nadu. In this study, 46.6% respondents were ST population, 27.9% of the respondents were OBC, SC population were16.4% and 9.1% respondents from General category. In the case of income category, majority of the respondents (62.8%) belong to BPL and 37.2 % respondents were from APL category. In the household size of person, majority of the respondents (76 %) said that they have about 4-6 persons in a house, 18.8% respondents opinioned that they have above 6 persons in their home and 5.5% respondents have house size between 2 and 4 persons.

Table 8.5: Occupation status before the year of 2000 by respondents of Attappady Hilly Region

Occupation	**Frequency**	**Percent**
Agriculture	226	58.9
Agriculture and Daily Wage	137	35.7
Agriculture and Business	21	5.5
Total	384	100

Source: Prepared by researcher

The ooccupation status of the respondents before and after year of 2000 showed that there were major changes in the occupation status of the respondent (table no 8.5 & 8.6). Occupation before the year of 2000, 59% of respondent were engaged in agriculture, 35.7% were in agriculture and daily wage and 5.5% respondent were engaged in agriculture and business activities. But, after the year of 2000, occupation status of the respondents totally changed. After the year of 2000, respondents only engaged in agriculture was reduced to 20.1% but 25.5% respondents depend on agriculture, daily wage and MGNRES activities. 20.1% were in agriculture and MGNRES, 19.5% respondent engaged in the daily wage and MGNRES, 7.8% were in the agriculture and daily wage and only 5.5% respondents were in agriculture and business. The ooccupation status of the respondents after the year of 2000 showed that there were major changes in the occupation status of the respondents, i.e. more respondents were engaged in MGNRES and daily wages occupation than only agriculture activities. This drastic change in the occupation status is due to the climatic variability, land degradation, and decline in agricultural production and wild life conflict according to the people's perception



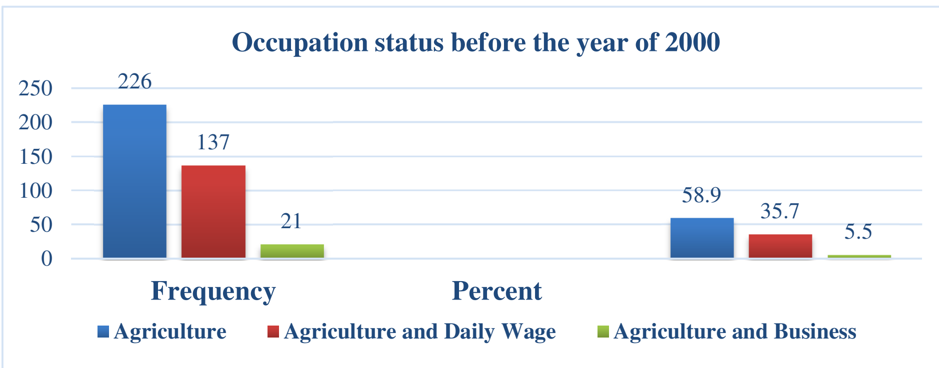
Source: Prepared by Researcher

Fig. 8.5: Education level of Respondents of the Attappady Hilly Region

Table 8.6: Occupation status after the year of 2000 by respondents of the Attappady Hilly Region

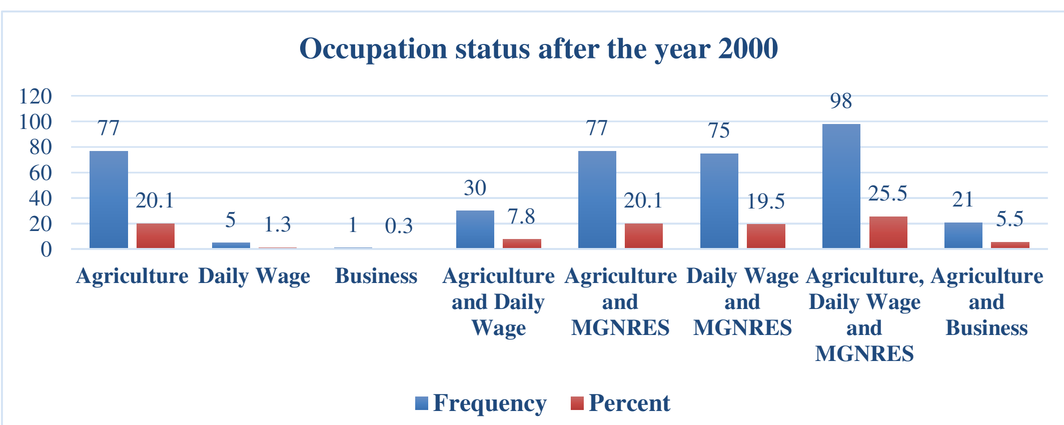
Occupations	Frequency	Percent
Agriculture	77	20.1
Daily Wage	5	1.3
Business	1	0.3
Agriculture and Daily Wage	30	7.8
Agriculture and MGNRES	77	20.1
Daily Wage and MGNRES	75	19.5
Agriculture, Daily Wage and MGNRES	98	25.5
Agriculture and Business	21	5.5
Total	384	100.0

Source: Prepared by Researcher



Source: Prepared by Researcher

Fig. 8.6: Occupation status before the year of 2000 by respondents of the Attappady Hilly Region

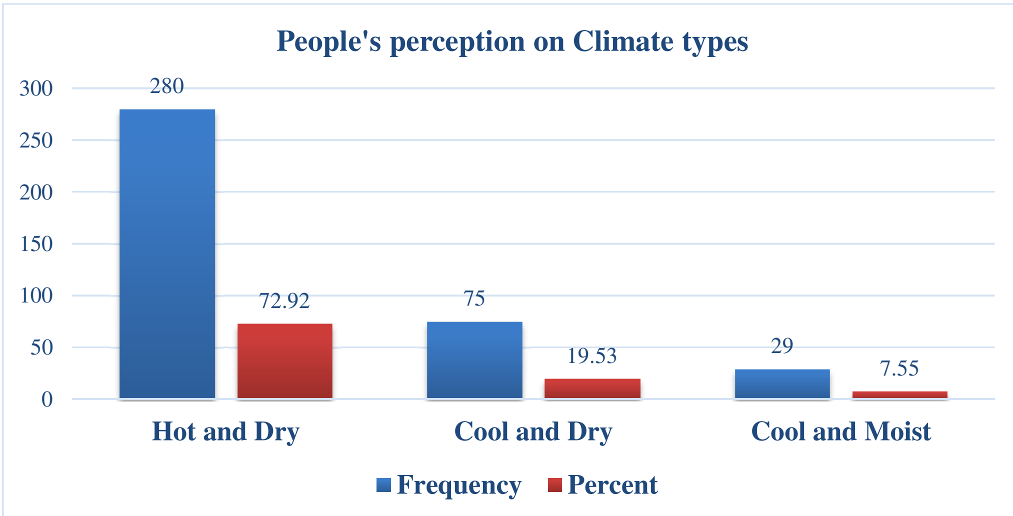


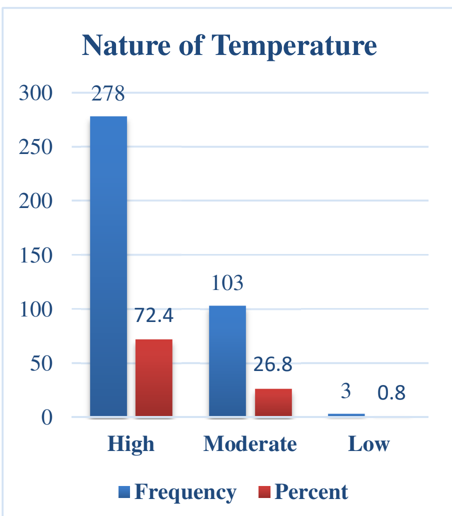
Source: Prepared by Researcher

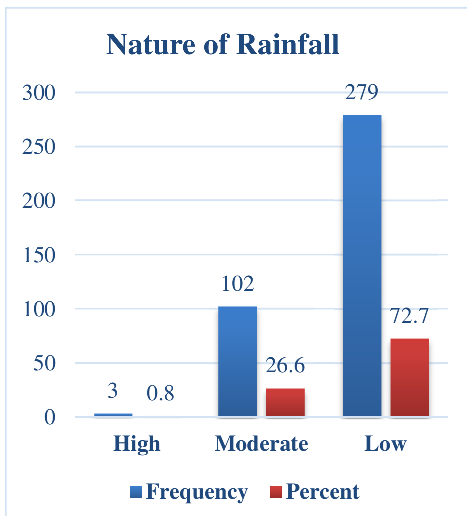
Fig. 8.7: Occupation status after year of 2000 by respondents of the Attappady Hilly Region

8.7 People's Perception on Climatic Variability and Rain Shadow Effect of the Attappady Hilly Region

Out of the 384 people surveyed about, 72.92 % respondents expressed that they experienced the Hot and Dry climate (Table No 8.7) and 72.7 % and 72.4% of respondents noticed that the region has been experiencing low rainfall and high temperature respectively for last three decades.







Source: Prepared by Researcher

Fig. 8.8: People's perception on Climate type and Nature of Rainfall and Temperature of the Attappady Hilly Region

Table 8.7: People's perception about Climate of the Attappady Hilly Region

Climate of of Attappady Hilly Region		
Climate type	Frequency	Percent
Hot and Dry	280	72.92
Cool and Dry	75	19.53
Cool and Moist	29	7.55
Total	384	100.0
Nature of Rainfall		
Rainfall	Frequency	Percent
High	3	.8
Moderate	102	26.6
Low	279	72.7
Total	384	100.0
Nature of Temperature		
Temperature	Frequency	Percent
High	278	72.4
Moderate	103	26.8
Low	3	.8
Total	384	100.0

Source: Prepared by Researcher

Table 8.8: Correlation of Temperature and Rainfall of the Attappady Hilly Region

Correlations between Temperature and Rainfall of of Attappady Hilly Region				
			Temperature of area	Rainfall of area
Kendall's tau_b	Temperature your area	Correlation Coefficient	1.000	-.956**
		Sig. (2-tailed)	.	.000
		N	384	384
	Rainfall of area	Correlation Coefficient	-.956**	1.000
		Sig. (2-tailed)	.000	.
		N	384	384
Spearman's rho	Temperature of area	Correlation Coefficient	1.000	-.963**
		Sig. (2-tailed)	.	.000
		N	384	384
	Rainfall of area	Correlation Coefficient	-.963**	1.000
		Sig. (2-tailed)	.000	.
		N	384	384
**. Correlation is significant at the 0.01 level (2-tailed).				

Source: Prepared by Researcher

The p-values of Spearman and Kendall's Correlation are less than 0.05 (5%) level of significance. It means that there is a significant relationship between temperature and rainfall of the study area. Moreover, Spearman and Kendall's Correlation value are -0.963 and -0.956 respectively (table No. 8.8) which means that there is very strong negative correlation between temperature and rainfall, i.e. when temperature is increasing, the amount of rainfall is decreasing in the study region.

When we calculate the relationship between temperature and rainfall of the study area, there are strong negative Spearman Correlation value of -.963 and Kendall's value of -.956 between temperature and rainfall (Table No. 8.8)

Table 8.9: Mean relationship between Remperature and Rainfall of the Attappady Hilly Region

Descriptive Statistics						
Temperature of area		N	Minimum	Maximum	Mean	Std. Deviation
High	Rainfall of area	274	1.00	3.00	2.9927	.12082
	Valid N (listwise)	274				
Moderate	Rainfall of area	65	1.00	2.00	1.9231	.26854
	Valid N (listwise)	65				
Low	Q33 Rainfall of area	45	1.00	3.00	1.1556	.52030
	Valid N (listwise)	45				

Source: Prepared by Researcher

The table No.8.9 shows that the mean relationship between temperature and rainfall of the study area. In high temperature region, mean value of rainfall is 2.99. It means that high temperature area has low rainfall. Therefore, when temperature increases, the amount of rainfall decreases. In the case of moderate temperature region, mean value of rainfall is 1.923. It means that moderate temperature area has moderate rainfall. But, in the area of low temperature region, mean value of rainfall is 1.15. It means that low temperature area has high rainfall. Therefore, when the temperature of the study area decreases, the rainfall amount increases. From this, it is concluded that the relationship between temperature and rainfall of the study area are inversely related which has been supported by Spearman correlation.

About 84.9% (table 8.10) respondent expressed that there is rain shadow effect ('*West hill prevents rainfall to East side* 'in native people language) in their region and it led to the condition of low rainfall, high temperature, dry wind flow, water scarcity, land degradation and low agriculture practice. Moreover, respondents noticed that there has been decreasing of rainfall and increasing trend of temperature in their region. Therefore, they face acute water scarcity problem and it has a great impact on agriculture and soil quality deterioration and thereby it affected the livelihoods of the people of the region. As temperature and rainfall have linked with the growth of natural vegetation, respondents expressed that their area mainly covered by scrubs, grass, catacus and bamboo. The climate difference between western and eastern part of the Attappady were very high due to various factors. About 81% (table 8.10) respondents mentioned that eastern part of Attappady experience comparatively low rainfall and high temperatures when compared to western side of Attappady. About 54.7 % (table 8.10) responded that the physical barrier effect on the western side (rain shadow effect) has very important role in the climate difference between western and eastern part of the study area. The 25.8% (table 8.10) expressed that it is because of deforestation, 14.8% by global warming, and 2.3% by high land use change.

According to Chandran, from Padavayal of Pudur panchayat," western part of Attappady receive high rainfall when compared to eastern side due to the presence of hills in the west. Moreover, eastern Attappady faces water scarcity because of the low rain fall availability. It also affected their farming activities and thereby their income".

As per Devadas from Nallasinga, of Sholayur panchayat," Eastern Attappady comparatively receive cool and dry wind, but rainfall is less. Generally, grass and shrubs are the common natural vegetation, therefore, people of this region depend more on animal rearing than cultivation. He said that low rainfall and wild animal conflict are the common problem of this region"

Vellama from Nellipathy of Agali panchayat, said that they mainly depend on goats rearing because of the availability of grass and low rainfall. They are not using their 4-acre farm land for cultivation due to low rain fall and low soil quality. They also face wild animal conflict and dry wind problem. She also said that they only get rainfall from Tami Nadu side, not from the west side because of the hills on western side of Attappady blocks the rain fall from west."

Table 8.10: People's perception on Climate variations due to Rain shadow effect of the Attappady Hilly Region

People's Perception on Rainfall decrease due to Rain shadow effect		
Response	Frequency	Percent
Yes	326	84.9
No	11	2.9
No opinion	47	12.2
Total	384	100.0

Low rain fall region by respondents		
Region	Frequency	Percent
Eastern Attappady	312	81.3
Whole Attappady	72	18.8
Total	384	100.0

Low rain fall region by respondents		
Region	Frequency	Percent
Eastern Attappady	312	81.3
Whole Attappady	72	18.8
Total	384	100.0

Reasons for climate variations in Attappady Hilly Region by respondent		
Reasons	Frequency	Percent
Deforestation	99	25.8
Land Use Change	9	2.3
Global Warming	57	14.8
Rain shadow effect	194	50.5
ALL	15	3.9
No Opinion	10	2.6
Total	384	100.0

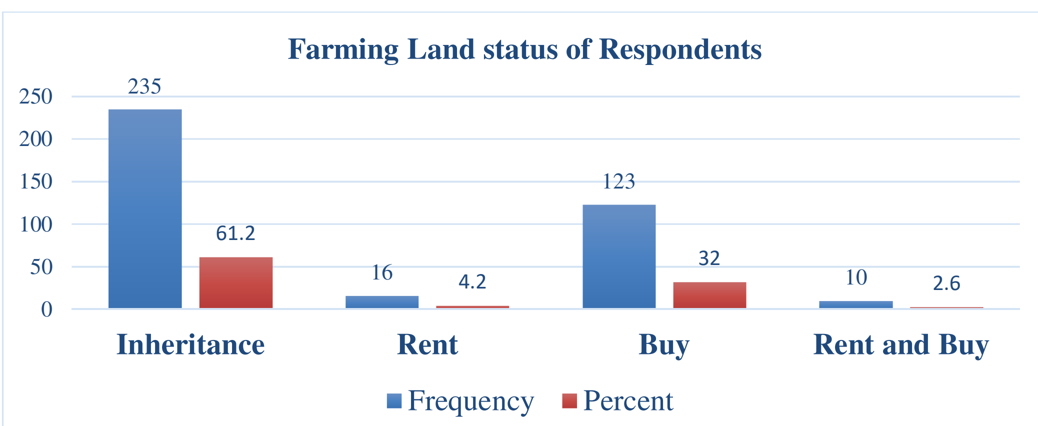
Source: Prepared by Researcher

8.8 People's Perception on Primary Activities with Climatic Variability of the Attappady Hilly Region

People of Attappady, traditionally, depended on agriculture for their livelihood. They cultivated their traditional crops in sufficient quantities for their food and nutritional security. The important traditional crops cultivated included millets, pulses and oilseeds such as *makkacholam* or maize (Zea mays), ragi or french millet (Eleusine coracana), *chama* or little millet (Panicum miliaceum), *thuvara* or red gram (Cajanus cajan), groundnut (Arachis hypogeae) and castor (Ricinus communis) especially, by tribal communities (Sachana et.al 2020). The government policy of granting individual ownership of land under the Government Land Assignment Acts caused land alienation in tribal areas and tribal communities were exploited by migrants and it led to loss of rights of tribals on their land. (Sachana, 2015). In recent years, nature of agricultural activities in Attappady area have transformed into a mix of traditional and modern cultivation. This led to deforestation and unsustainable and unscientific agricultural practices, and it negatively affected the agro-ecosystem, resulting in the climatic variability, drying up of rivers and degradation of land. This endangered agriculture situation forced them to abandon the cultivation of traditional food crops and adopted new crops like banana, coconut etc. This had badly impacted on their nutritional security and health status and resulted in various kinds of health issues. Due to these changes, many people were forced to left agriculture and search for other kind of livelihood activities, and those few who continued in agriculture shifted to new crops and practices (Sankar et .al 1990).

In Attappady, there was a transition of cropping pattern from a three-crop combination of fruits, spices and tuber to four crop combinations of fruits, spices, vegetables and tuber during the period 2001-2011 (Premakumar et al.2015). Recently, a small group of farmers has integrated some of the modern techniques of agriculture like micro irrigation, mulching etc. and tried to adapt to the changing situation. Agriculture has become the most vulnerable sector to climate change owing to its sensitivity to weather parameters, such as temperature and rainfall which significantly affects the yield of crops (Mendelsohn 2009). The Increased temperature and variation in precipitation are found to be reduce the yield (Adams 1998). As agriculture is the most important livelihood activity of the rain shadow region of Attappady, it was more negatively impacted from the climatic variation. It is clear that climatic variation has brought substantial economic losses to small land holders of farmers whose main source of livelihood derives from agriculture. Therefore, the study on the impact of climatic variation on agriculture helps to address the challenges in the farming sector and formulate policy and mitigation measures for agricultural development and livelihood of the study area. The present study covers the status of farming land, crop types, cultivated land, occupation, livestock and source of water for agriculture of the study area.

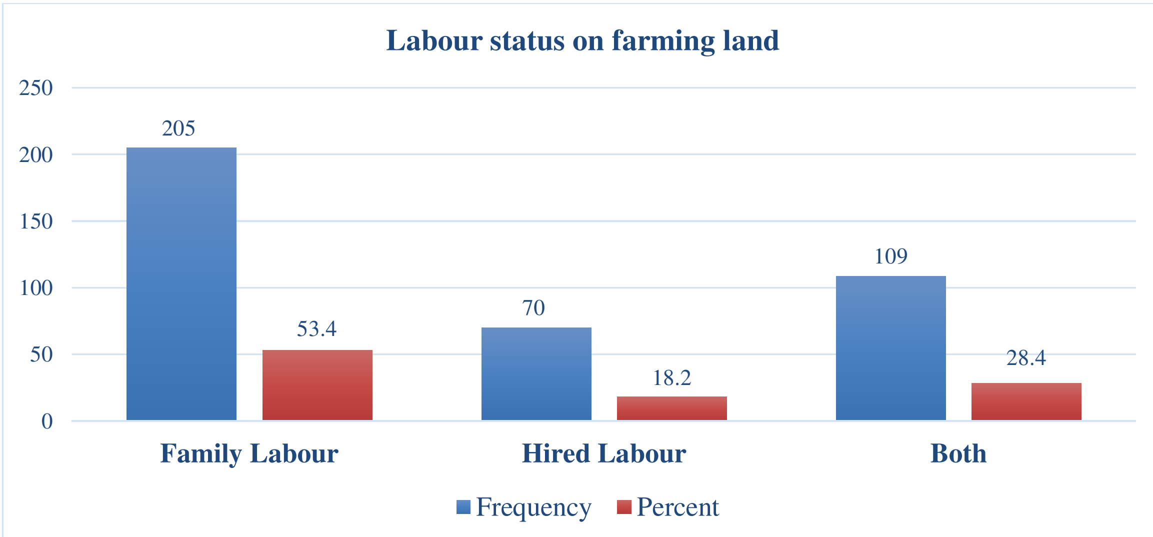
Among the 384 respondents surveyed, 61.2% (Fig. 8.9) reported that they acquired farming land through inheritance, identifying themselves as indigenous residents of the region. About 32% of the respondents purchased their land, while 4% rented land for farming. A smaller group, comprising 2.6%, acquired land through a combination of rent and purchase. This last category mainly includes migrants from other districts of Kerala and Tamil Nadu.



Source: Prepared by Researcher

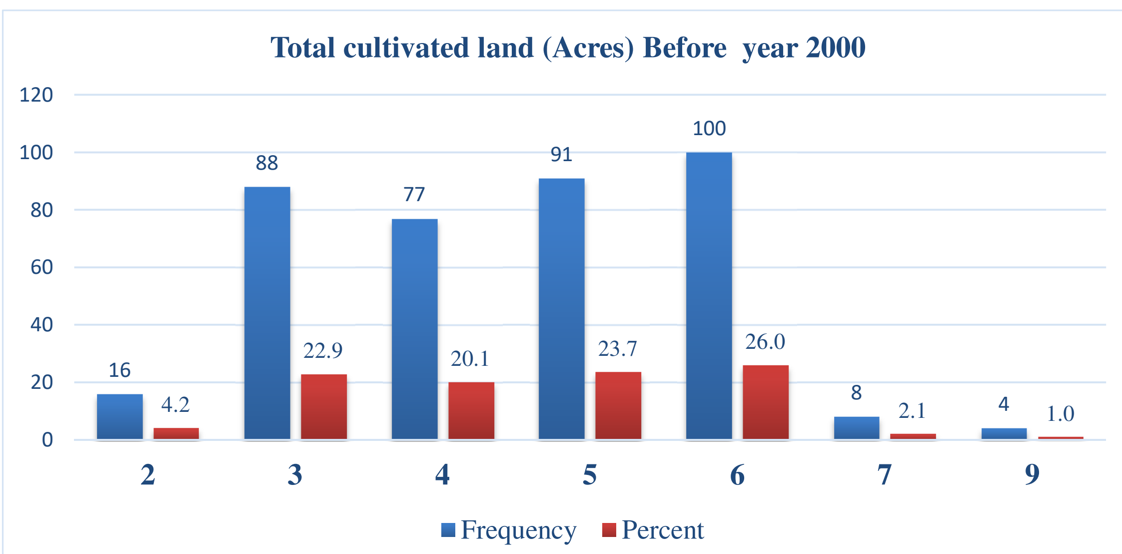
Fig. 8.9: Farming Land status of the Attappady Hilly Region

About 53.4% (fig 8.10) respondents opined that their land for cultivation was done by their family members, 18.2% by hired labour for cultivation and 28.4% by both the family and hired labour.



Source: Prepared by Researcher

Fig. 8.10: Labour status on farming land of the Attappady Hilly Region

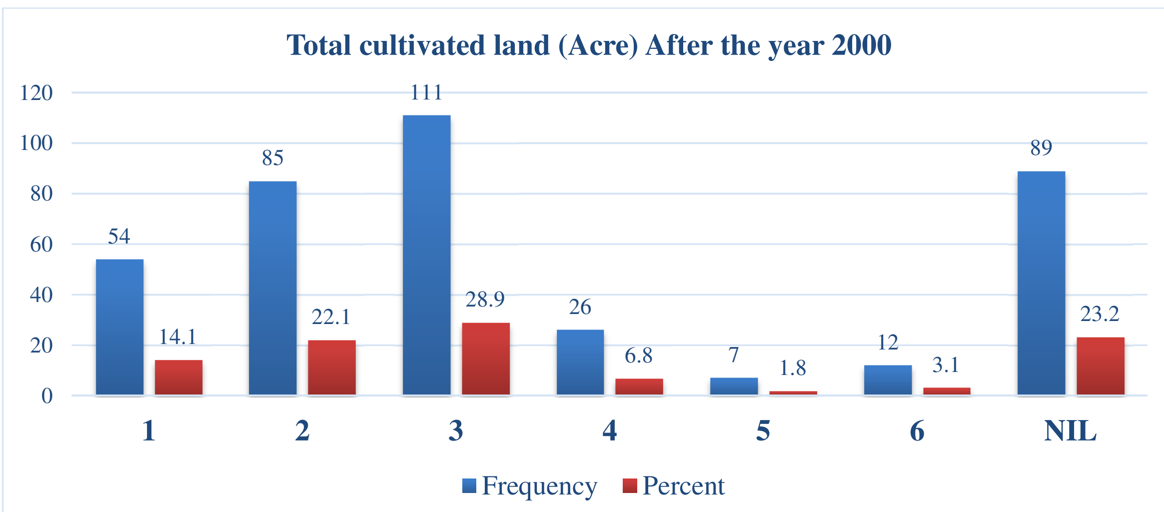


Source: Prepared by Researcher

Fig. 8.11: Total cultivated land (Acres) before year 2000 by respondents of the Attappady Hilly Region

Regarding the total cultivated land owned before the year 2000, 26% of respondents (Fig. 8.11) reported having 6 acres of cultivated land per person. Around 23.7% owned 5 acres, while 22.9% had 3 acres per respondent. Additionally, 20.1% of the respondents possessed 4 acres of cultivated land.

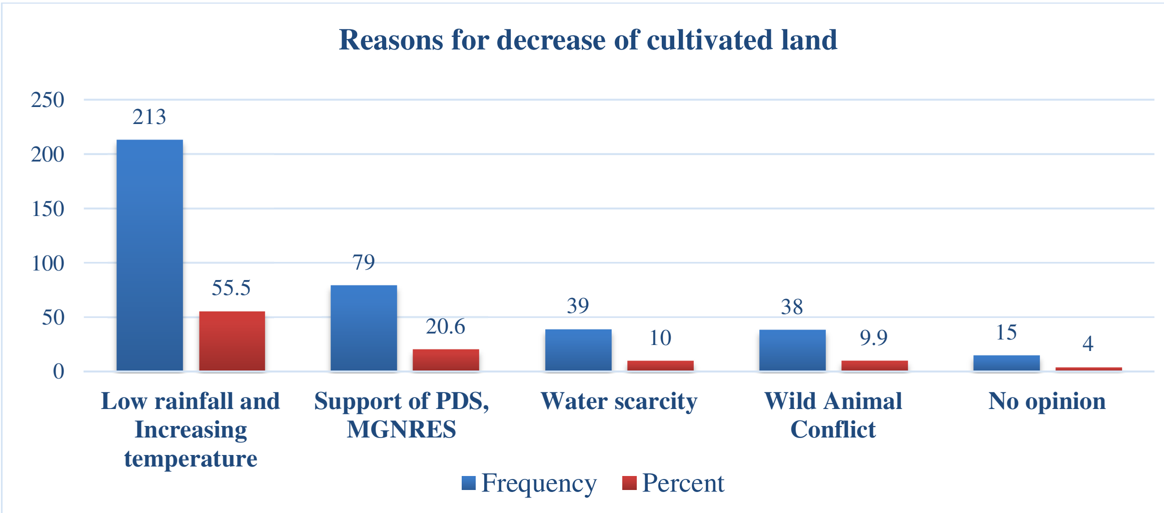
But after the year 2000, possession of total cultivated land per family has decreased. About 23.2% (fig 8.12) respondents expressed that they have abandoned their cultivated land due to low rainfall and high expense, 30% people have 3 acres of total cultivated land per person, 22% respondents have 2 acres of total cultivated land, and 14.4% people have 1 acre of total cultivated land per person. The possession of more than 5 or 6 acre of total cultivated land per person had reduced at an alarming rate.



Source: Prepared by Researcher

Fig. 8.12: Total cultivated land (Acres) after the year 2000 by respondents of the Attappady Hilly Region

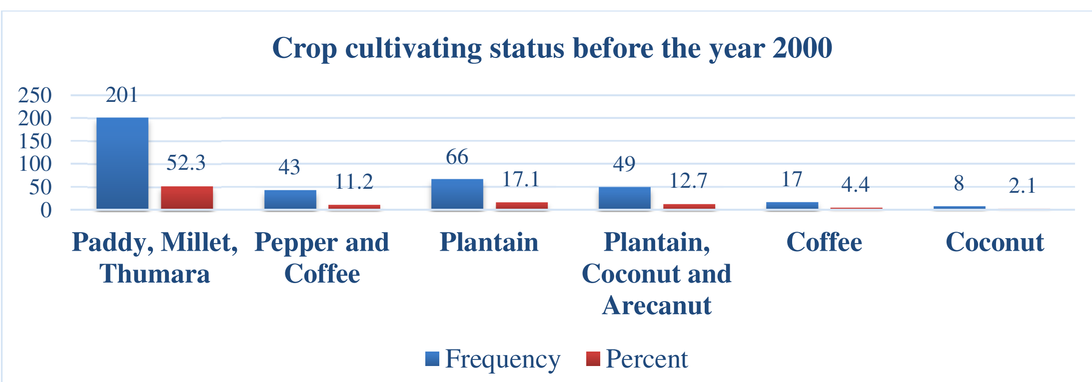
The 65.4% (fig 8.13) respondents expressed that their total cultivated land has decreased and it was mainly due to the decreasing rainfall, increasing temperature and wild animal conflict. About 20.6% opined that the essential goods distribution through Public Distribution System (PDS) and the starting of the MGNRES work scheme among the people also influenced their livelihood activities and it deviated them from cultivating their own farmland to other sectors and it led to the decrease of cultivation land.



Source: Prepared by Researcher

Fig. 8.13: Reason for decrease of cultivated land of the Attappady Hilly Region

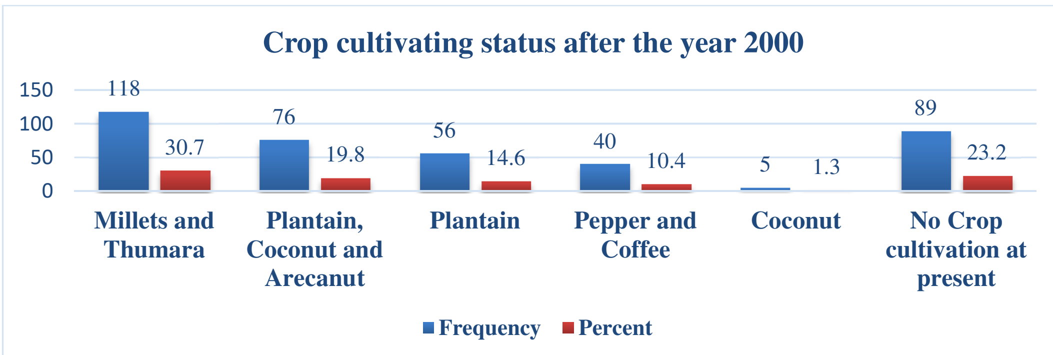
In Attappady, there was a transition of cropping pattern after the year of 2000 (Premakumar et al.2015). Before the year 2000, 52.3% (Fig 8.14) respondents expressed that their major crops were paddy, *thumara* and millets and 17.1% responded that they had done plantain, 11.2% cultivated pepper and coffee.



Source: Prepared by Researcher

Fig. 8.14: Crop cultivating status before the year 2000 by respondents of the Attappady Hilly Region

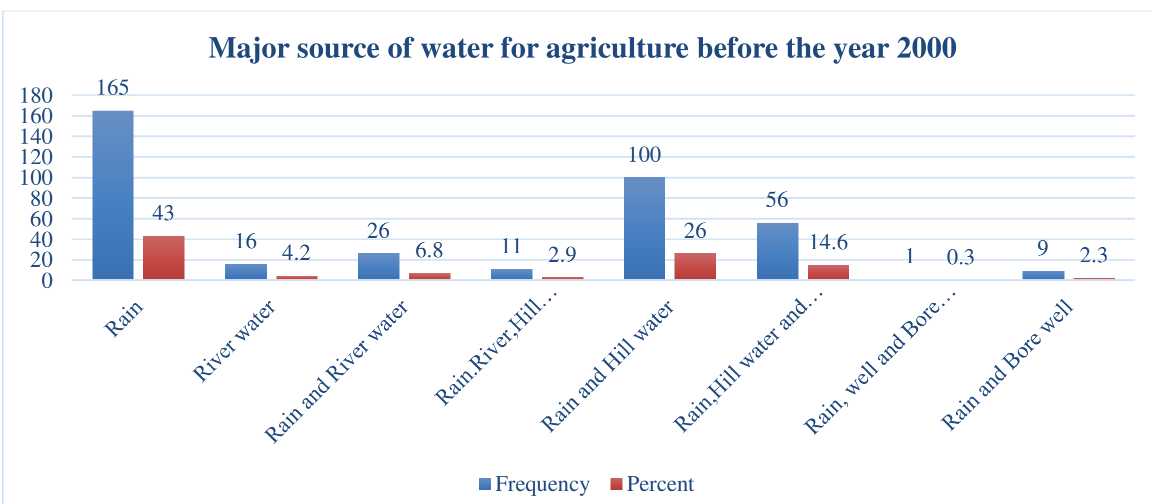
After 2000, 30.7% (fig 8.15) respondents mentioned that their major cultivation crops were *thumara* and millets, 20% opined that they have shifted to plantain, coconut, and areca nut crops, 14.6% by plantain, and 23.2% respondents opined that major crop land were converted to fallow land and paddy cultivation disappeared due to climate variation.



Source: Prepared by Researcher

Fig. 8.15: Crop cultivating status after the year 2000 by respondents of the Attappady Hilly Region

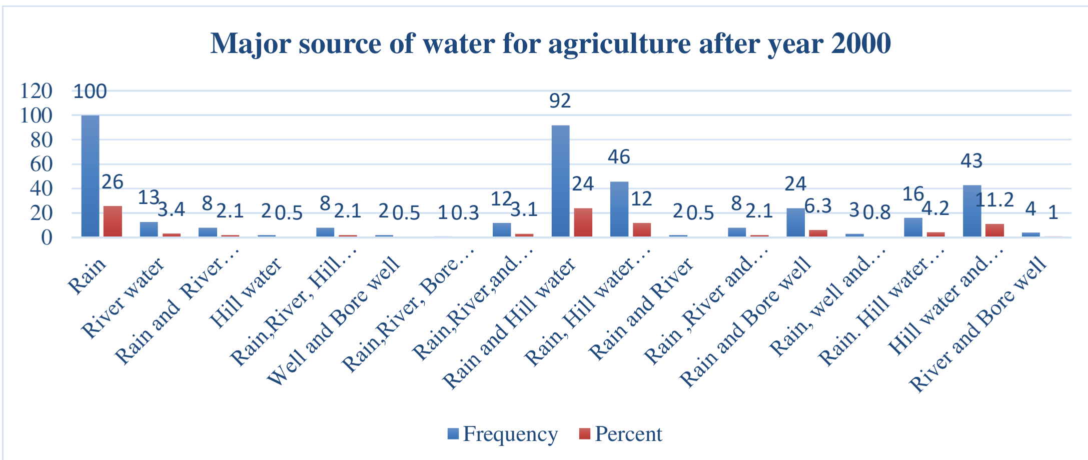
About 43% (fig 8.16) respondents expressed that major sources of water for agriculture were rainfall and 26 % of people said that rain and hill water were sources of water for agriculture. 4.2% of the respondents uses river water before the year of 2000.



Source: Prepared by Researcher

Fig. 8.16: Major sources of water for agriculture before year of 2000 of the Attappady Hilly Region

After the year 2000, due to a noticeable decline in rainfall, people began relying on multiple sources of water for agricultural purposes. According to the responses, 26% (Fig. 8.17) indicated that rainfall remained their primary source of irrigation. About 24% reported using a combination of hill water and rainwater, while 12% depended on a mix of rain, hill water, and bore wells. Additionally, 11.2% of respondents relied on hill water and bore wells as their main water sources for farming. The details are given fig no 8.17

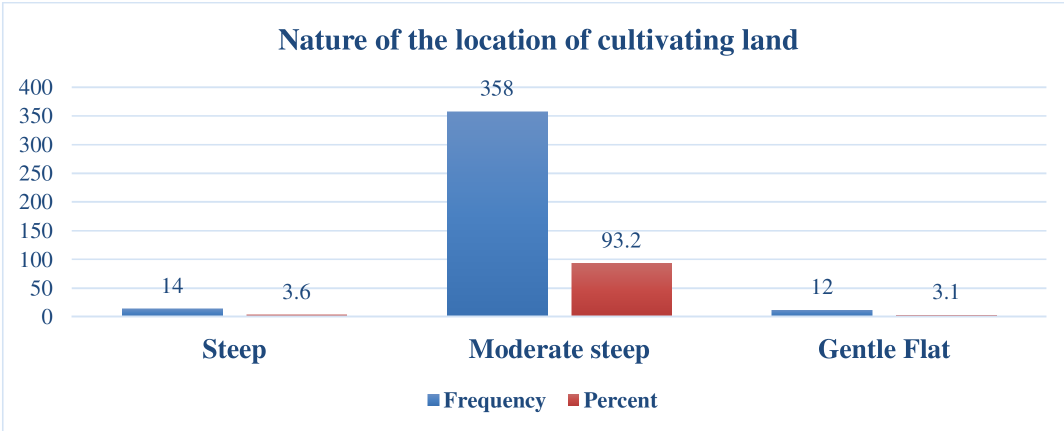


Source: Prepared by Researcher

Fig. 8.17: Major sources of water for agriculture After year of 2000 in the Attappady Hilly Region

Respondents also expressed concern over the decline in rainfall, which led many to start digging bore wells to meet their agricultural water needs. However, households belonging to the Below Poverty Line (BPL) category were particularly affected. Due to low rainfall, the high cost of agricultural inputs, and increased incidents of wild animal conflict, many of them were forced to reduce their cultivated land and shift to non-agricultural livelihoods in search of more stable income sources.

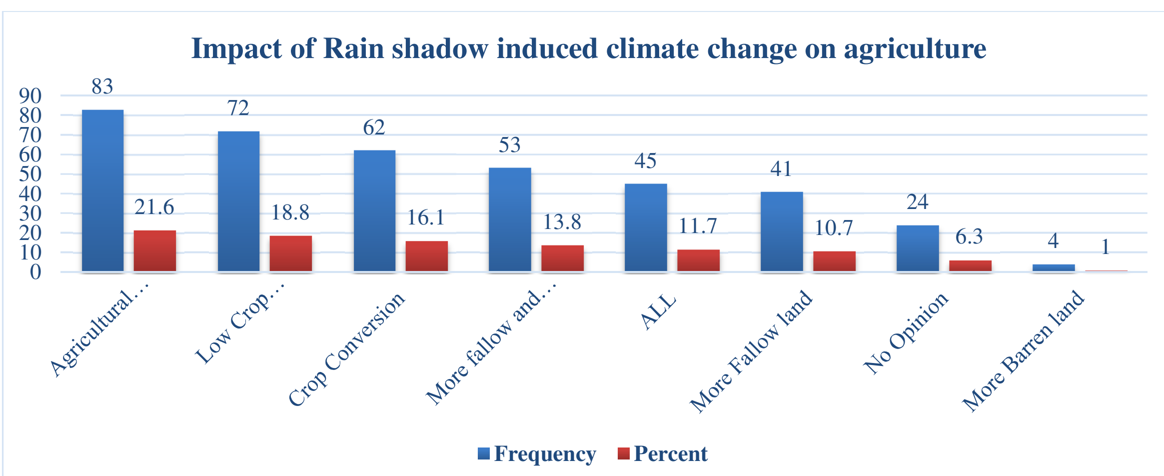
As the study area is located in the western ghat region, 93.2% (fig No 18) of respondents said that their cultivation lands were situated on moderate slope and only 3.6% respondents mentioned that their cultivating land were on steep slope and 3.1% by gentle flat area.



Source: Prepared by Researcher

Fig. 8.18: Nature of the location of cultivating land of the Attappady Hilly Region

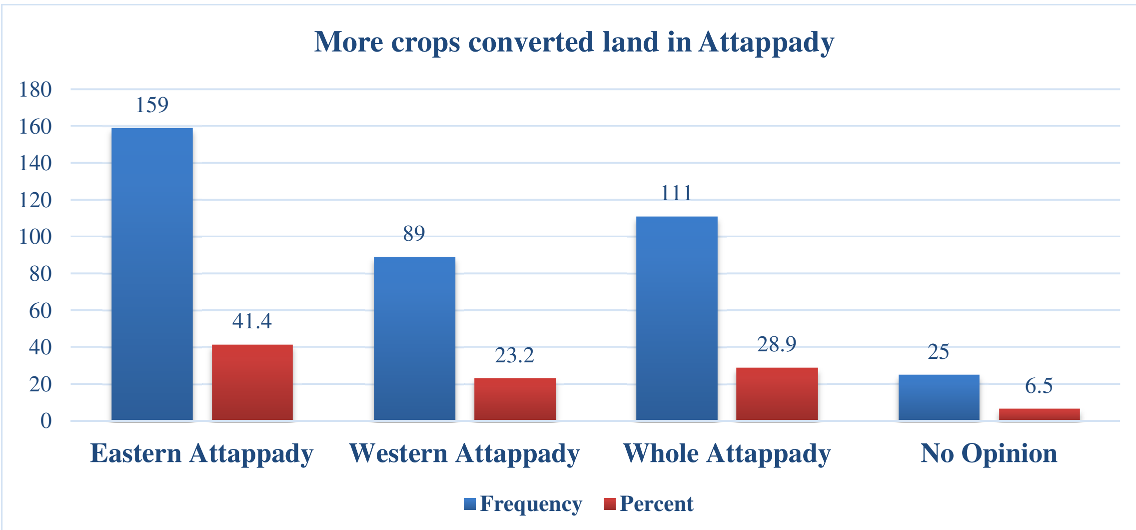
The climatic variability in the study area has had a significant impact on both agriculture and livelihood activities. According to the survey, 21.6% of respondents (Fig. 8.19) reported that these changes led to agricultural unemployment, while 18.8% observed a decline in crop productivity. About 16.1% of respondents indicated a shift towards crop conversion, and 25% reported an increase in fallow and barren land, highlighting the growing challenges faced by the farming community in the region.



Source: Prepared by Researcher

Fig. 8.19: Impact of Rain shadow induced climate change on agriculture by respondents of the Attappady Hilly Region

Climate variation in the study area has significantly influenced agricultural patterns and livelihood activities, leading to widespread cropland conversion in Attappady. According to the respondents, 41.4% (Fig. 8.20) observed that the eastern region of Attappady experienced the highest rate of cropland conversion. About 28.9% indicated that such changes occurred throughout Attappady, while 23.2% reported that western Attappady was the most affected.



Source: Prepared by Researcher

Fig. 8.20: More crops converted land in Attappady by respondents of the Attappady Hilly Region

According to Thomas A (Age;65) from Anakkatti of Sholayur panchayat;

"The crop has been poor in Attappady, especially in the eastern region, where rainfall has been severely deficient. Once, we cultivated a wide range of crops, but with the changing climate, rainfall has become unreliable and insufficient for cultivation," He further reported that underground water levels and soil quality have also significantly deteriorated. In the past, paddy, sugarcane, and cotton were commonly cultivated in the region. However, due to climate changes over the past three decades, these traditional crops have disappeared. In response, farmers have shifted to climate-resilient crops such as coconut, arecanut, and plantains, which are better suited to the prevailing environmental conditions.

According to Nanjiyamma, (Age; 65) from Kottathara of Agali panchayat.

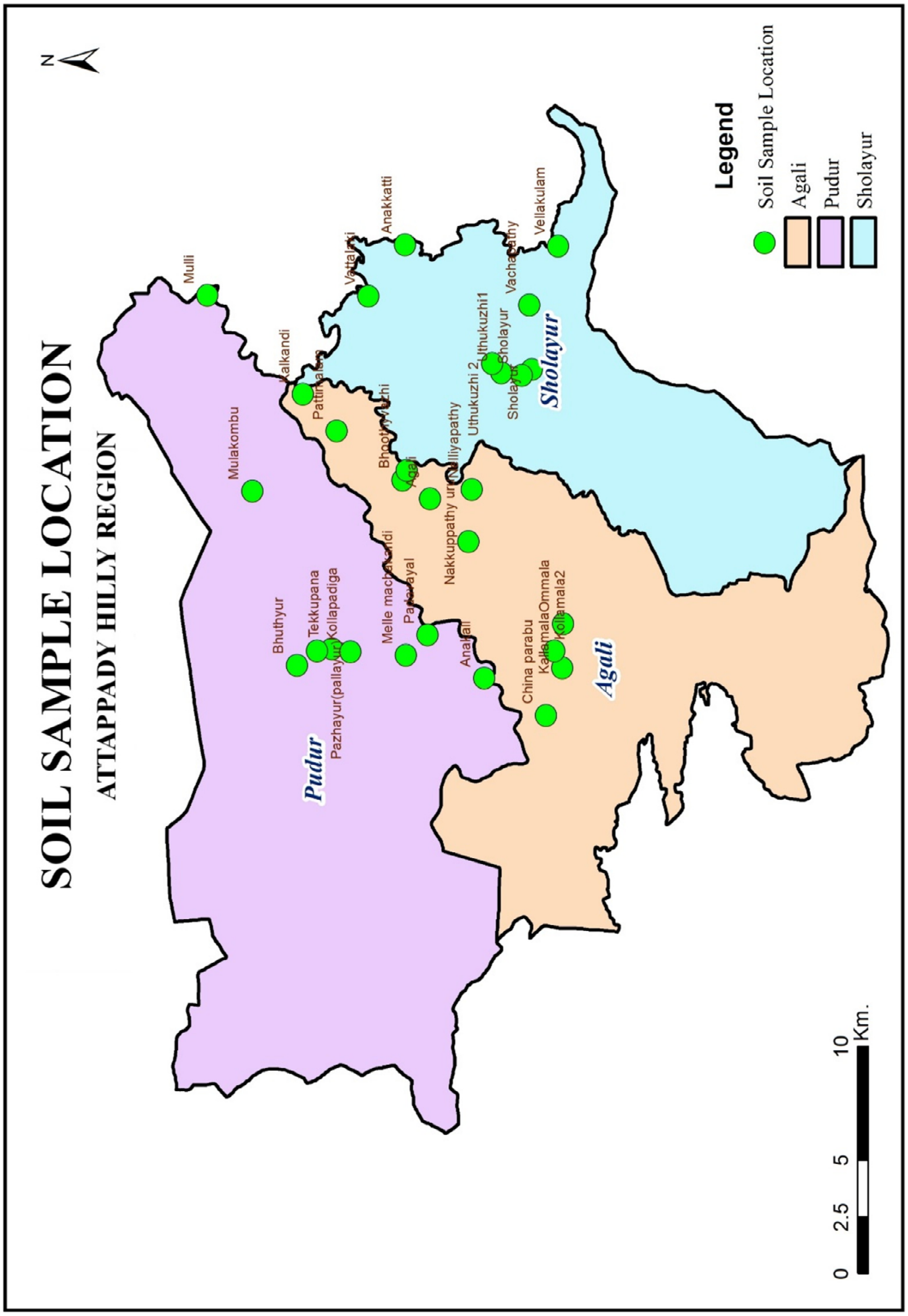
"Once, she had a larger area of cultivation land inherited from her family, where they grew vegetables, millets, *thumara*, and plantains, using both river water and rainfall for irrigation. However, today she cultivates only a small portion of land, growing limited amounts of vegetables, *thumara*, and plantain, primarily due to water scarcity. Rainfall has decreased significantly, and temperatures have risen, attributed to climate change. With declining rainfall, they now depend more on bore wells and river water for farming. The climate crisis has caused a major shift in both cultivation patterns and farming methods, deeply affecting their way of life. As a result, many farmers have reduced the size of their cultivated land and shifted from traditional crops to more commercial crops. Farming is no longer seen as viable by many, leading people to abandon agriculture and seek alternative livelihoods through MGNREGS, daily wage labor, and construction work."

8.9 People's perception on the impact of Rain shadow induced climate effect on land degradation of the Attappady Hilly Region

Land degradation refers to the reduction in the ability of land to provide essential benefits to humans (Daily, 1995). In agricultural lands, degradation often leads to a loss of soil organic carbon, which negatively impacts both land productivity and its function as a carbon sink. For millions of people, land degradation poses a critical threat to their livelihoods and survival (Kishk, 1990). Climate variability is often an inherent factor in land degradation that intensify existing land degradation processes. Rain shadow areas, characterized by reduced rainfall due to mountains blocking moisture-laden winds, can significantly contribute to land degradation. The climate in these regions strongly influences vegetation type, biomass, and biodiversity. High temperatures and low precipitation in drylands reduce organic matter production and accelerate its oxidation. Low organic matter leads to poor soil aggregation and stability, making these areas highly vulnerable to wind and water erosion (Sivakumar & Stefanski, 2007). The scarcity of rainfall in rain shadow regions often results in poor soil structure, reduced vegetation cover, and increased erosion potential (Sabová et al., 2022; Ratan & Priya, 2021). Understanding the relationship between rainfall and land degradation is vital, as regions with limited rainfall, like rain shadow areas, are more prone to soil erosion and land degradation.

The study of the land degradation in Attappady, Palakkad District, is crucial for understanding its effects on rural livelihoods. Rapid population growth due to in-migration has led to significant land degradation, causing unsustainable livelihoods among the indigenous communities (Manikandan, 2016). Farming has become economically unviable for most indigenous farmers, pushing them to diversify into irregular, low-paying farm and non-farm work, and increasing reliance on government aid (Mohamed, 2021). The loss of forests, shifting cultivation practices, and degradation of fertile land have further marginalized these communities' socio-economically. (Das et al., 2023). Attappady's unique combination of severe land degradation, poverty, and a predominantly tribal population makes it distinct both hydrologically and socially (Franke et al., 2005). Climate change has exacerbated land degradation along the mountain gradient in Attappady, further accelerating the loss of soil organic carbon, which diminishes soil quality and productivity while contributing to climate change (Manikandan et al., 2016).

The land degradation has become a major threat to people and their livelihood in Attappady. The severity of land degradation caused by the rain shadow effect in the Attappady hilly area, influence of topography and rainfall and temperature patterns in the region, has significant impact on climate change and agriculture on indigenous communities. Indian Meteorological Department rainfall and temperature data (1982-2024), land use changes over five decades, (1970-2024) and soil moisture data were used and integrated by means of Analytical Hierarchy

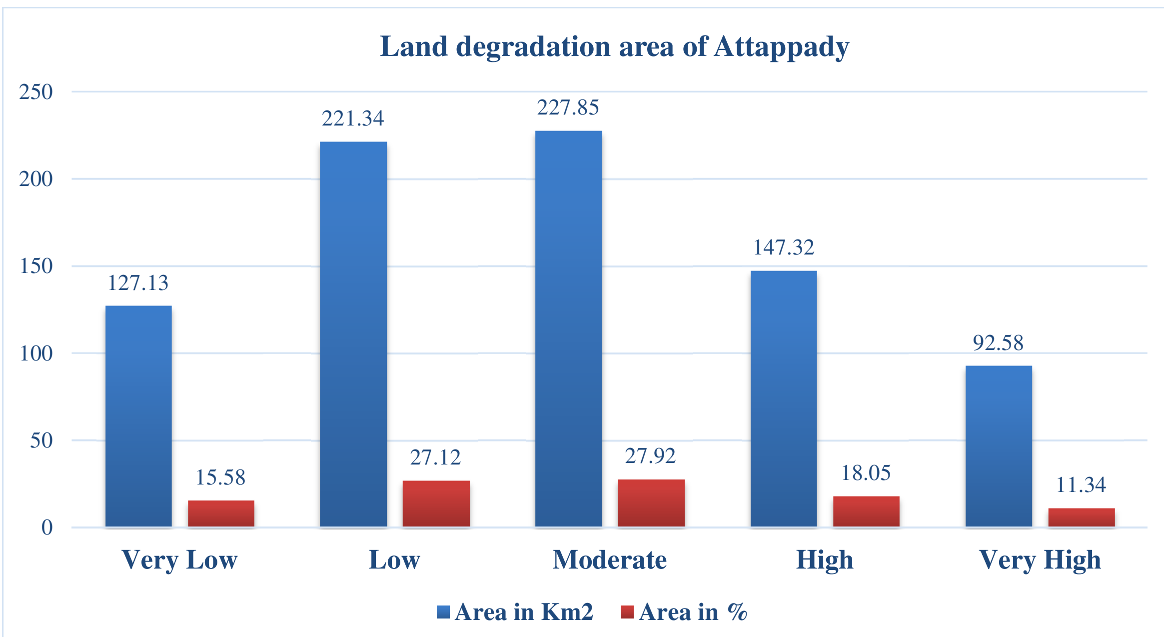


Source: Prepared by Researcher

Fig. 8.21: Locations of Soil Sample collection of the Attappady Hilly Region

Process (AHP) and the Multi-Influencing Factor (MIF) technique. Moreover, 28 soil samples were randomly collected from study area (fig 8.21) and tested in the lab and used in this study

The results of the study indicate varying degrees of land degradation across Attappady. Approximately 15.58% of the land is classified as experiencing very low degradation, while 27.12% falls under low degradation. About 27.92% of the area is affected by moderate degradation, followed by 18.05% under high degradation. Notably, 11.34% of the land is subjected to very high levels of degradation, highlighting significant environmental stress in certain parts of the region. (fig 8.22) (More details are given in chapter 6)

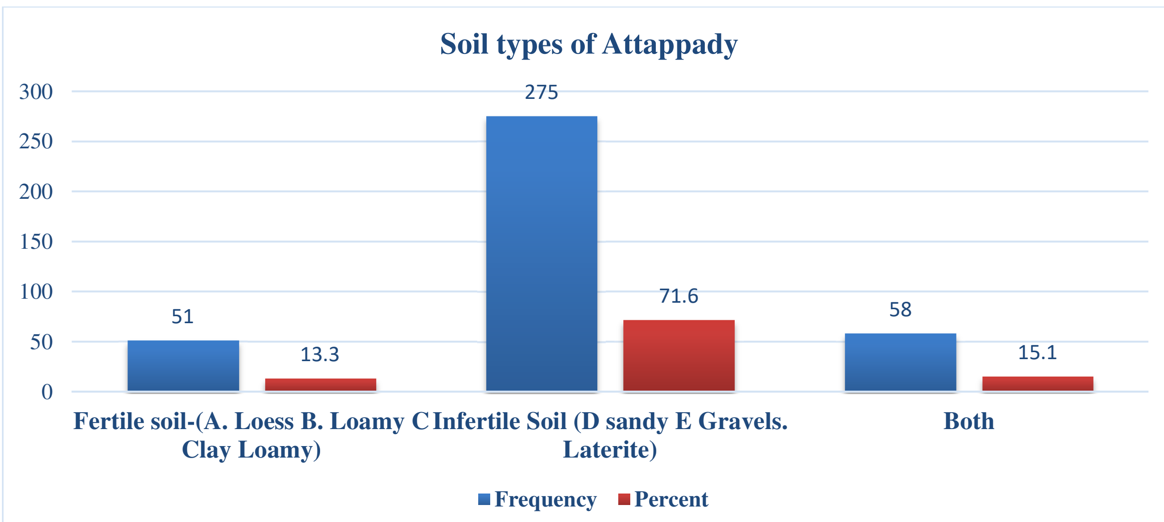


Source: Prepared by Researcher

Fig. 8.22: Land degradation area of the Attappady Hilly Region (sq.km)

The main causes of land degradation are natural and human/anthropogenic causes (Nkonya, et.al. 2011). In Attappady both natural and anthropogenic causes are responsible for land degradation. Anthropogenic causes include population growth, demographic change, deforestation, steep slope cultivation, changes in land use, grazing, agricultural intensification, loss of vegetative cover, land tenure, cropping pattern change, social marginalisation of tribals, and poverty of the people. At the same time, natural causes of land degradation consist of topography, slope of a region, variation of climatic conditions, soil erosion and decline in the water level, (Manikkandan 2016). The important goal of the study is to assess People's perception on impact of rain shadow induced land degradation on agriculture in the Attappady rain shadow region. People are asked to respond about the soil types, soil fertility level, land use change and crop conversion and their causes and consequences in the region.

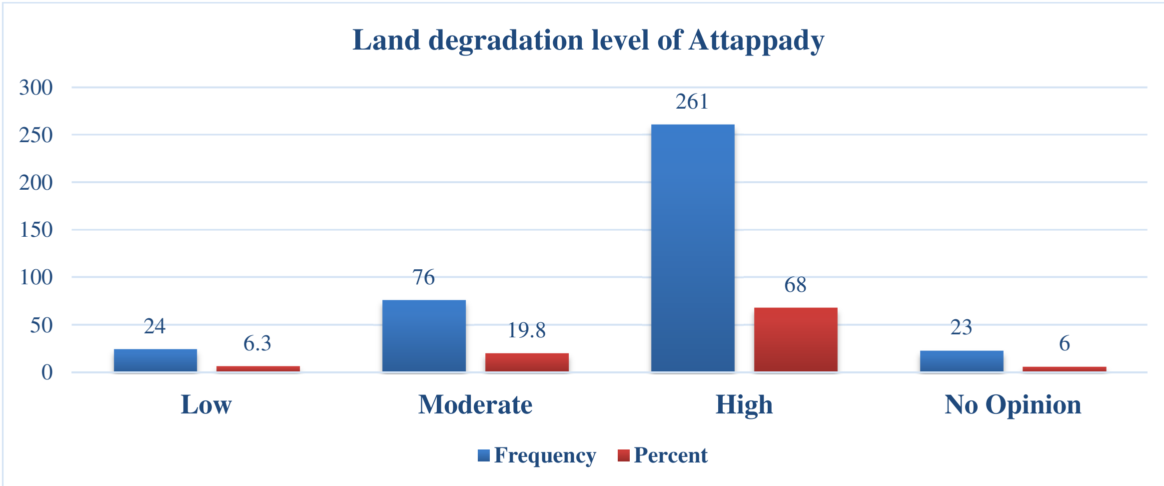
Out of the 384 respondents, 71.6 % expressed that soil was generally sandy and gravel type in their region, 13.3% mentioned that soil type was loamy and 15% respondents opined that sandy and gravel and loamy type were major soil type of their region. (fig 8.23)



Source: Prepared by Researcher

Fig. 8.23: Soil types of Attappady Hilly Region by respondents

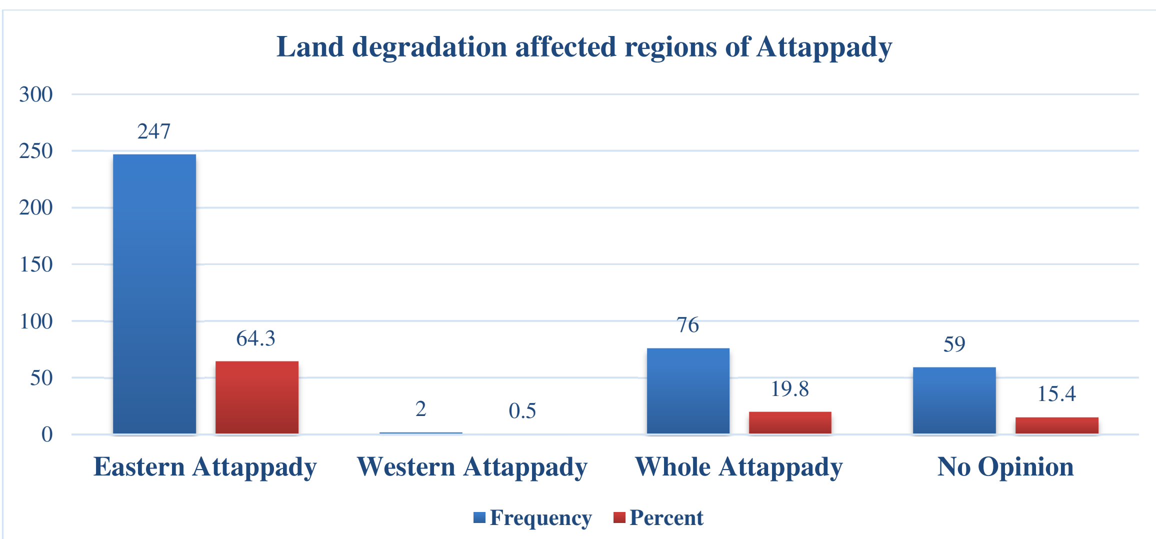
In the case of land degradation level of the study region, 68% (fig 8.24) people responded that land degradation level was high in their region, 16% by moderate level and 6.3% people opined that land degradation level is low. The people of the region also mentioned that low rainfall and increasing temperature has influenced the decrease of soil fertility of the region. Although road density is moderate, new building construction have been more active in the study area.



Source: Prepared by Researcher

Fig. 8.24: **Land degradation level of the Attappady Hilly Region by respondents**

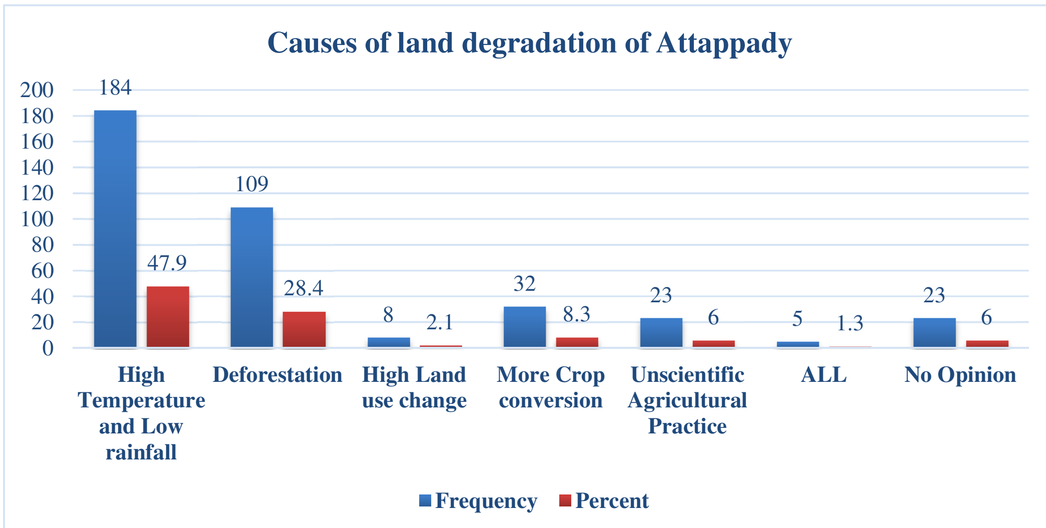
Land degradation in Attappady has been influenced by multiple factors and affects various parts of the region. According to the survey, 64.3% of respondents (Fig. 8.25) reported that Eastern Attappady is the most affected. Around 19.8% believed that land degradation impacts the entire Attappady region, while 0.54% opined that the western part is primarily affected.



Source: Prepared by Researcher

Fig. 8.25: Land Degradation affected regions by respondents of Attappady Hilly Region

There were various factors which formed the main causes of land degradation in Attappady. Out of the 384 respondents, 48% expressed that causes of land degradation in their region is due to high temperature and low rainfall, 28.4% mentioned that it is by deforestation, 8.3% respondents mentioned crops conversion and 6% said that it is due to unscientific agricultural practice in their region. (fig 8.26)



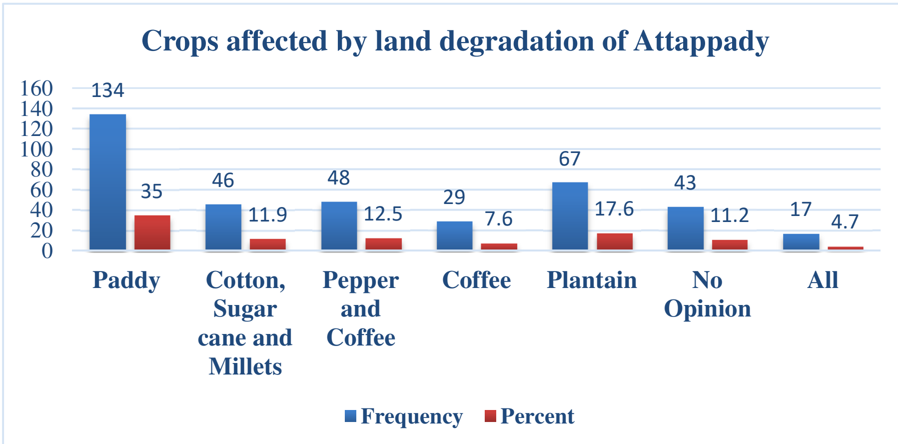
Source: Prepared by Researcher

Fig. 8.26: Causes of land degradation of the Attappady Hilly Region by respondents

Land degradation has significantly impacted the major crops cultivated in the Attappady region. Out of 384 respondents, 35% reported that paddy cultivation was the most affected. About 17.6% indicated that plantain was impacted, while 12.5% cited effects on pepper and coffee. Additionally, 12% of respondents noted that cotton, sugarcane, and millets were adversely affected. A smaller group, 4.7%, expressed that land degradation has affected all types of crops cultivated in the region. (fig 8.27)

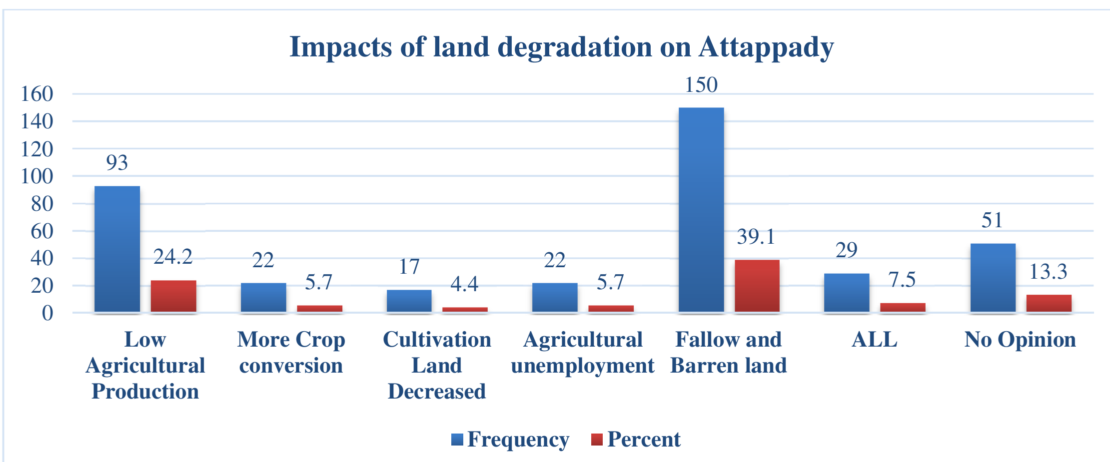
Land degradation has had a significant impact on the livelihoods and daily lives of the people in Attappady. According to the survey, 39.1% of respondents stated that the most serious consequence was the increase in fallow and barren land. About 24.2% reported that it resulted in low agricultural production, while 4.4% noted a decrease in the area under cultivation.

Additionally, 5.7% of respondents highlighted that land degradation has contributed to increased crop conversion and rising agricultural unemployment. (fig 8.28)



Source: Prepared by Researcher

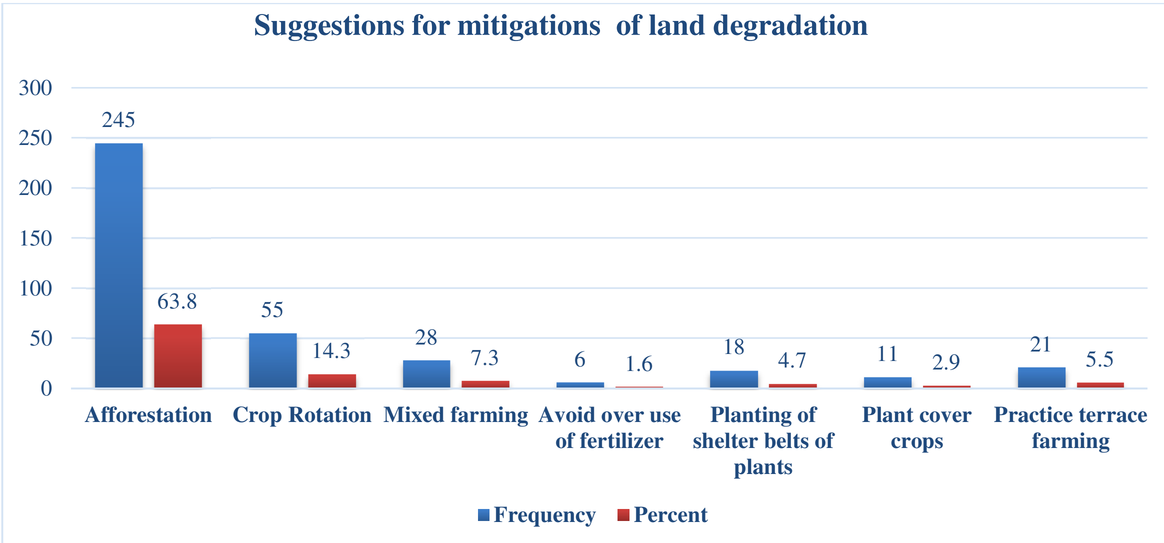
Fig. 8.27: Crops affected by land degradation by respondents of Attappady Hilly Region



Source: Prepared by Researcher

Fig. 8.28: Impacts of land degradation on the Attappady Hilly Region by respondents

The people of Attappady also suggested the steps to mitigate the problem of land degradation (fig8.29). About 64 % respondents expressed that afforestation is the best mitigation measure to reduce the land degradation, 14.3% people responded that crop rotation is best solution, 7.3% opined that mixed farming is good, 5.5% said that terraced faming is the best and 4.7% opined that planting of shelter belts of plants are best mitigation measure to reduce the land degradation in Attappady.



Source: Prepared by Researcher

Fig. 8.29: Suggestions for mitigation of Land degradation in the Attappady Hilly Region by respondents

According to Joseph from Manjakandi of Pudur panchayat "The crop cultivation has been badly affected by low soil quality and deficit rainfall, especially in the eastern part in Attapady. We are using chemical fertilizers in the farming field, but yield is very low. Therefore, many farmers have deserted their farms and search for other means of livelihood. The rivers are dried up and soil moisture level are low here. He also said that they have reduced their total cultivation land due to poor soil, low rainfall and wild life conflict. More farmers converted their crops into commercial crops due to the climate change and land degradation for the last couple of decades."

Kumaran from Boothivazhi of Agali panchayat, said that "Once, he had a larger area of cultivable land, where he grew millets, *thummara*, and plantains, relying on both river water and rainfall for irrigation. However, he is no longer able to cultivate the entire land due to water scarcity and low yields. He observes that rainfall deficiency and rising temperatures have severely degraded soil quality. As a result, farmers now depend more on bore wells for irrigation and have increasingly turned to chemical fertilizers to support commercial crop production. However, this shift has become financially unsustainable for ordinary farmers due to the high costs involved. He emphasized that climate change and poor soil conditions have significantly altered crop cultivation patterns and deeply affected their livelihoods."

8.10 Conclusion

The livelihood status of the people of Attappady are closely linked with its climatic and environmental factors. As Attappady taluk straddling the ecological divide between the region of orographic precipitation to the west and the rain shadow to the east, the rain shadow effect significantly influences rural livelihoods, especially in areas where rural populations are heavily dependent on rain-fed agriculture. The climate variability, particularly changes in rainfall patterns and increasing temperature create most pervasive stresses on rural communities of this region. The rain shadow effect of diminished rainfall and increasing temperature lowered the crop yields and created the economic losses and made the region's farmers more susceptible to food shortages and economic hardship. Moreover, rapid population growth and in-migration in this region have led to high land use and land cover change which has forced indigenous communities to diversify their livelihoods, and resulted in socio-economic marginalization. Also, both the rain shadow effect and high land use and land cover change exacerbated the land degradation process in Attappady. The study of climate change and land degradation in Attappady have become crucial for understanding its effects on rural livelihoods. The degradation of land led to a decline in agricultural productivity in Attappady. Traditional food crops of the region were being replaced by cash crops, which has resulted in nutritional insecurity among the tribal populations. The economic pressures resulting from reduced agricultural productivity often led to changes in land use. The conversion of land for agriculture, coupled with the loss of forest cover, leads to increased vulnerability to erosion and landslides. Therefore, degradation of land in Attappady has profound socioeconomic implications for local communities. The land degradation further exacerbates social inequalities and increased difficulties in accessing resources, education, and healthcare again entrenching poverty within these communities.

The main objective of this study was to analyses people's perception and knowledge on the impact of rain shadow induced land degradation on agricultural land productivity and their livelihood status. The present study tried to examine the vital role of the topo climate and its impact in the livelihood of the common people. This study is carried out in the three panchayats, namely Agali, Pudur and Sholayur of the Attappady taluk. Out of the 384 respondents, majority of the respondents expressed that they have been experiencing the hot and dry climate with low rainfall and high temperature for last three decades and the rain shadow effect has dominant role in creating the condition of low rainfall, high temperature, dry wind flow, water scarcity, land degradation and low agriculture practice in the study area. These situations also have led to low agricultural production, more agricultural unemployment, more crop conversion and also influenced the livelihood status of the people of the study area. Therefore, it is very essential to adopt sustainable development programmes and policies from the part of central and state government with participation of local communities to cope up and overcome these adverse environmental conditions and to bring a conducive socio-economic situation for the future generation.

CHAPTER 9

RECOMMENDATIONS

CHAPTER 9

RECOMMENDATIONS

9.1 Introduction

The research titled "**An Appraisal of Rain Shadow Effects and Livelihood Dynamics in the Attappady Hilly Region, Western Ghats, Kerala**" has successfully uncovered several previously unexplored scientific insights into the rain shadow mechanism and its broader implications. The study primarily addressed three fundamental research questions: what is a rain shadow and where is it located? How is it formed? And how does it influence land degradation and threaten local livelihoods? Even though the findings of this study are supported by well-established theoretical frameworks and validated through analytical and empirical methods, the outcome of any research is not an end in itself, but rather a gateway to further inquiry. In this study, the initial research questions— "What is the rain shadow phenomenon?" and "Where does it occur?"—have been effectively addressed through the demarcation and spatial mapping of rain shadow–affected areas within the Attappady Hilly Region. For example, although the Attappady hilly region exists as a single physical unit within the Western Ghats, the research findings reveal distinct climatic variations across different parts of the hills. These variations underscore the significant influence of topography on the microclimatic conditions of the region. Such findings clearly demonstrate the role of topographic features in shaping atmospheric patterns, particularly in relation to the rain shadow mechanism. The micro-scale approach in climate studies offers innovative methods for addressing the climate change crisis at the grassroots level. Furthermore, the research extended its inquiry to the questions of "How?" and "Why?", which were explored through experimental research methods. The results not only responded to these questions but also highlighted the interaction between climate variables and topography, demonstrating how terrain features influence localized climatic responses. The genesis and process of the rain shadow mechanism in the Attappady hills has offered a new perspective and pioneered alternative approaches to microclimatic studies, applicable in broader geographical contexts as well. Furthermore, the scientific community has increasingly examined the global climate change crisis and its associated impacts on land degradation from multiple perspectives, emphasizing the need for localized, terrain-specific research to better understand and address these interconnected challenges. However, this research focuses on a unique climatic phenomenon—the rain shadow effect—at the local level, and investigates its adverse impacts on land, particularly through the deterioration of soil health and the decline in agricultural potential. The concluding section of this thesis addresses the challenges faced by the native communities of Attappady as a result of land degradation caused by the rain shadow effect. Evidence gathered through field-based experimental studies in the project area offers critical insights and provides a new vision for developing sustainable strategies to mitigate the climate-induced crises affecting the region. These findings serve as a foundation for informed planning, policy intervention, and community-based adaptation measures aimed at restoring ecological balance and securing livelihoods. Such research is essential to understand the relevance of the inclusion of the environmental dimension to the developmental perspectives. To prevent the unchecked flow of ecological refugees and to sustain life in the present world, the principle of unity between natural phenomena and the coexistence of all life in the world must always be kept in mind. This chapter consist of summary of the study and recommendations.

9.2 Summary of the Study

The research work is completed with nine chapters that includes four core chapters. The core chapters scientifically examined the rainshadow induced land degradation and associated livelihood crisis. Moreover, the completed research work tries to make a visionary practical outputs and policies for the sustainable development of man and nature. The Attappady Hills, located on the eastern slopes of the Western Ghats, form one of the most ecologically sensitive and socio-economically vulnerable regions in Kerala. Unlike the rest of the Western Ghats, which are known for their high rainfall and dense forest cover, Attappady falls within a distinct rain shadow zone due to the orographic influence of the Ghats that obstruct the southwest monsoon winds. The total geographical area of Attappady is about of 829.45 km^2 and a population of 64,318 (Census 2011), Attappady consists of seven villages and three panchayats: Agali, Puthur, and Sholayur. The region experiences a rain shadow effect, receiving significantly less rainfall on its eastern side compared to the west, with annual rainfall ranging from less than 500 mm in the east to 2084 mm in the west. The region's rivers, including Bhavani and Siruvani, and their tributaries support agriculture and life in this ecologically sensitive area. Its rugged topography, ranging from 200 to 2400 meters above sea level, influences population density and land use patterns, as high altitude areas are less suitable for habitation. The slopes, primarily gentle in the central and eastern parts and steep in the north and south, impact drainage, soil properties, and agricultural practices. Geologically, the area comprises charnockites, gneiss, and high-grade metamorphic rocks, with soils ranging from clay in the west to gravelly loam in the central region. This topographic positioning of Attappady results in reduced rainfall and higher surface temperatures, creating a semi-arid microclimate with profound implications for land use, agriculture, vegetation, and livelihoods. Given the region's increasing exposure to land degradation and its fragile ecological balance, a scientifically validated demarcation of the rain shadow zone is essential.

Demarcating the precise rain shadow region in Attappady is the core research problem. To achieve accurate delineation, a combination of remote sensing data, climatic records, and topographic inputs was used. The study utilised multi-temporal Landsat 8 satellite imagery for estimating land surface temperature and assessing vegetation patterns. Sentinel-2 imagery was employed to validate land cover conditions, while Shuttle Radar Topography Mission (SRTM) data provided a 30-metre resolution digital elevation model used to derive elevation, slope, and aspect. Climatic data, particularly rainfall and temperature for a 40-year period (1981–2022), were collected from Indian Meteorological Department (IMD) datasets and cross-verified using ground station data from Mannarkkad. Additional administrative boundary layers, including village and panchayat shapefiles, were sourced from Kerala State Spatial Data Infrastructure. All datasets were projected to a uniform coordinate system (WGS 84 / UTM Zone 43N) and resampled to 30-metre resolution to ensure spatial alignment.

The rain shadow region was delineated through a multi-criteria decision analysis using both topographic and climatic indicators. The parameters selected included elevation, slope, aspect, annual rainfall, land surface temperature, and vegetation condition measured through the Normalised Difference Vegetation Index (NDVI). Each raster layer was normalised using min-max scaling, and a weighted overlay analysis was performed based on weights derived through the Analytic Hierarchy Process (AHP). Expert consultations and literature review guided the assignment of weights, giving higher importance to rainfall, followed by elevation, slope, NDVI, land surface temperature, and aspect. The consistency ratio of the AHP matrix was calculated and found to be within the acceptable limit, ensuring methodological validity. Using the QGIS raster calculator, a composite index was generated and classified into five categories representing the intensity of rain shadow conditions from very low to very high.

The results revealed a clear spatial pattern of rain shadow intensity across Attappady. Areas located in the eastern and northeastern sectors, particularly those with higher elevations and western-facing slopes, exhibited pronounced rain shadow characteristics. These zones were marked by low annual rainfall, high surface temperatures, and sparse vegetation. Villages such as Thavalam and Sholayur showed a strong rain shadow presence, with over two-thirds of their total area falling under the high and very high rain shadow categories. These villages also recorded the lowest annual rainfall, with values averaging below 900 mm, and the highest land surface temperatures, frequently exceeding 35 degrees Celsius. Pudur and Kottathara were moderately affected, with a mix of degraded slopes and vegetated valleys, while Agali showed a slightly less intense rain shadow effect due to its relatively better water availability and valley-based microclimate.

The spatial analysis demonstrated that rain shadow severity corresponds closely with environmental stress indicators such as temperature rise, vegetation loss, and seasonal water scarcity. Areas with high rain shadow intensity also coincided with regions of increased soil erosion and agricultural instability, setting the stage for further investigation in the subsequent chapters. The demarcation provides crucial evidence that the rain shadow effect is not uniformly distributed across Attappady, but rather concentrated in specific villages and terrains. This underscores the importance of spatially targeted interventions rather than a one-size-fits-all development approach.

After the demarcation of the rain shadow affected region, this study follows with the objective of modelling microclimate variability and its effect on rain shadow using long-term meteorological and spatial data. The analysis revealed how topographic variation particularly elevation governs rainfall, temperature, wind speed, humidity, and vegetation distribution across the area. Rainfall patterns show a pronounced gradient due to orographic lift. On the windward side (Phase I), rainfall reaches a maximum of 5218 mm, while the leeward region (Phase III) receives only 2038 mm on average. A regression coefficient (R^2) of 0.30 indicates a moderate correlation between horizontal distance and rainfall, validating the orographic influence on precipitation. Temperature variation is narrower but significant, ranging from

21.26°C to 24.22°C. The highest temperatures were observed in Phase I, while cooler temperatures prevailed in Phase II. A weak regression value of 0.215 suggests that temperature variability is influenced by multiple factors, including vegetation and elevation, not distance alone. Wind speed ranged from 3.43 to 3.49 m/s, showing a moderate increase from west to east, with an R^2 of 0.50. This suggests katabatic or foehn winds occur due to descending dry air on the leeward side, a typical feature in rain shadow zones.

Unexpectedly, relative humidity increased from 74.18% on the western side to 78.62% in the east. This trend may be due to micro valley condensation, residual moisture transport, and vegetation effects, indicating complex local climatic dynamics. The Mann-Kendall test confirms an increasing temperature trend in both wet and dry zones, with a highly significant Z-value of 29.78 for the dry zone. Rainfall shows an upward trend in the wet zone but remains statistically less significant in the dry zone ($Z = 1.63$, $p = 0.10$). Vegetation, assessed through NDVI, further supports the rain shadow effect. The western slopes showed denser cover (NDVI up to 0.91), while the leeward zone exhibited sparse vegetation (average NDVI 0.16). The correlation between vegetation and moisture availability confirms that rainfall governs ecological diversity in this hilly landscape. The region was divided into three zones, Phase I (0–30 km), Phase II (30–60 km), and Phase III (above 60 km) based on elevation and climatic gradients. This zonation allowed detailed modelling of how microclimatic parameters shift from the moist windward side to the dry leeward side.

The Attappady region, situated in the eastern rain shadow zone of the Western Ghats, is highly susceptible to land degradation due to a combination of natural climatic stress and unsustainable human interventions. The limited rainfall caused by the rain shadow effect, compounded by high surface temperatures and terrain fragility, accelerates processes such as soil erosion, vegetation loss, and nutrient depletion. Over the past few decades, the ecological balance of the region has been increasingly disturbed, posing serious threats to agricultural sustainability, water availability, and biodiversity.

To assess land degradation in Attappady's rain shadow region, the Multi-Influencing Factor (MIF) technique was used as the core method, enabling a composite understanding of the spatial and environmental variables that contribute to land deterioration. The MIF technique works on the principle that land degradation is rarely caused by a single factor; instead, it is the result of the combined influence of multiple environmental and anthropogenic drivers. For this study, ten carefully selected parameters were used to model land degradation, each representing a specific aspect of landscape vulnerability. These include rainfall, slope, topographic wetness index (TWI), relief, land use and land cover (LULC), NDVI, road density, drainage density, groundwater potential, and soil texture. These parameters were chosen based on their relevance to the terrain and climatic profile of Attappady and their documented impact on soil stability, vegetation condition, and surface processes. The generated outputs were classified into four categories: stable, moderately degraded, highly degraded, and severely degraded zones.

The results showed a significant increase in degraded land across Attappady, particularly in the villages of Sholayur, and parts of Pudur. Between 1987 and 2022, dense forest areas declined by over 18%, with corresponding increases in degraded scrub and barren lands. In Sholayur, over 62% of the area displayed signs of moderate to severe degradation, characterised by patchy vegetation, deep gully erosion, and exposed laterite. Pudur showed mixed conditions, with valley regions remaining relatively stable while higher ridges experienced deforestation and land abandonment. Agali and Kottathara, while showing signs of degradation, had better resilience due to their relatively moderate slopes and presence of perennial streams.

Soil quality stands as the fundamental pillar of agricultural productivity and ecological stability, representing the delicate balance of physical, chemical, and biological properties that sustain life. In the unique rainshadow region of Attappady, Kerala, this balance faces a critical challenge. Sheltered by the Western Ghats from monsoon rains, the area is prone to arid conditions that intensify the threat of land degradation, creating a vicious cycle where weakening soil leads to further environmental decline. This study delves into this complex relationship, evaluating how land degradation impacts soil health across Attappady and identifying pathways toward sustainable restoration.

Land degradation has a direct and detrimental effect on soil quality. The conversion of forests and grasslands to agricultural or barren lands, coupled with improper management practices, strips the soil of its protective vegetative cover. This loss accelerates the depletion of Soil Organic Carbon (SOC), a key indicator of soil health, and essential nutrients like nitrogen (N), phosphorus (P), and potassium (K). Consequently, the soil's capacity to retain water, support microbial life, and maintain its structure is severely compromised, leading to reduced fertility and lower agricultural yields. The rainshadow effect exacerbates these issues by limiting the moisture available for vegetation growth, making the exposed soil even more vulnerable to erosion and nutrient loss.

To quantify these impacts, this study employed a comprehensive methodology, collecting 28 soil samples from various land use types across Attappady. These samples were subjected to laboratory analysis for 13 key parameters, including pH, Electrical Conductivity (EC), macronutrients, micronutrients, and organic carbon. The data was then synthesized using Principal Component Analysis (PCA) to develop a holistic Soil Quality Index (SQI). The findings show the clear picture of the region's soil health:

- A significant portion of the area (30.08%) suffers from low organic carbon (<0.50%), and a similar area (30.02%) is deficient in low nitrogen (<280 kg/ha), both critical for soil fertility.
- The region exhibits major nutrient imbalances, heavily influenced by the arid climate. High magnesium levels (>150 ppm) were found in 97% of samples, and high calcium (>1600 ppm) in 6%, particularly in degraded, non-agricultural lands where limited rainfall prevents leaching.
- While most of the soil is favorably non-saline (30.08%) with a pH range from slightly acidic to normal, localized deficiencies in micronutrients like boron and zinc are prevalent, reflecting the varied impact of land use and degradation.

The resulting Soil Quality Index (SQI) categorized the region's soils from "very poor" to "excellent." The analysis revealed that while a majority of the taluk (64.03%) possesses "good" soil quality, a substantial combined area of 15.73% is classified as "poor" or "very poor," primarily concentrated around Sholayur and Agali. Crucially, a strong spatial correlation was established: areas with "Very Poor" soil quality (17%) corresponded directly with zones of "high" land degradation (28%). Conversely, "good" soil quality (28%) was linked to "low" degradation (40%), proving that healthy soil is resilient soil. The PCA model identified magnesium, pH, and phosphorus as the most dominant factors influencing soil quality, highlighting them as key targets for management interventions.

The livelihood and well-being of communities in the Attappady region are intrinsically tied to the health of their land and the stability of their climate. This study reveals that the region, situated in a distinct rain shadow zone, faces a critical convergence of environmental and socio-economic pressures. The dual threats of climate change characterized by rising temperatures and erratic rainfall and consequent land degradation have placed immense strain on the predominantly agriculture-based livelihoods. This has created a precarious situation, pushing local communities, especially indigenous populations, towards economic hardship, food insecurity, and socio-economic marginalization. Understanding the local population's perception of these interconnected challenges is paramount for developing effective and sustainable solutions.

To investigate these dynamics, this research adopted a comprehensive mixed-method approach within the three panchayats of Attappady: Agali, Pudur, and Sholayur. The study was grounded in primary data collected from 384 households, selected through a multistage sampling procedure. A combination of structured surveys, in-depth focus group discussions with experienced farmers, and direct field observations was employed to capture a holistic view of the situation. This methodology allowed for the validation of residents' perceptions with scientific data, ensuring a robust and nuanced analysis of the challenges faced by the community.

The demographic context of Attappady is crucial to understanding the current pressures on its resources. Historically a tribal-majority area, the region has undergone a significant demographic transformation since the mid-20th century due to large-scale in-migration. This has shifted the indigenous communities into a minority, intensifying the pressure on land and traditional livelihoods. The study's respondents reflected this complex social fabric, comprising both native people (61.2%) and migrants (38.8%), with a significant representation of Scheduled Tribes (46.6%) and a majority falling below the poverty line (62.8%), highlighting the vulnerability of the population.

The community's perception of climatic variability is both clear and alarming. An overwhelming majority of residents (72.9%) describe their climate as "Hot and Dry." They directly attribute this to the rain shadow effect, with 84.9% of respondents articulating that the western hills block rain-bearing winds, resulting in low rainfall, high temperatures, and severe water scarcity on the eastern side. This local knowledge is not merely anecdotal; it is strongly supported by the study's statistical analysis, which confirmed a significant negative correlation (-.994) between increasing temperature and decreasing rainfall, validating the lived experiences of the people.

The tangible impacts of this altered climate on land and livelihoods are profound. Respondents perceive a significant decline in soil quality, with 86% noting decreased fertility and a majority identifying their land as infertile sandy or gravelly soil. This perception aligns with the study's finding that over half the region suffers from moderate to very high levels of land degradation. This environmental decline has triggered a dramatic shift in the local economy. Agriculture, once the primary occupation for nearly 59% of residents, now solely supports only 20.1%. Many have been forced to abandon farming, decrease their cultivated land, and seek alternative income through daily wage labor or government schemes like MGNRES. This has led to the disappearance of traditional food crops like paddy and millets, which are being replaced by less water-intensive cash crops or, increasingly, left as fallow land. The cascading effects include not only agricultural unemployment and economic loss but also a critical threat to the nutritional security and cultural heritage of the Attappady people.

9.3 Recommendations for Sustainable Development of the Rain shadow affected areas in the Attappady Hilly Region

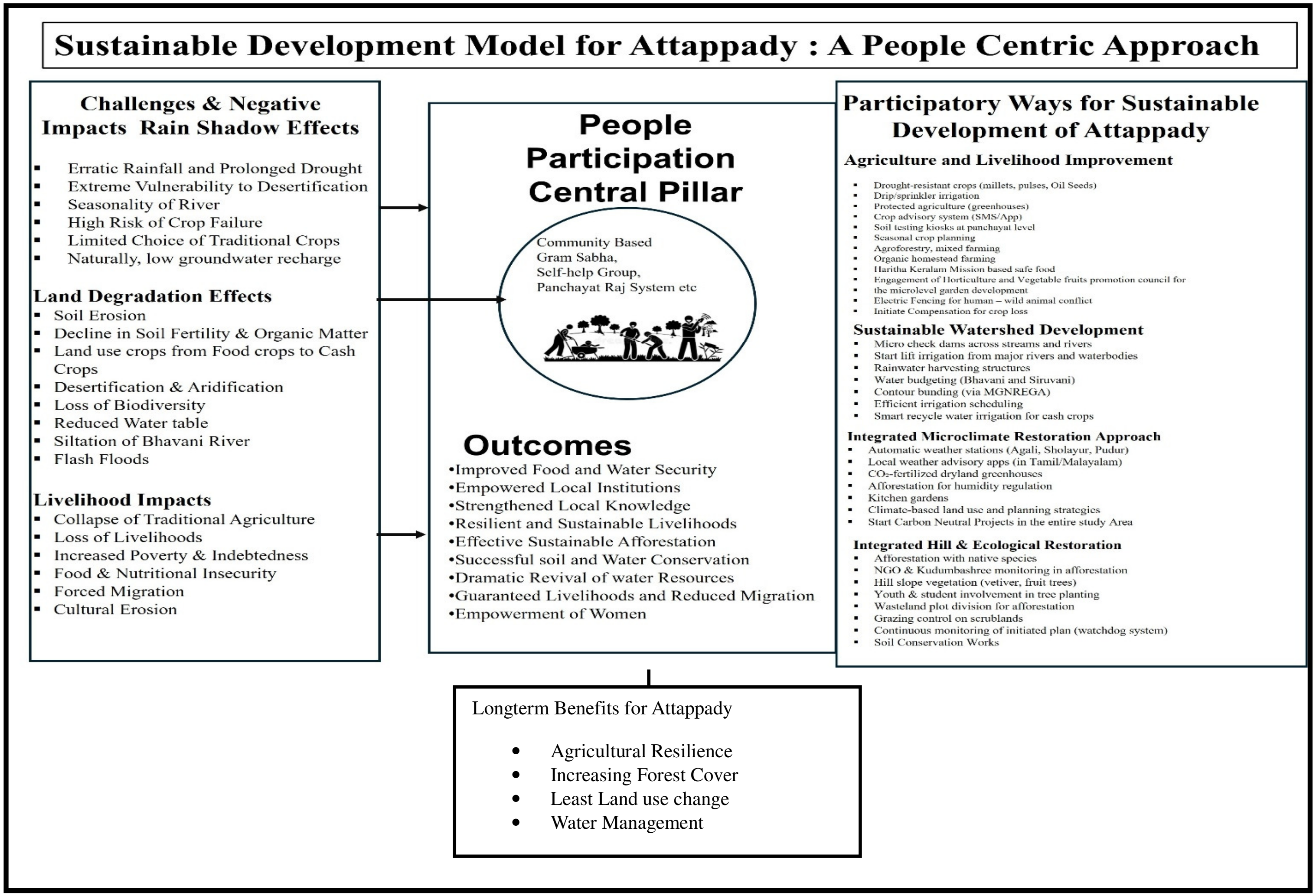
The rain shadow region of Attappady, nestled on the eastern slopes of the Western Ghats, is a land of both ecological richness and deep vulnerability. Despite its natural beauty and cultural heritage, the area faces critical challenges such as erratic rainfall, soil degradation, deforestation, and declining agricultural productivity. These issues have not only disrupted the fragile environment but have also severely impacted the livelihoods of indigenous communities who depend on the land for their sustenance. Over the years, unsustainable land use practices, the neglect of traditional knowledge systems, and the absence of inclusive development planning have worsened the region's socio-economic condition. Therefore, there is an urgent need for a sustainable development approach that maintains ecological balance, empowers local communities especially women and tribal groups and promotes long-term resilience through soil conservation, afforestation, water resource management, and livelihood diversification. The following section discusses various strategies, programmes and suggestions for fostering sustainable development in the Attappady rain shadow region through active local participation.

9.3.1 Sustainable Agriculture Initiatives for the Attappady Hilly Region

In Attappady, agriculture is one of the most vulnerable sectors to climate change-induced water scarcity. Continuous innovation and cutting-edge technology are crucial for sustainable farming in these harsh environments. Agricultural development in the rain shadow regions of Attappady is both a necessity and a challenge due to adverse climatic conditions. Success in this sector depends on sustained government support. Therefore, the researcher suggests for sustainable agricultural practices should be closely aligned with existing government initiatives and community participation. The government schemes should address the climate challenges of region, restore soil productivity, and ensure food security. These schemes should include the programs like promoting drought-resistant crops of millets and pulses, encouraging organic farming, improving soil fertility, and introducing integrated farming systems resilient to low-moisture conditions. These interventions aim to reduce input costs, diversify income sources, and stabilize crop yields. Integrating scientific practices with subsidies, crop insurance, and training enhances resilience and long-term sustainability. Indigenous communities in Attappady have a rich history of cultivating drought-resistant crops, and their traditional knowledge is invaluable for crop selection and management. Actively involving farmer groups, cooperatives, and tribal communities in planning and implementation ensures context-specific, culturally appropriate, and sustainable outcomes. Empowering local stakeholders to transforms them from beneficiaries into change-makers, and enable the agriculture in Attappady not just to survive, but to thrive.

9.3.2 Sustainable Land Management Practices for the Attappady Hilly Region

Land degradation in Attappady, highlights the complex interplay of natural and anthropogenic factors, including recurring droughts, deficient rainfall, and unsustainable land use practices. The deforestation, shifting cultivation, and loss of fertile land have resulted in soil moisture stress, water stress, and ecological degradation. This degradation has made a pressing issue on extreme socio-economic marginalization of the indigenous people. Therefore, there should be an urgent strategy for sustainable land management practices to mitigate land degradation and restore the ecological balance in Attappady. A comprehensive approach, combining advanced geospatial analysis with community-based interventions is essential to restoring degraded lands, conserving biodiversity, and enhancing the resilience of vulnerable communities. Empowering local communities through education, capacity-building, and alternative livelihood opportunities to alleviate the socio-economic impacts of land degradation. Encourage some interventions such as reforestation, soil conservation, water resource management, and the promotion of sustainable agricultural practices to reversing the degradation trends through the involvement of Gram Panchayats, local institutions, and community-based organizations. By adopting these kinds of interventions, we can achieve durable improvements in land productivity, water conservation, and livelihood security.



Source: Prepared by Researcher

Fig. 9.1: Sustainable Development Model for the Attappady Hilly Region

9.3.3 Sustainable Watershed Plan for the Attappady Hilly Region

Watershed development is critical for Attappady's rain shadow regions, where chronic water scarcity threatens agriculture and livelihoods. A holistic, community driven approach is needed to address this challenge. These initiatives align with national programs such as the Integrated Watershed Management Programme (IWMP), Jal Shakti Abhiyan, and the National Mission for a Green India, which support soil and water conservation, groundwater recharge, and ecological restoration. The collective impact of these measures will restore the hydrological balance, enhance agricultural productivity, support livestock, and ensure water availability for domestic use. Reviving traditional water harvesting systems further strengthens community resilience. The success of these watershed initiatives depends on decentralized planning and community participation. Empowering Panchayats and local watershed committees to identify, plan, and implement context specific solutions ensures that the unique needs of each micro watershed are met. This participatory approach promotes collective ownership, encourages long term maintenance, and builds social unity around natural resource management, laying the foundation for sustainable and inclusive water security in Attappady.

9.3.4 Integrated Hill and Ecological Restoration Programs for the Attappady Hilly Region

A dedicated hill area development strategy is vital to address the complex topographical and ecological challenges of Attappady's upland rain shadow regions. This plan should prioritize eco restoration through afforestation with native species, slope stabilization, and vegetative cover enhancement using fruit trees, and agroforestry species (Fig 9.2). Dividing degraded wastelands into manageable plots for afforestation and involving local youth and students in plantation drives will help restore the ecological balance while building environmental awareness at the grassroots. Additionally, grazing control in scrublands and the adoption of continuous monitoring systems, including a watchdog mechanism managed by NGOs and Kudumbashree units, will ensure the long-term success and sustainability of these efforts.

Such interventions will reduce soil erosion, mitigate the risk of landslides, and support microclimate stabilization, while also opening livelihood opportunities in horticulture, agroforestry, and ecotourism. For remote tribal settlements in the hill zones, these ecological improvements must be paired with rural infrastructure development particularly improved road access, market connectivity, and service delivery systems. The success of this plan hinges on the active participation of local self-governance institutions and community-based organisations, ensuring that projects are locally relevant, transparent, and inclusive. Critically, integrating indigenous knowledge and traditional land management practices will strengthen both ecological and cultural sustainability, making the restoration process truly effective and resilient in the long term. A robust resource management plan is essential for the sustainable use of soil, water, forests, and biodiversity, all of which are under strain in Attappady's rain shadow areas. Our approach (Fig 9.2) focuses on rehabilitating degraded ecosystems, conserving native flora and fauna, and promoting the efficient use of resources through initiatives like western Ghats development programs, carbon neutral projects, National Mission on climate and agriculture, systematic soil health monitoring, large scale afforestation, and community led forest management. The expected outcomes include improved soil fertility, increased forest cover, and greater resilience to climate shocks. At the household level, these benefits would translate into better access to firewood, fodder, and nontimber forest products, directly supporting rural livelihoods. The foundation of this strategy is community-based resource governance. By empowering local bodies of village ecodevelopment committees or Vana Samrakshana Samithis, we can enable residents to safeguard their natural heritage. This approach ensures that conservation goals are effectively aligned with local livelihood needs, making the entire effort more sustainable and impactful.

9.3.5 An Integrated Approach to Microclimate Restoration for the Attappady Hilly Region

Improving the local climate in the dry regions of Attappady is essential for the well-being of both people and nature. These areas often face problems of low rainfall, high temperatures, and poor soil conditions. To solve these issues, we need a combined effort that brings together farming, water conservation, hill area development, and better use of natural resources. This can be done by making good use of government programs and, most importantly, by involving the local people especially Self-Help Groups (SHGs) in planning and carrying out the work. Some simple but effective steps include setting up weather stations in Agali, Sholayur, and Pudur to provide timely weather updates to the local people. Since this area receives high solar radiation, solar energy can be promoted for irrigation, powering automated weather stations, and supplying clean energy to households. The government should support the installation and maintenance of these systems.

We can also use mobile apps in local languages of Malayalam and Tamil to share information about weather, pests, and farming tips. Planting more trees across the region will help keep the land cooler and hold more moisture in the soil. At the same time, encouraging kitchen gardens and shade loving crops can help families grow their own food, even during dry spells. Greenhouses that use less water and protect crops from harsh weather can also make a big difference. We should also plan land use carefully, based on the climate and needs of each area. Starting carbon reduction projects in the region can help slow down the effects of climate change. When all these efforts come together, the land becomes cooler, crops grow better, and people feel less pressure from extreme heat and water shortage. Over time, these changes will lead to healthier land, better farming, and stronger, more self-reliant communities in Attappady.

9.3.6 A Community Based Approach to Sustainable Development for the Attappady Hilly Region

To address the rain shadow and its associated issues, active community participation and decentralized governance in the sustainable development programme is essential. Our plan is designed (Fig 9.2) around a bottom-up approach, actively involving Gram Panchayats, local institutions, and community-based organizations in every stage of planning and implementation. When local people are treated as stakeholders rather than mere beneficiaries, it builds trust, accountability, and stronger ownership of projects. This deep level of community participation ensures that interventions are culturally appropriate, address genuine needs, and are maintained over the long term. By adopting this model, we can achieve durable improvements in land productivity, water conservation, and livelihood security, all while reinforcing democratic practices at the grassroots level. Thus, this study area, Attappady, has a unique geographical location and climatic condition with Western Ghats that obstruct the moisture laden wind from the Arabian sea and causing 'rain shadow' on the eastern part of Attappady and making an ecological divide between the region of orographic precipitation to the west and the rain shadow to the east in Attappady. The combined effects of both the physiography and rain shadow induced climate and land degradation have exerted more impact on land, soil, vegetation and livelihood dynamics of the people of Attappdy. Through the proper strategies and suggestions, we can foster sustainable development in the rain shadow region of Attappady with help of active community participation and decentralized governance.

…………………………………………

REFERENCES

Sl. No.	Contents
1	**BIBLIOGRAPHY**
2	**APPENDIX**
3	**QUESTIONNAIRE**
4	**FIELD PHOTOS**
5	**LIST OF RESEARCH PAPERS PUBLISHED**
6	**DETAILS OF RESEARCH PAPERS PRESENTED IN THE CONFERENCE**

BIBLIOGRAPHY

A.D, M., & Kurian, V. M. (2016). Theory and Practical Implication of Land Degradation and Livelihood: Case of Attappady Region in Kerala. Asia-Pacific Journal of Rural Development, 26(1), 85–104. doi.org/10.1177/1018529120160103

AbdelRahman, M. A. E., Natarajan, A., Hegde, R., & Prakash, S. S. (2019). Assessment of land degradation using comprehensive geostatistical approach and remote sensing data in GIS-model builder. Egyptian Journal of Remote Sensing and Space Science, 22(3), 323–334. doi.org/10.1016/j.ejrs.2018.03.002

Abdu, A., Laekemariam, F., Gidago, G., & Getaneh, L. (2023). Explaining the Soil Quality Using Different Assessment Techniques. Applied and Environmental Soil Science, 2023. https://doi.org/10.1155/2023/6699154

Abdulmalik, Kemalo, and Isreal Zewide. "Effect of land degradation on livelihood." Asian J Plant Sci Res 11.5 (2021): 149-153

Abu Hammad, A., & Tumeizi, A. (2012). Land degradation: Socioeconomic and environmental causes and consequences in the eastern Mediterranean. Land Degradation and Development, 23(3), 216–226. doi.org/10.1002/ldr.1069

Adam, H. N., Kjosavik, D. J., & Shanmugaratnam, N. (2018). Adaptation trajectories and challenges in the Western Ghats: A case study of Attappady, south India. Journal of Rural Studies, 61, 1–11. https://doi.org/10.1016/j.jrurstud.2018.05.002

Adams, R.M.; Hurd, B.H.; Lenhart, S.; Leary, N. Effects of global climate change on agriculture: An interpretative review. Clim. Res. 1998, 11, 19–30. [CrossRef]

Adger N, Dessai S, Goulden M, Hulme M, Lorenzoni I, Nelson R, Naess O, Wolf J, Wreford A (2009). Are there social limits to adaptation to climate change? Climatic Change 93:335–354

Adjekukor, J. A., & Joseph, O. O. (2024). Soil Quality Index Modeling for Sustainable Agriculture in Niger Delta: A Statistical Approach. International Journal of Research Publication and Reviews, 5200–5207. doi.org/10.55248/gengpi.5.0624.1587

Adlakha, V., Lang, K. A., Patel, R. C., Lal, N., & Huntington, K. W. (2013). Rapid long-term erosion in the rain shadow of the Shillong Plateau, Eastern Himalaya. Tectonophysics, 582, 76–83. doi.org/10.1016/j.tecto.2012.09.022

Adugna, A., & Abegaz, A. (2016). Effects of land use changes on the dynamics of selected soil properties in northeast Wellega, Ethiopia. *Soil*, *2*(1), 63-70.

AHADS Status Report 2010

AHADS, 2008. Status report, Attappady Hill Area Development Society (AHADS), Attappady, Kerala, India, pp. 5-26

Ahmad, N., & Pandey, P. (2018). Assessment and monitoring of land degradation using geospatial technology in Bathinda district, Punjab, India. Solid Earth, 9(1), 75–90. doi.org/10.5194/se-9-75-2018

Aighewi I T, Nosakhare O K, Ishaque A B (2013) Land use – land cover changes and sewage loading in the Lower Eastern shore watersheds and coastal bays of Maryland: Implications for surface water quality. Journal of Coastal Research 29(5): 1073-1082

Akinori, Takeuchi., Peter, B., Larson. (2005). Oxygen isotope evidence for the late Cenozoic development of an orographic rain shadow in eastern Washington, USA. Geology, 33(4):313-316. doi: 10.1130/G21335.1

Akinyemi, F. O., Tlhalerwa, L. T., & Eze, P. N. (2021). Land degradation assessment in an African dryland context based on the Composite Land Degradation Index and mapping method. Geocarto International, 36(16), 1838–1854. doi.org/10.1080/10106049.2019.1678673

Alex, J., & Arunkumar, T. A. (2024). Western Ghats Dilemma: Conservation Vs Livelihood. Ecology, Environment & Conservation, 30(Suppl.), S22–S27. https://doi.org/10.53550/eec.2024.v30i07s.005

Alexander, J., Zaslavski. (2023). Impact of Fluctuations in Rainfall on the Livelihoods of Families in the Rain Shadow Zone of Maharashtra State: A Historical Perspective. 241-256. doi: 10.1007/978-981-19-8722-9_14

Alexander,T.G., Balagopalan, M., Thomas, T. P., Mary, M.V., Sankar, S., and Nair, S.S. 1986. Soils in relation to anthropic disturbances: A case study in the western half of Attappady in Kerala. Eco-development of Western Ghats. KFRI Scientific Paper No. 468: 229-232

Alexis, Berg., Benjamin, R., Lintner., Kristen, Findell., Sonia, I., Seneviratne., Bart, van, den, Hurk., Agnès, Ducharne., Frédérique, Cheruy., Stefan, Hagemann., David, M., Lawrence., Sergey, Malyshev., Arndt, Meier., Pierre, Gentine. (2015). Interannual Coupling between Summertime Surface Temperature and Precipitation over Land: Processes and Implications for Climate Change*. Journal of Climate, 28(3):1308-1328. doi: 10.1175/JCLI-D-14-00324.1

Alkaradaghi, K., Ali, S. S., Al-Ansari, N., Laue, J., & Chabuk, A. (2019). Landfill site selection using MCDM methods and GIS in the Sulaimaniyah Governorate. Iraq. Sustainability, 11(17), 4530.

Anaeze, C., Offodile, II. (2022). Climate Change and Its Impacts Assessment Through Geospatial Technology-A Theoretical Study from Extreme Weather Perspective for Disasters Resilient India. 425-436. doi: 10.1007/978-981-19-3567-1_25

Andreas, Dieter, Muehlbauer. (2006). Dynamics vs. aerosol induced warm-phase microphysics and orographic precipitation.

Annan, Wu., Guoping, Li. (2022). Roles of the Topographically-Affected Boundary Layer Low-Level Jet in the Moisture Transport Process of Nocturnal Rainstorms in Mountainous Areas around the Western Sichuan Basin. Atmosphere, 14(1):84-84. doi: 10.3390/atmos14010084

Aparecido, L. E. de O., Cabral de Moraes, J. R. da S., Meneses, K. C. de, Torsoni, G. B., Lima, R. F. de, & Costa, C. T. S. (2020). Köppen-Geiger and Camargo climate classifications for the Midwest of Brasil. Theoretical and Applied Climatology, 142(3), 1133–1145. https://doi.org/10.1007/S00704-020-03358-2

Ariel, A., Farias., Ariel, A., Farias., Ariel, A., Farias., Cristina, Armas., Cristina, Armas., Aurora, Gaxiola., Alex, P., Cea., Jose, Luis, Cortés., Ramiro, Pablo, López., Ramiro, Pablo, López., Fernando, Casanoves., Milena, Holmgren., Peter, L., Meserve., Peter, L., Meserve., Julio, R., Gutiérrez., Douglas, A., Kelt., Douglas, A., Kelt. (2021). Species interactions across trophic levels mediate rainfall effects on dryland vegetation dynamics. Ecological Monographs, 91(2) doi: 10.1002/ECM.1441

Ashish, Alex., K., Vidyasagaran. (2016). The marketing of non-timber forest products in the western ghats region of Attappady, Kerala. Economic Affairs, 61(3):355-363. doi: 10.5958/0976-4666.2016.00046.2

Asrat, P., & Simane, B. (2018). Farmers' perception of climate change and adaptation strategies in the Dabus watershed, North-West Ethiopia. Ecological Processes, 7(1). https://doi.org/10.1186/s13717-018-0118-8

B., N., Suma., C., V., Srinivasa. (2021). Impact of Rainfall on Land Use and Land Cover Analysis. 809-821. doi: 10.1007/978-981-15-6828-2_59

Baatuuwie, B., Agyare, W. A., & Forkuo, E. K. (2017). COMMUNITIES' PERCEPTIONS OF LAND DEGRADATION: A CASE STUDY IN THE SAVANNA BELT OF THE WHITE VOLTA BASIN. https://www.researchgate.net/publication/314217470

Bandyopadhyay, S., Jaiswal, R. K., Hegde, V. S., & Jayaraman, V. (2009). Assessment of land suitability potentials for agriculture using a remote sensing and GIS based approach. International Journal of Remote Sensing, 30(4), 879–895. doi.org/10.1080/01431160802395235

Barry, R. G., & Blanken, P. D. (2016). Microclimate and Local Climate. https://www.cambridge.org/core/books/microclimate-and-local-climate/E97B39EE505CC7FEDC0C971653F13F45

Barstad, I., Grabowski, W. W., & Smolarkiewicz, P. K. (2007). Characteristics of large-scale orographic precipitation: Evaluation of linear model in idealized problems. Journal of Hydrology, 340(1–2), 78–90. doi.org/10.1016/j.jhydrol.2007.04.005

Batterbury, S. (2001). Landscapes of Diversity: A Local Political Ecology of Livelihood Diversification in South-Western Niger. Ecumene, 8(4), 437–464. doi.org/10.1177/096746080100800404

Belij, S., Ducic, V., Radovanović, M., & Milovanović, B. (2007). Climate zoning and position of the upper forest limit on the Mt. Stara Planina. 57, 21–34. https://scindeks.ceon.rs/article.aspx?artid=0514-58990702021b

Bhagat, R., Shimpale, V. B., Deshmukh, R. B., Pawar, S., Mahavidyalaya, M., & Baramati, S. (2017). Floristic Diversity and Conservation Assessment of Important Species in Baramati-A Rain-shadow Area. 1, 11–14. www.ajesjournal.com.

Bhardwaj, A. (2024). Impact of Global Warming. International Journal Of Recent Trends In Multidisciplinary Research, 10–14. https://doi.org/10.59256/ijrtmr.20240405002

Bhatta, G. D., Aggarwal, P. K., & Shrivastava, A. (2015). Livelihood diversification and climate change adaptation in Indo-Gangetic plains: implication of rainfall regimes. Journal of Agriculture and Environment, 16(June), 77–94. doi.org/10.3126/aej.v16i0.19841

Bhatta, G. D., Aggarwal, P. K., & Shrivastava, A. (2015). Livelihood diversification and climate change adaptation in Indo-Gangetic plains: implications of rainfall regimes. Journal of Agriculture and Environment, 16(June), 77–94. doi.org/10.3126/aej.v16i0.19841

Borderieux, J., De Lombaerde, E., De Pauw, K., Sanczuk, P., Vangansbeke, P., Vanneste, T., De Frenne, P., Gégout, J., & Serra-Diaz, J. M. (2024). Topoclimate buffers floristic diversity from macroclimate in temperate mountain forests. https://doi.org/10.32942/x2xc8t

Borivoj, Sarapatka., Marek, Bednar. (2022). Rainfall Erosivity Impact on Sustainable Management of Agricultural Land in Changing Climate Conditions. Land, 11(4):467-467. doi: 10.3390/land11040467

Bouma, J.: Land quality indicators of sustainable land management across scales, (2002). Agr. Ecosyst. Environ., 88, 129–136, doi.org/10.1016/S0167-8809(01)00248-1.

Brabant, P. (2010). A Land Degradation Assessment and Mapping Method. A Standard Guideline Proposal, 8, 1–56. http://horizon.documentation.ird.fr/exl-doc/pleins_textes/divers12-04/010054639.pdf

Brilla B J, Lancelet T S (2015) Land use change and its impact on water quality – A case study of Kalady Panchayat, Kerala, India. Land use/land cover changes and its impact: Spatial challenges and Geospatial Technologies 1 : 266-280

Bruce, Lankford., Catherine, M., Pringle., Jon, Stuart., McCosh., Mlungisi, Maxwell., Shabalala., Tim, Hess., Jerry, W., Knox. (2022). Irrigation area, efficiency and water storage mediate the drought resilience of irrigated agriculture in a semi-arid catchment.. Science of The Total Environment, 859: doi: 10.1016/j.scitotenv.2022.160263

Brye K R, Pirani A L (2005) Native soil quality and the effects of Tillage in the Grand Prairie Region of Eastern Arkansas. The American Midland Naturalist 154 : 28-41.

Bunning, S., McDonagh, J., & Rioux, J. (2011). Manual for local level assessment of land degradation and sustainable land management. Part 1 – Planning and Methodological Approach, Analysis and Reporting. Lada, 165.

Burton S, Shah P B, Schreier H (1989) Soil degradation from converting forest land into agriculture in the Chitawan District of Nepal. Mountain Research and Development 9 : 393-404.

C. J. Tucker and S. E. Nicholson, "Variations in the Size of the Sahara Desert from 1980 to 1997," Ambio, Vol. 28, 1999, pp. 587-591

Carlos, N., A., Salinas, Rodriguez., Richard, Ashley., Berry, Gersonius., Jeroen, Rijke., Assela, Pathirana., Chris, Zevenbergen. (2014). Incorporation and application of resilience in the context of water-sensitive urban design: linking European and Australian perspectives. Wiley Interdisciplinary Reviews: Water, 1(2):173-186. doi: 10.1002/WAT2.1017

Carney D 1998 Approaches to sustainable livelihoods for the rural poor Poverty Briefing Overseas Development Institute, London

Celine, Van, den, Hende., Bert, Van, Schaeybroeck., Bert, Van, Schaeybroeck., Jan, Nyssen., Sander, Van, Vooren., Michiel, Van, Ginderachter., Michiel, Van, Ginderachter., Piet, Termonia., Piet, Termonia. (2021). Analysis of rain-shadows in the Ethiopian Mountains using climatological model data. Climate Dynamics, 56(5):1663-1679. doi: 10.1007/S00382-020-05554-2

Chatterjee, B., & Dwivedi, A. (2022). Challenges of Climate Resilient Livelihoods and an Inquiry of Mitigation Strategies in India (pp. 3–22). https://doi.org/10.1007/978-981-16-6966-8_1

Che Lat, D., Mat Yusof, D. A., Yasin, M. H., Razali, R., Zainuddin, A. N., Kasuan, N., & Mohamed Jais, I. B. (2024). Soil quality index at pasir gudang industrial area. Deleted Journal, 36(1), 17–22. doi.org/10.11113/mjce.v36.21606

Chris, Fremantle., Leslie, Mabon. (2021). Cultural Adaptations: lessons learned evaluation report. doi: 10.48526/RGU-WT-1513437

Cochran,W.G (1984), Sample size determination and sample techniques

Coelho, A. P., Tassim, I. A., Orioli, Y. U., Cardoso, E. N. L., & Fernandes, C. (2024). Soil quality index to access the impacts of long-term vinasse application in sugarcane areas. Soil Science Society of America Journal. doi.org/10.1002/saj2.20785

Colle, B. A. (2004). Sensitivity of orographic precipitation to changing ambient conditions and terrain geometries: An idealized modeling perspective. Journal of the Atmospheric Sciences, 61(5), 588–606. doi.org/10.1175/1520-0469(2004)

Colle, B. A. (2008). Two-dimensional idealized simulations of the impact of multiple windward ridges on orographic precipitation. Journal of the Atmospheric Sciences, 65(2), 509–523. doi.org/10.1175/2007JAS2305.1

Cristina, Radin., Verònica, Nieves. (2024). Exploring Regional Ocean Climate Variability: Insights from Integrated Clustering and Principal Component Analysis. doi: 10.5194/egusphere-egu24-120

Critchfield H J (2009) General Climatology. PHI Learning Private Limited - New Delhi, Fourth Edition

Dai, Q. (2024). Impact of Climate Change on the Emergence and Decline of Ancient Civilizations-Historical Climate Reconstruction from Earth Science Perspectives. Deleted Journal, 3, 276–281. https://doi.org/10.62051/q7wcg470

Daily, G. C. (1995). Restoring value to the world's degraded lands. Science, 269(5222), 350-354.

Dakeso, T. (2024). The Status of Land Degradation Induced by Soil Erosion and Management Options in Duna District, Hadiya Zone, Central Ethiopia. Hydrology, 12(4), 85–91. https://doi.org/10.11648/j.hyd.20241204.12

Dale V H (1997) The relationship between land use change and climate change. Ecological Applications 7 : 753-769

Daly, C., Taylor, G., & Gibson, W. (1997). The Prism approach to mapping precipitation and temperature.10thAMSConferenceonAppliedClimatology,1,14. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.730.5725&rep=rep1&type=pdf

Damseaux, A., Fettweis, X., Lambert, M., & Cornet, Y. (2020). Representation of the rain shadow effect in Patagonia using an orographic-derived regional climate model. International Journal of Climatology, 40(3), 1769–1783. doi.org/10.1002/joc.6300

Damseaux, A., Fettweis, X., Lambert, M., & Cornet, Y. (2020). Representation of the rain shadow effect in Patagonia using an orographically derived regional climate model. International Journal of Climatology, 40(3), 1769–1783. doi.org/10.1002/joc.6300

Das, A., & Mallick, P. H. (2024). Exploring livelihood dependency on provisioning ecosystem services in a protected tropical forest area of eastern India: keys to sustainable forest management. Environment, Development and Sustainability, 1-23.

Dawoe E K, Quashine S J S, Oppong S K (2014) Effect of land use conversion from forest to cocoa agroforest on soil characteristics and quality of a Ferric Lixisol in lowland humid Ghana. AgroforestSyst88 : 87-99.

De Frenne, P. (2017). Holocene book review: Microclimate and local climate. The Holocene, 27(10), 1607. https://doi.org/10.1177/0959683617719340

Debela, N., Mohammed, C., Bridle, K., Corkrey, R., & McNeil, D. (2015). Perception of climate change and its impact by smallholders in pastoral/agropastoral systems of Borana, South Ethiopia. SpringerPlus, 4(1). https://doi.org/10.1186/s40064-015-1012-9

Dejanira, Ferreira, Braz., Tércio, Ambrizzi., Rosmeri, Porfírio, da, Rocha., Iago, Algarra., Raquel, Nieto., Luis, Gimeno. (2021). Assessing the moisture transports associated with nocturnal low-level jets in continental South America. Frontiers in Environmental Science, 9 doi: 10.3389/FENVS.2021.657764

Deressa, T. T., Hassan, R. M., & Ringler, C. (2011). Perception of and adaptation to climate change by farmers in the Nile basin of Ethiopia. The Journal of Agricultural Science, 149(1), 23-31

Dharumarajan, S., Veeramani, S., Beeman, K., Lalitha, M., Janani, N., Srinivasan, R., & Hegde, R. (2019). Potential Impacts of Climate Change on Land Degradation and

Desertification: Land Degradation and Climate Change (pp. 183–195). IGI Global. https://doi.org/10.4018/978-1-5225-7387-6.CH010

Dianwei L, Zongming W, Kaishan S, Bai Z, Liangjun H, Ni H, Sumei Z, Ling L, Chunhua Z, Guangjia J (2009) Land use/cover changes and environmental consequences in Songnen Plains, NE China. Chin. Geogra. Sci. 19(4) : 299- 305

Dibas, Shrestha. (2013). Study of the precipitation characteristics around mountainous regions in South Asia and South America.

Dir, A. L., Cyders, M. A., Mosher, C. E., Rand, K. L., & Hazer, J. (2012). Head of the Graduate Program Date. 9(December).

Dlamini, P., & Chaplot, V. (2016). The Impact of Land Degradation on the Quality of Soils in a South African Communal Rangeland. InTech. https://doi.org/10.5772/63128

Dlamini, P., & Chaplot, V. (2016). The Impact of Land Degradation on the Quality of Soils in a South African Communal Rangeland. InTech. https://doi.org/10.5772/63128

Dula, Etana. (2011). Household Demographics, Assets, and Sustainable Rural Livelihoods: A Case Study from Rain-Endowed South Western Ethiopia. 265-281. doi: 10.1007/978-90-481-8918-2_13

Dung, N. M., & Hai Ninh, N. T. (2024). Farmers' Perceptions on Land Degradation: A Case Study in Vietnam. Current World Environment, 18(3), 1356–1369. https://doi.org/10.12944/cwe.18.3.35

Edison, E., & Devi, R. (2019). Tribal Land Alienation, Agricultural Changes and Food Culture Transition in Attappady. South Asia Research, 39(1), 61–77. https://doi.org/10.1177/0262728018817858

Eduardo, Weide, Luiz., Stephanie, Fiedler. (2023). Global climatology of low-level-jets: occurrence, characteristics, and meteorological drivers.doi:10.22541/essoar.169945233.35476430/v1

En, O., & Pc, A. (n.d.). Climate change monitoring and geoinformatics: A geospatial perspective. www.allmultidisciplinaryjournal.com

Erickson, J. L., & West, S. D. (2002). The influence of regional climate and nightly weather conditions on activity patterns of insectivorous bats. Acta Chiropterologica, 4(1), 17–24. doi.org/10.3161/001.004.0103

Erqi, Xu., Hongqi, Zhang. (2020). Change pathway and intersection of rainfall, soil, and land use influencing water-related soil erosion. Ecological Indicators, 113:106281-. doi: 10.1016/J.ECOLIND.2020.106281

Everest, T., Sungur, A., & Ozcan, H. (2021). Determination of agricultural land suitability with a multiple-criteria decision-making method in Northwestern Turkey. International Journal of Environ mental Science and Technology, 18(5), 1073–1088. doi.org/10.1007/s13762-020-02869-9

FAO. (1976). A framework for land evaluation. Italy.

FAO. (2006). Livelihood adaptation to climate variability and change in drought-prone areas of Bangladesh: developing institutions and options. In Case Study - Institutions for Rural Development, FAO (Issue No.5). cabi:20083073694

Feng, Q., Liu, W., & Xi, H. (2009). Relationship between soil physiochemistry and land degradation in the lower Heihe River basin of northwestern China. *Frontiers of Earth Science in China*, *3*(4), 490-499.

Ferrara, C., Barone, P. M., & Salvati, L. (2015). Towards a socioeconomic profile for areas vulnerable to soil compaction? A case study in a Mediterranean country. *Geoderma*, *247*, 97-107.

Fiona, Nunan. (2022). 2. Livelihoods. doi: 10.4324/9781003014041-3

Fitriani, Fitriani., Hesty, Tambajong., R., Lekatompessy., Fransin, Kontu., Imelda, C, Laode. (2023). The impact of the food crisis and climate change on the lives of local communities. doi: 10.22487/agroland.v0i0.1957

Flynn, W. J., Nesbitt, S. W., Anders, A. M., & Garg, P. (2017). Mesoscale precipitation characteristics near the Western Ghats during the Indian Summer Monsoon as simulated by a high-resolution regional model. Quarterly Journal of the Royal Meteorological Society, 143(709), 3070–3084. doi.org/10.1002/qj.3163

Foley J A, DeFries R, Asner G P, Barford C, Bonan G, Carpenter S R, Chapin F S, Coe M T, Daily G C, Gibbs H K, Helkowski J H, Holloway T, Howard E A, Kucharik C J, Monfreda C, Patz J A, Prentice C, Ramankutty N, Snyder P K (2005) Global Consequences of Land Use. Science 309 : 570-574

François-Nicolas, Robinne., Dennis, W., Hallema., Kevin, D., Bladon., Mike, D., Flannigan., Gabrielle, Boisramé., Christian, Bréthaut., Stefan, H., Doerr., Giuliano, Di, Baldassarre., Louise, Gallagher., Amanda, K., Hohner., Stuart, J., Khan., Alicia, M., Kinoshita., Rua, S., Mordecai., Rua, S., Mordecai., João, Pedro, Nunes., Petter, Nyman., Cristina, Santín., Gary, Sheridan., Cathelijne, R., Stoof., Matthew, P., Thompson., James, M., Waddington., Yu, Wei. (2021). Scientists' warning on extreme wildfire risks to water supply. Hydrological Processes, 35(5):58-. doi: 10.1002/HYP.14086

G, K, Khadse., Pawan, Labhasetwar., S, R, Wate. (2012). Water resource management: an Indian perspective. Journal of environmental science & engineering, 54(4):577-591.

Galewsky, J. (2008). Oregraphic clouds in terrain-blocked flows: An idealized modeling modeling study. Journal of the Atmospheric Sciences, 65(11), 3460–3478. doi.org/10.1175/2008JAS2435.1

Galewsky, J. (2009). Rain shadow development during the growth of mountain ranges: An atmospheric dynamics perspective. Journal of Geophysical Research: Earth Surface, 114(1), 1–17. doi.org/10.1029/2008JF001085

Gary, Minkley. (2012). Rainwater harvesting, homestead food farming, social change and communities of interests in the eastern cape, south africa. Irrigation and Drainage, 61:106-118. doi: 10.1002/IRD.1684

Gashaw, T., Bantider, A., & G/Silassie, H. (2014). Land Degradation in Ethiopia: Causes, Impacts and Rehabilitation Techniques. Journal of Environment and Earth Science, 4(9), 98–105. http://www.iiste.org/Journals/index.php/JEES/article/viewFile/12963/13288

Gashu, K., & Muchie, Y. (2018). Rethink the interlink between land degradation and livelihood of rural communities in Chilga district, Northwest Ethiopia. Journal of Ecology and Environment, 42(1), 1–11. https://doi.org/10.1186/S41610-018-0077-0

Gianoli, F., Weynants, M., & Cherlet, M. (2023). Land degradation in the European Union - Where does the evidence converge? Land Degradation and Development, 34(8), 2256–2275. doi.org/10.1002/ldr.4606

Gilder, E., & Pal, D. K. (2015). Climate Change – Probable Socio-Economic Systems (SES) Implications And Impacts In The Anthropocene Epoch. 21(2), 308–317. https://doi.org/10.1515/KBO-2015-0052

Gore, P. G., Roy, B. A., & Hatwar, H. R. (2011). Impact of Climate Change Land Degradation over India. National Climate Centre, Research Report, IMD Pune, 1.

Greg, Bankoff. (2017). Living with Hazard: Disaster Subcultures, Disaster Cultures and Risk-Mitigating Strategies. 45-59. doi: 10.1007/978-3-319-49163-9_2

Grujic, D., Govin, G., Barrier, L., Bookhagen, B., Coutand, I., Cowan, B., Hren, M. T., & Najman, Y. (2018). Formation of a Rain Shadow: O and H Stable Isotope Records in Authigenic Clays From the Siwalik Group in Eastern Bhutan. Geochemistry, Geophysics, Geosystems, 19(9), 3430–3447. doi.org/10.1029/2017GC007254

Gunnell, Y. (1997). Relief and climate in south Asia: The influence of the western ghats on the current climate pattern of peninsular India. International Journal of Climatology, 17(11), 1169–1182. doi.org/10.1002/(SICI)1097-0088(199709)

Guo L B, Gifford R M (2002) Soil carbon stocks and land use change: A Meta analysis. Global Change Bio l8 : 345-360.

H., L., Striem. (1979). Some aspects of the relation between monthly temperatures and rainfall, and its use in evaluating earlier climates in the middle east. Climatic Change, 2(1):69-74. doi: 10.1007/BF00138227

Hajabbasi M A, Jalalian A, Karimzadeh H R (1997) Deforestation effects on soil physical and chemical properties, Lordegan, Iran. Plant and Soil 190 : 301-308.

Hald, M. (2001). Climate Change and Paleoceanography (pp. 281–290). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-56876-3_17

Halder, S., Parekh, A., Chowdary, J. S., & Gnanaseelan, C. (2022). Dynamical and moist thermodynamical processes associated with Western Ghats rainfall decadal variability. Npj Climate and Atmospheric Science, 5(1), 1–11. doi.org/10.1038/s41612-022-00232-y

Hanhai, Liu., Yun, Shi., Ling, Fu. (2018). Study on the Coupling Relationship Between Land Surface Composition and Land Surface Temperature Based on 3S Technology. 1-4. doi: 10.1109/AGRO-GEOINFORMATICS.2018.8476005

Hansen A J, Brown D G (2005) Land use change in Rural America: Rates, drivers, and consequences. Ecological Society of America,15(6) : 1849-1850

Harikishan, G., Padmakumari, B., Maheskumar, R. S., Pandithurai, G., & Min, Q. L. (1955). Journal of geophysical research. Nature, 175(4449), 238. doi.org/10.1038/175238c0

Harris, L. B., & Taylor, A. H. (2020). Rain-shadow forest margins resilient to low-severity fire and climate change but not high-severity fire. Ecosphere, 11(9). doi.org/10.1002/ecs2.3258

Hatfield, J. L. (2014). Soil Degradation, Land Use, and Sustainability (pp. 61–74). Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-55262-5_4

Henry, B., McKeon, G., Syktus, J., Carter, J., Day, K., Rayner, D. (2007). Climate Variability, Climate Change and Land Degradation. In: Sivakumar, M.V.K., Ndiang'ui, N. (eds) Climate and Land Degradation. Environmental Science and Engineering. Springer, Berlin, Heidelberg. doi.org/10.1007/978-3-540-72438-4_11

Hess D, Tasa D. (2011). McKnight's Physical Geography – A Landscape Appreciation. PHI Learning Private Limited - Delhi, Tenth Edition

Hill MJ, Braaten R, Veitch SM, Lees BG, Sharma S (2005) Multicriteria decision analysis in spatial decision support: the ASSESS analytic hierarchy process and the role of quantitative methods and spatially explicit analysis. Environ. Modell. Software 20: 955–976. doi: doi.org/10.1016/j.envsoft.2004.04.014

Hoffmann, R. (2022). Contextualizing climate change impacts on human mobility in African drylands. Earth's. Futures, 10, e2021EF002591

Houston, J., & Hartley, A. J. (2003). The central andean west-slope rainshadow and its potential contribution to the origin of hyper-aridity in the Atacama Desert. International Journal of Climatology, 23(12), 1453–1464. doi.org/10.1002/joc.938 https://nishantsinha51.shinyapps.io/SQICAL/

http://hdl.handle.net/10603/82165

http://scioteca.caf.com/bitstream/handle/123456789/1091/RED2017-Eng

https://extension.umn.edu/micro-and-secondary-macronutrients/magnesium-crop-production

https://timesofindia.indiatimes.com/city/thiruvananthapuram/attapadi-tribal-belt-reelingunder-severe-drought/articleshow/57239706.cms

https://timesofindia.indiatimes.com/city/thiruvananthapuram/attapadi-tribal-belt-reeling-under-severe-drought/articleshow/57239706.cms

Hughes, M., Hall, A., & Fovell, R. G. (2009). Blocking in areas of complex topography, and its influence on rainfall distribution. Journal of the Atmospheric Sciences, 66(2), 508–518. doi.org/10.1175/2008JAS2689.1

Hussain, A., Mahapatra, B., & Rasul, G. (2019). Adaptation in Mountain Agriculture: Food Security in the Hindu-Kush Himalayan (HKH) Region (pp. 211–236). Springer, Cham. https://doi.org/10.1007/978-3-319-99347-8_10

Hussein, A. F., Jameel, B. I., & Abd, K. K. (2018). Comparative analysis of Fuzzy MCDM methods for material selection in biomedical application. Association of Arab Universities Journal of Engi neering Sciences, 25(2), 137–148.

I., Jaisankar., A., Velmurugan., T., P., Swarnam., A., K., Singh. (2018). Hotspots: An Introduction and Role in Conservation. 1-21. doi: 10.1007/978-981-10-6983-3_1

Idowu, O. J., Van Es, H. M., Abawi, G. S., Wolfe, D. W., Ball, J. I., Gugino, B. K., ... & Bilgili, A. V. (2008). Farmer-oriented assessment of soil quality using field, laboratory, and VNIR spectroscopy methods. *Plant and Soil*, *307*(1), 243-253.

Ifejika Speranza, C., Wiesmann, U., & Rist, S. (2014). An indicator framework for assessing livelihood resilience in the context of social-ecological dynamics. Global Environmental Change, 28(1), 109–119. doi.org/10.1016/j.gloenvcha.2014.06.005

Ifejika Speranza, C., Wiesmann, U., & Rist, S. (2014). An indicator framework for assessing livelihood resilience in the context of social-ecological dynamics. Global

Environmental Change, 28(1), 109–119. doi.org/10.1016/j.gloenvcha.2014.06.005

Ikusemoran, Mayomi., E.C., Andrew., YUSUF, BELLO. (2024). Geospatial techniques for mapping and analysis of climatic variables in gombe state, north-east nigeria.. Federal University of Dutsinma Journal of Agriculture and Agricultural Technology, 9(2):153-170. doi: 10.33003/jaat.2023.0902.20

Ioras, F., Bandara, I., & Kemp, C. (2014). Introduction to climate change and land degradation. 15–52. https://dialnet.unirioja.es/servlet/articulo?codigo=4997441

Javed, A., Jamal, S., & Khandey, M. Y. (2012). Climate Change Induced Land Degradation and Socio-Economic Deterioration: A Remote Sensing and GIS Based Case Study from Rajasthan, India. Journal of Geographic Information System, 4(3), 219–228. doi.org/10.4236/JGIS.2012.43026

Jayachandran, V. N., Varghese, M., Murugavel, P., Todekar, K. S., Bankar, S. P., Malap, N., Dinesh, G., Safai, P. D., Rao, J., Konwar, M., Dixit, S., & Prabha, T. V. (2020). Cloud condensation nuclei characteristics during the Indian summer monsoon over a rain-shadow region. Atmospheric Chemistry and Physics, 20(12), 7307–7334. doi.org/10.5194/acp-20-7307-2020

Jayesh, Phadtare., Jennifer, K., Fletcher., Andrew, N., Ross., Andrew, G., Turner., Reinhard, Schiemann. (2022). Froude-number-based rainfall regimes over the Western Ghats mountains of India. Quarterly Journal of the Royal Meteorological Society, 148(748):3388-3405. doi: 10.1002/qj.4367

Jiang, Q. (2003). Moist dynamics and orographic precipitation. Tellus A: Dynamic Meteorology and Oceanography, 55(4), 301. doi.org/10.3402/tellusa.v55i4.14577

Jiang, Q. (2007). Precipitation over multiscale terrain. Tellus, Series A: Dynamic Meteorology and Oceanography, 59(3), 321–335. doi.org/10.1111/j.1600-0870.2007.00232.x

Jincy P.P (2019), Agricultural Regionalisation in Kongu uplands, Tamilnadu, India, Bharathidasan University, Tiruchirappalli

Joanne, Nightingale., Stuart, R., Phinn. (2003). Assessment of Relationships Between Precipitation and Satellite Derived Vegetation Condition Within South Australia. Australian Geographical Studies, 41(2):180-195. doi: 10.1111/1467-8470.00204

Johnston R J (2000). Geography and Geographers: Anglo-American Human Geography since 1945. Arnold – London, Fifth reprinted edition

Johnston, Ron, and James D. Sidaway. Geography and geographers: Anglo-American human geography since 1945. Routledge, 2015.

Joseph, Galewsky. (2009). Rain shadow development during the growth of mountain ranges:

An atmospheric dynamics perspective. Journal of Geophysical Research, 114 doi: 10.1029/2008JF001085

Joseph, S., & Anil, P. (2020). Land Degradation and Sustainable Development in Attappady: A Case Study. Journal of Environmental Management, 45(3), 123-134.

Juana J, Kahaka Z, Okurut F (2013) Farmers' perceptions and adaptations to climate change in sub-Sahara Africa: a synthesis of empirical studies and implications for public policy in African agriculture. J Agric Sci 5: 121–135

Juanita, L., Beytell. (2023). How meteorological and cloud processes affect water isotopes in a tropical rain shadow region?. doi: 10.5194/egusphere-egu23-5260

Julien, Cretat., Benjamin, Pohl. (2012). How Physical Parameterizations Can Modulate Internal Variability in a Regional Climate Model. Journal of the Atmospheric Sciences, 69(2):714-724. doi: 10.1175/JAS-D-11-0109.1

Jumiun, S., Darwis, D., Namriah, N., Ginting, S., Leomo, S., & Zulfikar, Z. (2024). Analisis Indeks Kualitas Tanah pada Tipe Penggunaan Lahan Berbeda di Kecamatan Maginti. AGRONU JURNAL AGROTEKNOLOGI, 3(01), 1–11. doi.org/10.53863/agronu.v3i01.564

Jyothirmayi P, Anilkumar R (2011) Changing land use pattern and some environmental implications in the Valapattanam River Basin, Kannur District of Kerala State. Proceedings of the third International Geography Congress on Sustainable Natural Resources Management under changing climatic scenarios by CWRDM : 352-356

K., Chandrasekar., M., V., R., Sesha., A., T., Jeyaseelan., Ravi, Shankar, Dwivedi., Partha, Sarathi, Roy. (2006). Vegetation response to rainfall as monitored by NOAA-AVHRR. Current Science, 91(12):1626-1633.

K., Khemmoudj., hocine, bendadouche., S., Merabet. (2016). Water resources in semi arid and sustainable development, case djemila northeast algerian region. LARHYSS Journal, 249-258.

K., P., Shimod. (2023). Geospatial Technology for Analysing the Dynamics in Microclimate with Special Reference to Land Surface Temperature of Tropical Cities: A Case Study. Springer geography, 321-340. doi: 10.1007/978-3-031-24767-5_15

Kairis, O., Kosmas, C., Karavitis, C., Ritsema, C., Salvati, L., Acikalin, S., Alcalá, M., Alfama, P., Atlhopheng, J., Barrera, J., Belgacem, A., Solé-Benet, A., Brito, J., Chaker, M., Chanda, R., Coelho, C., Darkoh, M., Diamantis, I., Ermolaeva, O., … Ziogas, A. (2014). Evaluation and Selection of Indicators for Land Degradation and Desertification Monitoring: Types of Degradation, Causes, and Implications for

Management. Environmental Management, 54(5), 971–982. doi.org/10.1007/s00267-013-0110-0

Kalle Hirvonen, Elia Machado, A. M. S. (2024). This document is discoverable and free to researchers across the globe due to the work of AgEcon Search . Help ensure our sustainability Actors Influencing Prince pf Agricultural Products and Stability Counte .

Kanhu, Charan, Panda., Ravendra, Singh., Vijay, K., Singh., Saurav, Singla., Pradosh, Kumar, Paramaguru. (2022). Impact of climate change induced future rainfall variation on dynamics of arid-humid zone transition in the western province of India.. Journal of Environmental Management, 325 Pt B:116646, doi: 10.1016/j.jenvman.2022.116646

Karlen D L, Mausbach M J, Doran J W, Cline R T, Harris R F, Schuman G E (1997) Soil quality: A concept definition and framework for evaluation. Soil Science Society of America Journal 90 : 644-650

Kawy, W. A. M. A., & Darwish, K. M. (2019). Assessment of land degradation and implications on agricultural land in Qalyubia Governorate, Egypt. Bulletin of the National Research Centre, 43(1), 1–14. doi.org/10.1186/s42269-019-0102-1

Kevin, J., Gaston., Lauren, A., Holt. (2018). Nature, extent and ecological implications of night-time light from road vehicles.. Journal of Applied Ecology, 55(5):2296-2307. doi: 10.1111/1365-2664.13157

Khuong, M. H., Tran, T. P., Hoang, P. A., Doan, T. T., Cao, T. S., & Nguyen, X. H. (2024). Assessment of the current status of soil quality and types of land degradation in Quang Ninh province, Vietnam. doi.org/10.1088/1755-1315/1345/1/012020

Kirui, O. K., Mirzabaev, A., & von Braun, J. (2021). Assessment of land degradation 'on the ground' and from 'above.' SN Applied Sciences, 3(3), 1–13. doi.org/10.1007/s42452-021-04314-z

Kishk, M. A. (1990). Desert encroachment in the fingers of the Nile Valley, Egypt. Sand Transport and Desertification in Arid Lands. World Scientific, London, 196-208.

Klinges, D. H., Maclean, I. M. D., & Scheffers, B. R. (2025). Redrawing Köppen-Geiger classes with microclimate: implications for nature and society. Frontiers in Ecology and the Environment. https://doi.org/10.1002/fee.2831

Kodjovi, E. (n.d.). Faculty of Art And Humanities Department of Geography Farmers' Perception on Land Degradation and Local strategies for Land Restoration and Livelihood Improvement in Mopti Region, Mali.

Koeppel, G. (1993). A struggle for water. American Heritage of Invention & Technology, 9(3), 19–30.

Kolawole, E. S., & Okonkwo, W. I. (2022). Impacts of Climate Change on Environment and the Remedies. International Journal of Weather, Climate Change and Conservation Research, 8(2), 1–9. https://doi.org/10.37745/ijwcccr.15/vol8n219

Kolawole, O. D., Motsholapheko, M. R., Ngwenya, B. N., Thakadu, O., Mmopelwa, G., & Kgathi, D. L. (2016). Climate variability and rural livelihoods: How households perceive and adapt to climatic shocks in the Okavango Delta, Botswana. Weather, Climate, and Society, 8(2), 131–145. doi.org/10.1175/WCAS-D-15-0019.1

Kolawole, O. D., Motsholapheko, M. R., Ngwenya, B. N., Thakadu, O., Mmopelwa, G., & Kgathi, D. L. (2016). Climate variability and rural livelihoods: How households perceive and adapt to climatic shocks in the Okavango Delta, Botswana. Weather, Climate, and Society, 8(2), 131–145. doi.org/10.1175/WCAS-D-15-0019.1

Kosmas, C., Kairis, O., Karavitis, C., Ritsema, C., Salvati, L., Acikalin, S., … Ziogas, A. (2014). Evaluation and selection of indicators for land degradation and desertification monitoring: Methodological approach. Environmental Management, 54(5), 951e970.

Kosmas, C., Kairis, O., Karavitis, C., Ritsema, C., Salvati, L., Acikalin, S., Alcalá, M., Alfama, P., Atlhopheng, J., Barrera, J., Belgacem, A., Solé-Benet, A., Brito, J., Chaker, M., Chanda, R., Coelho, C., Darkoh, M., Diamantis, I., Ermolaeva, O., Ziogas, A. (2014). Evaluation and Selection of Indicators for Land Degradation and Desertification Monitoring: Methodological Approach. Environmental Management, 54(5), 951–970. doi.org/10.1007/s00267-013-0109-6

Kostadis, J., Papaioannou., Michiel, de, Haas. (2017). Weather shocks and agricultural commercialization in colonial tropical Africa: did cash crops alleviate social distress?. Research Papers in Economics

KPDNA. (2018). Kerala Post Disaster Needs Assessment Floods and Landslides-August 2018 European Union Civil Proteccon and Humanitarian Aid.

Kumar, A., Pramanik, M., Chaudhary, S., & Negi, M. S. (2021). Land evaluation for sustainable devel opment of Himalayan agriculture using RS-GIS in conjunction with analytic hierarchy process and frequency ratio. Journal of the Saudi Society of Agricultural Sciences, 20(1), 1–17. doi.org/ 10.1016/j.jssas.2020.10.001

Kumar, B. P., Babu, K. R., Anusha, B. N., & Rajasekhar, M. (2022). Geo-environmental monitoring and assessment of land degradation and desertification in the semi-arid regions using Landsat 8 OLI / TIRS, LST, and NDVI approach. Environmental Challenges, 8 (December 2021). doi.org/10.1016/j.envc.2022.100578

Kumar, R., & Jyoti Das, A. (2014). Climate Change and its Impact on Land Degradation:

Imperative Need to Focus. Journal of Climatology & Weather Forecasting, 2(1). doi.org/10.4172/2332-2594.1000108

Kumar, R., Singh, A., & Sharma, P. (2019). Climate Change and Its Impact on Land Degradation in Semi-Arid Regions: A Review. Environmental Science and Pollution Research, 26(15), 14867-14879.

Kumar, S., Mishra, A. K., Pramanik, S., Mamidanna, S., & Whitbread, A. (2020). Climate risk, vulnerability and resilience: Supporting livelihood of smallholders in semiarid India. Land Use Policy, 97(April), 104729. doi.org/10.1016/j.landusepol.2020.104729

Kumar, S., Mishra, A. K., Pramanik, S., Mamidanna, S., & Whitbread, A. (2020). Climate risk, vulnerability and resilience: Supporting livelihood of smallholders in semiarid India. Land Use Policy, 97(April), 104729. doi.org/10.1016/j.landusepol.2020.104729

Kumari, P., Somvanshi, S. P. S., Kumar, A., & Singh, B. V. (2018). Livelihood Security of Poor Families through Poultry Backyard Rearing System in Auraiya District of Uttar Pradesh. Journal of Krishi Vigyan, 7(special), 94. doi.org/10.5958/2349-4433.2018.00166.6

Kunhaman, M., (1981). Development of Tribal Economy. Classical Publishing Company, New Delhi.

L., Jen, Shaffer. (2017). Rain Rituals as a Barometer of Vulnerability in an Uncertain Climate. J3ea, 19(1):1-17. doi: 10.5038/2162-4593.19.1.1228

Lal, R. (1994). Soil erosion research methods. CRC Press.

Lamb, H.H.: Climate: Present, past and future, Vol. I. Fundamentals and climate now. London: Methuen & Co., Ltd., 1972, 613 pp.

Langley T S J, Keirstead D R (2005) Soil properties and land use history : A case study in New Hampshire. Northeastern Naturalist 12 : 391-402.

Lat, D. C., Yusof, D. A. M., Yasin, M. H., Razali, R., Zainuddin, A. N., Kasuan, N., & Jais, I. B. M. (2024). SOIL QUALITY INDEX AT PASIR GUDANG INDUSTRIAL AREA. *Malaysian Journal of Civil Engineering*, *36*(1), 17-22.

Lawson, C. R., Bennie, J., Hodgson, J. A., Thomas, C. D., & Wilson, R. J. (2014). Topographic microclimates drive microhabitat associations at the range margin of a butterfly. Ecography, 37(8), 732–740. https://doi.org/10.1111/ECOG.00535

Lei, Qiao., Xuhui, Wang., Pete, Smith., Jinlong, Fan., Yuelai, Lu., Bridget, A., Emmett., Rongqi, Li., Stephen, Dorling., Haiqing, Chen., Sha, Liu., Tim, G., Benton., Yaojun, Wang., Y., Ma., Rongfeng, Jiang., Fusuo, Zhang., Shilong, Piao., Christoph, Müller., Huaqing, Yang., Yanan, Hao., Wang, Li., Mingsheng, Fan. (2022). Soil quality both increases crop production and improves resilience to climate change. Nature Climate Change, 12(6):574-580. doi: 10.1038/s41558-022-01376-8

Li, X., Li, H., Yang, L., & Ren, Y. (2018). Assessment of soil quality of croplands in the Corn Belt of Northeast China. Sustainability (Switzerland), 10(1). doi.org/10.3390/su10010248

Li, Z., Deng, X., Yin, F., & Yang, C. (2015). Analysis of Climate and Land Use Changes Impacts on Land Degradation in the North China Plain. Advances in Meteorology, 2015. doi.org/10.1155/2015/976370

Lundquist, J. D., Minder, J. R., Neiman, P. J., & Sukovich, E. (2010). Relationships between barrier jet heights, orographic precipitation gradients, and streamflow in the Northern Sierra Nevada. Journal of Hydrometeorology, 11(5), 1141–1156. doi.org/10.1175/2010JHM1264.1

M. V. K. Sivakumar and R. Stefanski, Climate and Land Degradation—An Overview, In: Climate and Land Degradation, Springer-Verlag Berlin Heidelberg, 2007, pp. 105-135. doi:10.1007/978-3-540-72438-4_6

M., D., Patil., Suhas, P., Wani., Kaushal, K., Garg. (2016). Conservation Agriculture for Improving Water Productivity in Vertisols of Semi-Arid Tropics. Current Science, 110(9):1730-1739. doi: 10.18520/CS/V110/I9/1730-1739

M., G., Winter. (2015). The Vulnerability Shadow Cast by Debris Flow Events. 641-644. doi: 10.1007/978-3-319-09060-3_113

Mahen, Konwar., R., S., Maheskumar., J., R., Kulkarni., Eyal, Freud., Bhupendra, Nath, Goswami., Daniel, Rosenfeld. (2010). Suppression of warm rain by aerosols in rain-shadow areas of India. Atmospheric Chemistry and Physics, 10(7):17009-17027. doi: 10.5194/ACPD-10-17009-2010

Maheskumar, R. S., Padmakumari, B., Morwal, S. B., & Kulkarni, J. R. (2021). Role of Topography and Aerosols in the Rainfall over the Western Ghats and Rain Shadow Regions as Inferred from Aircraft Measurements. 47(2), 86–95.

Maia Call1 & Clark Gray (2020). Climate anomalies, land degradation, and rural out-migration in Uganda. doi.org/10.1007/s11111-020-00349-3, Population and Environment (2020) 41:507–528

Malav, L. C., Yadav, B., Tailor, B. L., Pattanayak, S., Singh, S. V., Kumar, N., Reddy, G. P. O., Mina, B. L., Dwivedi, B. S., & Jha, P. K. (2022). Mapping of Land Degradation Vulnerability in the Semi-Arid Watershed of Rajasthan, India. Sustainability (Switzerland), 14(16), 1–16. doi.org/10.3390/su141610198

Manikandan, A.D., V., Mathew, Kurian. (2016). Theory and Practical Implication of Land Degradation and Livelihood: Case of Attappady Region in Kerala:. Asia-Pacific journal of rural development, 26(1):85-104. doi: 10.1177/1018529120160103

Manjusha, K., & Jojo, B. (2022). Land Alienation and Subversion Strategies on Land Rights: Perspectives from Attappady. Journal of Land and Rural Studies, 11(1), 7–18. https://doi.org/10.1177/23210249221129389

Mann R, Saini D, Sharma Swati, Dhorde. A and Gupta A (2023). Paradoxical behaviour of rainfall and temperature over ecologically sensitive areas along the Western Ghats. doi: 10.21203/rs.3.rs-2581616/v1

Mark, A., Minor. (2023). Climate Zones Shifts, Ice Melt and Stadial Cooling. 97-106. doi: 10.1007/978-3-031-23709-6_12

Maxwell, D., Larbi, W. O., Lamptey, G. M., Zakariah, S., & Armar-Klemesu, M. (1998). lo(Sao Farming in the Shadow of the City: Changes in Land Rights and Livelihoods in Peri-Urban Accra Cities Feeding People Series Report 23. https://idl-bnc-idrc.dspacedirect.org/bitstream/handle/10625/22606/108520.pdf?sequence=11

Mayhew S (2015) Oxford Dictionary of Geography. OXFORD University Press- Oxford

Mayomi, Ikusemoran., Yusuf, Bello. (2023). Geospatial techniques for mapping and analysis of climatic variables in gombe state, north-east nigeria. 9(1):189-205. doi: 10.33003/jaat.2023.0901.25

McNichol, B. H., Wang, R., Hefner, A. M., Helzer, C. J., McMahon, S. M., & Russo, S. E. (2022). Topographically driven microclimatic gradients shape patterns of forest structure, diversity, and composition at a forest-grassland transition zone. bioRxiv. https://doi.org/10.1101/2022.09.15.508106

Mendas, A., Mebrek, A., & Mekranfar, Z. (2021). Comparison between two multicriteria methods for assessing land suitability for agriculture: Application in the area of Mleta in western part of Algeria. Environment, Development and Sustainability, 23, 9076–9089. doi.org/10.1007/ s10668-020-01012-5

Mercy, Varghese., Jerry, Jose., A.S., Anu., Palani, Murugavel., E.A., Resmi., Sudarsan, Bera., Sabu, Thomas., Mahen, Konwar., Nandakumar, Kalarikkal., Thara, V., Prabha. (2021). Cloud and aerosol characteristics during dry and wet days of southwest monsoon over the rain shadow region of Western Ghats, India. Meteorology and Atmospheric Physics, 133(4):1299-1316. doi: 10.1007/S00703-021-00811-3

Meriem, Chakroun., Marjolaine, Chiriaco., Sophie, Bastin., Hélène, Chepfer. (2014). Using regional simulations and spatial lidar to study regional cloud variability.

Mesene, M. (2017). Extent & Impact of Land Degradation and Rehabilitation Strategies: Ethiopian Highlands. Journal of Environment and Earth Science, 7(11), 22–32. https://www.iiste.org/Journals/index.php/JEES/article/download/39691/40809

Michelot, N. (2014). L'influence des topoclimats sur la pollution de l'air aux particules dans le sud-ouest des Alpes-Maritimes. http://www.theses.fr/2014NICE2007

Miglietta, M. M., & Buzzi, A. (2004). A numerical study of moist stratified flow regimes over isolated topography. Quarterly Journal of the Royal Meteorological Society, 130(600 PART A), 1749–1770. doi.org/10.1256/qj.02.225

Miglietta, M. M., & Rotunno, R. (2005). Simulations of moist nearly neutral flow over a ridge. Journal of the Atmospheric Sciences, 62(5), 1410–1427. doi.org/10.1175/JAS3410.1

Mikhailova, E. A., Zurqani, H. A., Lin, L., Hao, Z., Post, C. J., Schlautman, M. A., Post, G. C., & Shepherd, G. B. (2024). Accounting for Climate and Inherent Soil Quality in United Nations (UN) Land Degradation Analysis: A Case Study of the State of Arizona (USA). Climate, 12(12), 194. https://doi.org/10.3390/cli12120194

Mingxing, Li., Peili, Wu., David, M., H., Sexton., Zhuguo, Ma. (2021). Potential shifts in climate zones under a future global warming scenario using soil moisture classification. Climate Dynamics, 56(7):2071-2092. doi: 10.1007/S00382-020-05576-W

Minoru, Kasada., Kei, Uchida., Naoto, Shinohara., Takehito, Yoshida. (2022). Ecosystem-based disaster risk reduction can benefit biodiversity conservation in a Japanese agricultural landscape. Frontiers in Ecology and Evolution, 10 doi: 10.3389/fevo.2022.699201

Miriam, Marzen., Thomas, Iserloh., João, L., M., P., de, Lima., Wolfgang, Fister., Johannes, B., Ries. (2017). Impact of severe rain storms on soil erosion: Experimental evaluation of wind-driven rain and its implications for natural hazard management.. Science of The Total Environment, 590:502-513. doi: 10.1016/J.SCITOTENV.2017.02.190

Mitchell, J.M.: An overview of climatic variability and its causal mechanisms. Quaternary Res. 6 (1976) 481.

Miyagawa, S. (n.d.). Dynamics of rainfed lowland rice varieties in north-east Thailand. 41–48.

Mod, H. K., Mod, H. K., Scherrer, D., Scherrer, D., Di Cola, V., Broennimann, O., Blandenier, Q., Breiner, F. T., Buri, A., Goudet, J., Goudet, J., Guex, N., Guex, N., Lara, E., Mitchell, E. A. D., Niculita-Hirzel, H., Pagni, M., Pellissier, L., Pellissier, L., … Guisan, A. (2020). Greater topoclimatic control of above- versus below-ground communities. Global Change Biology, 26(12), 6715–6728. https://doi.org/10.1111/GCB.15330

Mohamed, E. S., Belal, A. A., Abd-Elmabod, S. K., El-Shirbeny, M. A., Gad, A., & Zahran, M. B. (2021). Smart farming for improving agricultural management. The Egyptian Journal of Remote Sensing and Space Science, 24(3), 971-981.

Monjur, Mourshed., Raed, Fawzi, Mohammed, Ameen. (2016). Environmental, social and economic challenges for urban development: stakeholder's perception in a developing economy.

Monkhouse F J (1954) The Principles of Physical Geography. University of London Press Ltd. - London.

Morwal, S. B., Narkhedkar, S. G., Padmakumari, B., Maheskumar, R. S., & Kulkarni, J. R. (2018). Characteristics of precipitating monsoon clouds over rain-shadow and drought-hit regions of India using radar. Climate Dynamics, 50(9–10), 3571–3594. doi.org/10.1007/s00382-017-3826-3

Msipa, A., Lombard, A., Aucamp, I., & Baade, J. (2025). Land Degradation's Influence on Livelihoods of Small-Scale Farmers and Land Care Workers in Ladybrand, South Africa. Land Degradation & Development. https://doi.org/10.1002/ldr.5474

Mudbhatkal, A., & Amai, M. (2018). Regional climate trends and topographic influence over the Western Ghat catchments of India. International Journal of Climatology, 38(5), 2265-2279.

Mukherjee, A., & Lal, R. (2014). Comparison of soil quality index using three methods. PLoS ONE, 9(8). doi.org/10.1371/journal.pone.0105981

Nair, P. R., & Krishnakumar, V. (2021). Socio-Economic Impacts of Land Degradation in Rural India: A Case Study of Attappady. Indian Journal of Agricultural Economics, 76(2), 24-247.

Nan, Wei., Yongjiu, Dai., Minghua, Zhang., Liming, Zhou., Duoying, Ji., Siguang, Zhu., Lili, Wang. (2014). Impact of precipitation-induced sensible heat on the simulation of land-surface air temperature. Journal of Advances in Modeling Earth Systems, 6(4):1311-1320. doi: 10.1002/2014MS000322

Narkhedkar, S. G., Morwal, S. B., Padmakumari, B., Deshpande, C. G., Kothawale, D. R., Maheskumar, R. S., & Kulkarni, J. R. (2015). Rainfall mechanism over the rain-shadow region of north peninsular India. Climate Dynamics, 45(5–6), 1493–1512. doi.org/10.1007/s00382-014-2403-2

Naseer A, Pandey P (2018) Assessment and monitoring of land degradation using geospatial technology in Bathinda district, Punjab, India. Solid Earth 9(1):75–90. doi.org/10.5194/se-9-75- 2018

Natural Resources Conservation Services (NRCS): Soil Health, available at: http://www.nrcs.usda.gov/wps/portal/nrcs/main/ soils/health

Nciizah, T. (2023). Land degradation and livelihood strategies in rural Zimbabwe: the case of two A1 farms in Shurugwi District. https://doi.org/10.21504/10962/365989

Neiman, P. J., Ralph, F. M., White, A. B., Kingsmill, D. E., & Persson, P. O. G. (2002). The statistical relationship between upslope flow and rainfall in California's coastal mountains: Observations during CALJET. Monthly Weather Review, 130(6), 1468–1492. doi.org/10.1175/1520-0493(2002)130<1468:TSRBUF>2.0.CO;2

Neiman, P. J., Sukovich, E. M., Martin Ralph, F., & Hughes, M. (2010). A seven-year wind profiler-based climatology of the windward barrier jet along California's Northern Sierra Nevada. Monthly Weather Review, 138(4), 1206–1233. doi.org/10.1175/2009MWR3170.1

Ngandam Mfondoum, A. H., Etouna, J., Nongsi, B. K., Mvogo Moto, F. A., & Noulaquape Deussieu, F. G. (2016). Assessment of Land Degradation Status and Its Impact in Arid and Semi-Arid Areas by Correlating Spectral and Principal Component Analysis Neo-Bands. International Journal of Advanced Remote Sensing and GIS, 5(1), 1539–1560. doi.org/10.23953/cloud.ijarsg.77

Nkonya, E., Gerber, N., Baumgartner, P., von Braun, J., De Pinto, A., Graw, V., ... & Walter, T. (2011). The economics of desertification, land degradation, and drought toward an integrated global assessment. ZEF-Discussion Papers on Development Policy, (150).

Nosrati, K. (2013). Assessing soil quality indicator under different land use and soil erosion using multivariate statistical techniques. *Environmental monitoring and assessment*, *185*(4), 2895-2907.

Nunow, A. A. (2024). The Nexus Between Climate Change and Livelihoods in Arid and Semi-Arid (ASAL) Areas of Kenya: Evidence from the Literature. International Journal of Social Science and Human Research, 7(06). https://doi.org/10.47191/ijsshr/v7-i06-113

Nursita, D. (2020). Soil quality index analysis in efforts to overcome land degradation in nganjuk regency. 15(2), 96–106. https://doi.org/10.29122/JSTMB.V15I2.4564

Nwokoro, C.V., Chima, F.O., 2017. Impact of environmental degradation on agriculturalproduction and poverty in rural Nigeria. American International Journal of Contemporary Research 7, 2.

Odufuwa, B. O., Odufuwa, B. A., & Fasina, S. O. (2012). Climate change and livelihood: the two sides of a coin. Indonesian Journal of Geography, 44(1). https://doi.org/10.22146/IJG.2390

Okou F A Y, Assogbadjo A E, Bachmann Y, Sinsin B (2014) Ecological factors influencing physical soil degradation in the Atacora Mountain chain in Benin, West Africa. Mountain Research and Development 34 : 157-166.

Oldfather, M. F., Britton, M. N., Papper, P., Koontz, M. J., Halbur, M. M., Dodge, C., Flint, A. L., Flint, L., & Ackerly, D. D. (2016). Effects of topoclimatic complexity on the composition of woody plant communities. Aob Plants, 8(8), 1–15. https://doi.org/10.1093/AOBPLA/PLW049

Ollier D. Cliff. (2004). Mountain Building and Climate: Mechanisms and Timing. Geogr. Fis. Dinam. Quat., 27(5), 139–149.

Padmakumari, B., Maheskumar, R. S., Harikishan, G., Morwal, S. B., & Kulkarni, J. R. (2018). Rain-shadow: An area harboring "Gray Ocean" clouds. Atmospheric Research, 205(October 2016), 70–79. doi.org/10.1016/j.atmosres.2018.02.005

Pani, P. (2020). Land degradation and socio-economic development (pp. 978–973). Springer Nature.

Papendick, Robert I., and James F. Parr. "Soil quality the key to a sustainable agriculture." American Journal of Alternative Agriculture 7.1-2 (1992): 2-3.

Paper, O., Secondary, C. A., Author, C., & Scaria, R. (n.d.). Arabian Journal of Geosciences Assessing the Impact of Rainshadow Phenomenon on Land Degradation Using Geospatial Techniques : A Case Study of Attappady Region in the Western Ghats.

Parthasarathy. G R.,and Rengan G R., (2010). Momograph on Landforms-11, Madurai Kamaraj University, Madurai.

Phadtare, J. A., Fletcher, J. K., Ross, A. N., Turner, A. G., & Schiemann, R. K. H. (2022). Froude-number-based rainfall regimes over the Western Ghats mountains of India. Quarterly Journal of the Royal Meteorological Society, 148(748), 3388–3405. doi.org/10.1002/qj.4367

Piya, L., Maharjan, K. L., & Joshi, N. P. (2019). Climate Change and Rural Livelihoods in Developing Countries (pp. 11–33). Springer, Singapore. https://doi.org/10.1007/978-981-13-5784-8_2

Podwika, M., Sołek-Podwika, K., Kaleta, D., & Ciarkowska, K. (2020). The Effect of Land-Use Change on Urban Grassland Soil Quality (Southern Poland). Journal of Soil Science and Plant Nutrition, 20(2), 473–483. doi.org/10.1007/S42729-019-00132-W

Potential Impacts of Climate Change on Land Degradation and Desertification (pp. 1374–1387). (2022). IGI Global eBooks. doi.org/10.4018/978-1-6684-3686-8.ch067

Pramanik, M. K. (2016). Site suitability analysis for agricultural land use of Darjeeling district using AHP and GIS techniques. Modeling Earth Systems and Environment, 2(2), 56. doi.org/10. 1007/s40808-016-0116-8

Prasannakumar V., (2007). Geomorphology of Kerala , International centre for Kerala studies, University of Kerala, Kariavattom

Premakumar, K., Anandan, R. and Nagarathinam, S. (2015). A study on crop combination regions in Palakkad district, Kerala. Int. J. Geomatics Geosci. 6(2):1430-1441

Pricope, N. G., Husak, G., Lopez-Carr, D., Funk, C., & Michaelsen, J. (2013). The climate-population nexus in the East African Horn: Emerging degradation trends in rangeland and pastoral livelihood zones. Global Environmental Change, 23(6), 1525–1541. doi.org/10.1016/j.gloenvcha.2013.10.002

Priya, R. (2021). Land Degradation and Agricultural Productivity. In: Land Degradation in India. SpringerBriefs in Environmental Science. Springer, Cham. doi.org/10.1007/978-3-030-68848-6_5

Qiang, Li., Leslie, Nii, Odartey, Mills., Sue, McNeil., Nii, Attoh-Okine. (2012). Exploring Impact of Climate Change on Pavement Performance and Design.

Qiao, L., Wang, X., Smith, P., Fan, J., Lu, Y., Emmett, B. A., Li, R., Dorling, S., Chen, H., Liu, S., Benton, T. G., Wang, Y., Ma, Y., Jiang, R., Zhang, F., Piao, S., Müller, C., Yang, H., Hao, Y., … Fan, M. (2022). Soil quality both increases crop production and improves resilience to climate change. Nature Climate Change, 12(6), 574–580. doi.org/10.1038/s41558-022-01376-8

Qiu L, Wei X, Zhang X, Cheng J, Gale W, Guo C, Long T (2012) Soil organic carbon losses due to land use change in a semi arid grassland. Plant and Soil 355 : 299-309.

Quentin, Renard., Gowrappan, Muthusankar., Raphaël, Pélissier. (2009). Data Paper – High-Resolution Topographic and Bioclimatic Data for the Southern Western Ghats of India (IFP_ECODATA_BIOCLIM).

R., Vishnu., Anil, Kumar., Hamza, Varikoden., K, Sarath, Krishnan., T.S., Sreekanth., V., N., Subi, Symon., S., Murali, Das., G., Mohan, Kumar. (2013). Convective thundercloud development over the western ghats mountain slope in Kerala.

Radhakrishnan, P., (2012). Studies on Spatio-temporal Changes of Forest Ecosystems in Attapaddy Valley, Nilgiri Biosphere Reserve (Doctoral dissertation). Forest Research Institute University, Dehradun.

Rains, E. M., & Sloane, N. J. A. (1998). The Shadow Theory of Modular and Unimodular Lattices. Journal of Number Theory, 73(2), 359–389. doi.org/10.1006/jnth.1998.2306

Rajan, Janardhanan. (2021). Water Management: A Key to Sustainable Development. 387-400. doi: 10.4018/978-1-7998-8327-2.CH023

Rajendran, K., Kitoh, A., Srinivasan, J., Mizuta, R., & Krishnan, R. (2012). Monsoon circulation interaction with Western Ghats orography under changing climate: Projection by a 20-km mesh AGCM. Theoretical and Applied Climatology, 110(4), 555–571. doi.org/10.1007/s00704-012-0690-2

Rajesh, T. P., Suresh, K. R., & Manoj, K. (2018). Community-Based Approaches to Combat Land Degradation: Lessons from Kerala. International Journal of Sustainable Development, 21(4), 345-360.

Ram, Ranjan., Sanhita, S, Athalye. (2009). Drought resilience in agriculture: the role of technological options, land use dynamics, and risk perception. Natural Resource Modeling, 22(3):437-462. doi: 10.1111/J.1939-7445.2009.00044.X

Razafindratsima, O. H., Kamoto, J. F. M., Sills, E. O., Mutta, D. N., Song, C., Kabwe, G., Castle, S. E., Kristjanson, P. M., Ryan, C. M., Brockhaus, M., & Sunderland, T. (2021). Reviewing the evidence on the roles of forests and tree-based systems in poverty dynamics. Forest Policy and Economics, 131(August), 102576. doi.org/10.1016/j.forpol.2021.102576

Reed, M. S., & Stringer, L. C. (2016). Land degradation, desertification and climate change: Anticipating, assessing and adapting to future change. Routledge.

Reeves, H. D., Lin, Y. L., & Rotunno, R. (2008). Dynamic forcing and mesoscale variability of heavy precipitation events over the Sierra Nevada Mountains. Monthly Weather Review, 136(1), 62–71. doi.org/10.1175/2007MWR2164.1

Reith, J., Ghazaryan, G., Muthoni, F., & Dubovyk, O. (2021). Assessment of land degradation in semiarid Tanzania-using multiscale remote sensing datasets to support sustainable development goal 15.3. Remote Sensing, 13(9), 1–21. doi.org/10.3390/rs13091754

Reynolds, J. F., Maestre, F. T., Kemp, P. R., Stafford-Smith, D. M., & Lambin, E. (2007). Natural and Human Dimensions of Land Degradation in Drylands: Causes and Consequences. Terrestrial Ecosystems in a Changing World, May 2014, 247–257. doi.org/10.1007/978-3-540-32730-1_20

Ribot, J. (2014). Cause and response: vulnerability and climate in the Anthropocene. The Journal of Peasant Studies, 41(5), 667–705. doi.org/10.1080/03066150.2014.894911

Robert, A., Houze. (2012). Orographic effects on precipitating clouds. Reviews of Geophysics, 50(1) doi: 10.1029/2011RG000365

Roe, G. H., Montgomery, D. R., & Hallet, B. (2003). Orographic precipitation and the relief of mountain ranges. Journal of Geophysical Research: Solid Earth, 108(B6). doi.org/10.1029/2001jb001521

Roger G. Barry (2008). Mountain Weather and Climate (Third Edition). Cambridge University Press.

Rohli, Robert V. Vega, Anthony J - Climatology (2018, Jones & Bartlett Learning) libgen.li. (n.d.).

Roy, P. S., Ramachandran, R. M., Paul, O., Thakur, P. K., Ravan, S., Behera, M. D., Sarangi, C., & Kanawade, V. P. (2022). Anthropogenic Land Use and Land Cover Changes—A Review on Its Environmental Consequences and Climate Change. In *Journal of the Indian Society of Remote Sensing* (Vol. 50, Issue 8, pp. 1615–1640). Springer. https://doi.org/10.1007/s12524-022-01569-w

Roy, P., Paul, S., Chakrabortty, R., Saha, A., & Chowdhuri, I. (2022). A systematic review on climate change and geo-environmental factors induced land degradation: Processes, policy-practice gap and its management strategies. Geological Journal. doi.org/10.1002/gj.4649

Roy, S., Singha, N., Bose, A., Basak, D., & Chowdhury, I. R. (2023). Multi-influencing factor (MIF) and RS–GIS-based determination of agriculture site suitability for achieving sustainable development of Sub-Himalayan region, India. Environment, Development and Sustainability, 25(7), 7101–7133. doi.org/10.1007/s10668-022-02360-0

Rusinga, O., Chapungu, L., Moyo, P., & Stigter, K. (2014). Perceptions of climate change and adaptation to microclimate change and variability among smallholder farmers in Mhakwe Communal Area, Manicaland province, Zimbabwe. Ethiopian Journal of Environmental Studies and Management, 7(3), 310. doi.org/10.4314/ejesm.v7i3.11

Rusoke, T. (2024). Global Warming and Climate Change (pp. 335–356). Informa. https://doi.org/10.1201/9781032715438-17

S. Archer, D. Schimel and E. Holland. (1995). Mechanisms of Shrubland Expansion: Land Use, Climate, or CO2? Climatic Change, Vol. 29, No. 1, 1995, pp. 91-99. doi:10.1007/BF01091640

Sabova, Zuzana, et al. (2022) The role of intense rainfall events on the land degradation processes in the Slovak and Polish catchments. EGU General Assembly Conference Abstracts. 2022

Sachin, Saharan., Janardan, Singh., Rahul, Sharma., Akshay, Singh., Kunal, Narwal., B., S., Rana., Saroj, Kumari., Divyanshu, Prashar. (2024). Revitalizing Rainfed Agriculture:

The Transformative Potential of Watershed Development. International Journal of Plant and Soil Science, 36(7):969-987. doi: 10.9734/ijpss/2024/v36i74809

Saguye, T. S. (2017). Analysis of Farmers' Perception on the Impact of Land Degradation Hazard on Agricultural Land Productivity in Jeldu District in West Shewa Zone, Oromia, Ethiopia. In Journal of Natural Sciences Research www.iiste.org ISSN (Vol. 7, Issue 9). Online. www.iiste.org

Sahu, J. J., Gandhi Krishi Vishwavidyalaya, I., Chaudhary, I., Murari, K., & Correspondence Jubuli Sahu, I. J. (2018). Rainfall based crop planning in rain shadow districts of Chhattisgarh state by using rainfall and crop data. ~ 2916 ~ Journal of Pharmacognosy and Phytochemistry, 7(5), 2916–2920.

Salih, A. A. M., Ganawa, E. T., & Elmahl, A. A. (2017). Spectral mixture analysis (SMA) and change vector analysis (CVA) methods for monitoring and mapping land degradation/desertification in arid and semiarid areas (Sudan), using Landsat imagery. Egyptian Journal of Remote Sensing and Space Science, 20, S21–S29. doi.org/10.1016/j.ejrs.2016.12.008

Sanchez-Moreno, J. F., Mannaerts, C. M., & Jetten, V. (2014). Influence of topography on rainfall variability in Santiago Island, Cape Verde. International Journal of Climatology, 34(4), 1081–1097. doi.org/10.1002/joc.3747

Sandeep, P., Reddy, G. P. O., Jegankumar, R., & Arun Kumar, K. C. (2021). Modeling and Assessment of Land Degradation Vulnerability in Semi-arid Ecosystem of Southern India Using Temporal Satellite Data, AHP and GIS. Environmental Modeling and Assessment, 26(2), 143–154. doi.org/10.1007/s10666-020-09739-1

Sangeetha P V (2004) Land use/land cover changes and its impact on the biophysical environment- A case study in the Chalakkudi River Basin. Thesis submitted to the University of Kerala for the award of the degree of Doctor of Philosophy in Geography

Sankar, S. and Muraleedharan, P.K. (1990). Human ecology in Attappady reserve. In: Nair, K.K.N., Bhat, K. V., Sharma, J. K. and Swarupanandan, V. (Ed.) Tropical Forest Ecosystem Conservation and Development in South and South-East Asia. Proceedings of the MAB Regional Training Workshop.1-13 May 1989, Peechi. Kerala Forest research Institute: p127-131.

Sarah, M., Durant., Sarah, M., Durant., Tim, Wacher., Sultana, Bashir., Rosie, Woodroffe., P., De, Ornellas., C., Ransom., John, Newby., Teresa, Abáigar., Mohanad, Abdelgadir., H., El, Alqamy., Jonathan, E., M., Baillie., M., Beddiaf., Farid, Belbachir., Farid, Belbachir., Amel, Belbachir-Bazi., A., A., Berbash., N., E., Bemadjim., R., Beudels-

Jamar., Luigi, Boitani., Christine, Breitenmoser., M., Cano., P., Chardonnet., Ben, Collen., William, A., Cornforth., F., Cuzin., P., Gerngross., B., Haddane., M., Hadjeloum., A., Jacobson., A., Jebali., F., Lamarque., David, Mallon., K., Minkowski., Steven, L., Monfort., B., Ndoassal., B., Niagate., Gianetta, Purchase., Gianetta, Purchase., S., Samaïla., Abdoulkarim, Samna., Claudio, Sillero-Zubiri., Alaaeldin, Soultan., M., R., Stanley, Price., Nathalie, Pettorelli. (2014). Fiddling in biodiversity hotspots while deserts burn? Collapse of the Sahara's megafauna. Diversity and Distributions, 20(1):114-122. doi: 10.1111/DDI.12157

Sarah, M., Durant., Tim, Wacher., Sultana, Bashir., Rosie, Woodroffe., P., De, Ornellas., C., Ransom., John, Newby., Mohanad, Abdelgadir., Jonathan, E., M., Baillie., M., Beddiaf., Farid, Belbachir., Amel, Belbachir-Bazi., A., A., Berbash., R., Beudels-Jamar., Luigi, Boitani., Christine, Breitenmoser., M., Cano., P., Chardonnet., Ben, Collen., William, A., Cornforth., F., Cuzin., P., Gerngross., B., Haddane., Andrew, P., Jacobson., A., Jebali., F., Lamarque., David, Mallon., K., Minkowski., Steven, L., Monfort., Gianetta, Purchase. (2014). VIEWPOINT Fiddling in biodiversity hotspots while deserts burn? Collapse of the Sahara's megafauna.

Sarma, M., & Pais, J. (2008). Financial Inclusion and Development: A Cross Country Analysis. In Annual Conference of the Human Development and Capability Association, New Delhi, 168(10–13), 1–30. doi.org/10.1002/jid

Sathis, S., (1989). Attappady – a Profile. Archana Press, Trivandrum.

Sato, T. (2005). The TianShan Rain-shadow Influence on the Arid Climate Formation in Northwestern China. Sola, 1, 13–16. doi.org/10.2151/sola.2005-004

Scott, A., Isard., Mark, R., Welford., Steven, E., Hollinger. (1995). A simple soil moisture index to forecast crop yields. Physical Geography, 16(6):524-538. doi: 10.1080/02723646.1995.10642569

Senapati, U., & Das, T. K. (2020). Assessment of potential land degradation in akarsa watershed, west bengal, using gis and multi-influencing factor technique. Advances in Science, Technology and Innovation, 187–205. doi.org/10.1007/978-3-030-23243-6_11

Sharma P, Rai S C, Sharma R, Sharma E (2004) Effects of land use change on soil microbial C, N and P in a Himalayan Watershed. Pedobiologia 48 : 83-92.

Shobha, Nandargi. (2017). Temporal and Spatial Analysis of Rainfall and Associated Normalized Difference Vegetation Index (NDVI) over the Pune District, India. 3(4):1-6. doi: 10.21859/FOCSCI-03041452

Shoumik, A. A. B., Błońska, E., & Lasota, J. (2024). Soil Quality Index According to Diverse Land Use Systems Across the Europe. Land Degradation & Development. doi.org/10.1002/ldr.5438

Shoumik, B. A. A., Błońska, E., & Lasota, J. (2024). Soil Quality Index According to Diverse Land Use Systems Across the Europe. Land Degradation & Development. doi.org/10.1002/ldr.5438

Simon, Chamaillé-Jammes., Hervé, Fritz., Felix, Murindagomo. (2006). Spatial patterns of the NDVI–rainfall relationship at the seasonal and interannual time scales in an African savanna. International Journal of Remote Sensing, 27(23):5185-5200. doi: 10.1080/01431160600702392

Singh, A., Timsina, K., Detsen, K., Bhutia, O., Balasuddareshwaran, A., Management, N. R., & Management, N. R. (2010). Vulnerability of high land communities to climate induced change and practical adaptive capacity. May 2016, 1–12.

Singh, B. K., Bardgett, R. D., Smith, P., & Reay, D. S. (2010). Microorganisms and climate change: Terrestrial feedbacks and mitigation options. Nature Reviews Microbiology, 8, 779–790

Singh, E. A., & Shindikar, M. R. (2023). A Comprehensive Review on Climate Change and Its Effects. International Journal of Enviornment and Climate Change. https://doi.org/10.9734/ijecc/2023/v13i113240

Sivakumar, M. V. K., & Stefanski, R. (2007). Climate and land degradation — an overview. Environmental Science and Engineering (Subseries: Environmental Science), 9783540724377, 105–135. doi.org/10.1007/978-3-540-72438-4_6

Smith, R. B., & Barstad, I. (2004). A linear theory of orographic precipitation. Journal of the Atmospheric Sciences, 61(12), 1377–1391. doi.org/10.1175/1520-0469(2004)061

Solomon, N., Birhane, E., Tilahun, M., Schauer, M., Gebremedhin, M. A., Gebremariam, F. T., Gidey, T., & Newete, S. W. (2024). Revitalizing Ethiopia's highland soil degradation: a comprehensive review on land degradation and effective management interventions. Discover Sustainability, 5(1). https://doi.org/10.1007/s43621-024-00282-7

Soman. K., (2002). Geology of Kerala, Geological Society of India, Bangalore

Sommer R, Paun E (2011). Organic Carbon in soils of Central Asia – status quo and potentials for sequestration. Plant and Soil 338 : 273-288.

Sonalkar, Sumit. Post eco-restoration changes in vegetation and edaphic attributes of Eastern Attappady, Kerala. Diss. Department of Forest Management and Utilisation, College of Forestry, Vellanikkara, 2016.

Sprunger, C. D. (2023). The effect of soil degradation on human, animal and plant health. Open Access Government. doi.org/10.56367/oag-039-10403

Staatsuniversitatsbibliothek, N., Geology, P., Ab, A., Desert, A., Andes, C., Amer-, S., Hemisphere, S., America, S., Desert, A., America, S., Current, H., Cordillera, A., Cordillera, A., Andes, T., Pacific, S., America, S., Desert, A., Depression, C., Andes, C., Seaway, C. A. (2016). Andean uplift and climate change. 160, 7–10.

Strahler A H, Strahler A N (2006). Modern Physical Geography. John Wiley & Sons - New York, Fourth Edition

Sujith, Ravi., Paolo, D'Odorico. (2005). A field-scale analysis of the dependence of wind erosion threshold velocity on air humidity. Geophysical Research Letters, 32(21) doi: 10.1029/2005GL023675

Sundari, S. K. K. (2023). Introduction (pp. 1-C0P27). Oxford University Press eBooks. https://doi.org/10.1093/oso/9780197645109.003.0001

Swarnima, Singh., R., B., Singh. (2021). Climate Dynamics and Livelihood Vulnerability Assessment. 195-230. doi: 10.1007/978-981-16-4648-5_7

Syers J K, Powlson D S, Rapport I, Sanchez P A, Lal R, Greenland D J, Ingram J (1997). Managing soils for long term productivity (and discussion). Philosophical Transactions: Biological Sciences 352 : 1011-1021.

Tagore, G. S., Bairagi, G. D., SHARMA, N. K., SHARMA, R., BHELAWE, S., & VERMA, P. . (2012). Mapping of Degraded Lands Using Remote Sensing and GIS Techniques Mapping of Degraded Lands Using Remote Sensing and GIS Techniques. Journal of Agricultural Physics, 12(1), 29–36.

Tahir, Z., Haseeb, M., Mahmood, S. A., Batool, S., Abdullah-Al-Wadud, M., Ullah, S., & Tariq, A. (2025). Predicting land use and land cover changes for sustainable land management using CA-Markov modelling and GIS techniques. *Scientific Reports*, *15*(1). https://doi.org/10.1038/s41598-025-87796-w

Tamlin, M., Pavelsky., Stefan, Sobolowski., Sarah, B., Kapnick., Sarah, B., Kapnick., Jason, B., Barnes. (2012). Changes in orographic precipitation patterns caused by a shift from snow to rain. Geophysical Research Letters, 39(18) doi: 10.1029/2012GL052741

Tarbuck E J, Lutgens F K, Tasa D G. (2016). Earth: An Introduction to Physical Geology. Pearson India Education Services Private Limited- Noida, 11th Edition

Tawde, S. A., & Singh, C. (2015). Investigation of orographic features influencing spatial distribution of rainfall over the Western Ghats of India using satellite data. International Journal of Climatology, 35(9), 2280–2293. doi.org/10.1002/joc.4146

Taylor, M., & Bhasme, S. (2021). Between deficit rains and surplus populations: The political ecology of a climate-resilient village in South India. Geoforum, 126(January 2020), 431–440. doi.org/10.1016/j.geoforum.2020.01.007

Teferi E, Bewket W, Simane B (2016). Effects of land use and land cover on selected soil quality indicators in the head water area of the Blue Nile basin of Ethiopia. Environ Monit Assess 188 : 213-221.

Tesfahunegn, G. B. (2014). Soil quality assessment strategies for evaluating soil degradation in Northern Ethiopia. Applied and Environmental Soil Science, 2014. https://doi.org/10.1155/2014/646502

Tesfahunegn, G. B. (2019). Farmers' perception on land degradation in northern Ethiopia: Implication for developing sustainable land management. Social Science Journal, 56(2), 268–287. https://doi.org/10.1016/j.soscij.2018.07.004

Tesfaye Samuel Saguye, Analysis of Farmers' Perception on the Impact of Land Degradation Hazard on Agricultural Land Productivity in Jeldu District in West Shewa Zone, Oromia, Ethiopia,2017, Vol.7, No.9, 2017

Thampi P K., Nair N G K., and Santosh M., (1984). Alkali granite-syenite-carbonatite association in Munnar Kerala, India;implications for rifting, alkaline magmatism and liquid immiscibility, Proceedings of the Indian Academy of Science (Earth and Planetary Science)., Vol. 93, PP: 149–158

Thomas, A., & Cheung, W. W. L. (2024). Impacts of Climate Change. Frontiers for Young Minds, 12. https://doi.org/10.3389/frym.2024.1355408

Thomas, R., & Duraisamy, V. (2018). Hydrogeological delineation of groundwater vulnerability to droughts in semi-arid areas of western Ahmednagar district. The Egyptian Journal of Remote Sensing and Space Science, 21(2), 121–137.

Thomas, R., Parish., Richard, D., Clark., Todd, D., Sikora. (2020). Nocturnal Destabilization Associated with the Summertime Great Plains Low-Level Jet. Monthly Weather Review, 148(11):4641-4656. doi: 10.1175/MWR-D-19-0394.1

Thornbury W D (2008) Principles of Geomorphology. New Age International Publishers - New Delhi, Revised Second Edition

Tiwari, P. C. (2024). Climate Change induced Drought and its Impact on Subsistence Farming and Food System in High Mountains: An Interpretation of Women's Insight in a Rain-fed Watershed, Kumaon Lesser Himalaya, India. Disaster Advances, 17(12), 9–22. https://doi.org/10.25303/1712da09022

Trewartha G T, Robinson A H, Hammond E H (1967) Elements of Geography: Physical and

Cultural. McGraw Hill Book Company - New York, Fifth Edition

Tuan, Vu, Dinh., Tuan, Vu, Dinh., Hieu, Nguyen., Xuan-Linh, Tran., Nhat-Duc, Hoang. (2021). Predicting Rainfall-Induced Soil Erosion Based on a Hybridization of Adaptive Differential Evolution and Support Vector Machine Classification. Mathematical Problems in Engineering, 2021:1-20. doi: 10.1155/2021/6647829

Turner II B L (1992) Local faces, global flows: The role of land use and land cover in global environmental change. Land Degradation and Rehabilitation 5:71-78

Turner, H. (1980) Types of microclimate at high elevations. In U. Benecke and M. R. Davis (eds), Mountain Environments and Subalpine Tree Growth. Wellington: Technical Paper No. 70, Forest Research Institute, New Zealand Forest Service, pp. 21–6.

Turyasingura, B., Ayiga, N., & Benzougagh, B. (2022). Re-thinking on land degradation and its impacts on livelihoods of the farmers in Kanungu District, Uganda. Research Square, 1, 0–22.

Ulrich, A., Ifejika Speranza, C., Roden, P., Kiteme, B., Wiesmann, U., & Nüsser, M. (2012). Small-scale farming in semi-arid areas: Livelihood dynamics between 1997 and 2010 in Laikipia, Kenya. Journal of Rural Studies, 28(3), 241–251. doi.org/10.1016/j.jrurstud.2012.02.003

Ummah, M. S. (2019). In Sustainability (Switzerland) (Vol. 11, Issue 1).

Usman, S., Jayeoba, J. O., & Kundiri, A. M. (2024). Climate Change at a Global Concept: Impacts and Adaptation Measures. International Journal of Enviornment and Climate Change, 14(6), 445–459. https://doi.org/10.9734/ijecc/2024/v14i64242

V., Yesubabu., Biyo, Thomas., C.V., Srinivas., Ghouse, Basha., Ravi, Kumar, Kunchala. (2024). Impact of Western Ghats orography on the simulation of extreme precipitation over Kerala, India during 14–17 August 2018. Atmospheric Research, doi: 10.1016/j.atmosres.2023.107211

Valeria, Zavala., Sébastien, Carretier., Stéphane, Bonnet. (2020). Influence of orographic precipitation on the topographic and erosional evolution of mountain ranges. Basin Research, 32(6):1574-1599. doi: 10.1111/BRE.12443

Varghese, M., Leena, P. P., Murugavel, P., Bankar, S., Todekar, K., Chowdhuri, S., Safai, P. D., Malap, N., Konwar, M., Dixit, S., Rao, Y. J., & Prabha, T. V. (2020). New particle formation observed from a rain shadow region of the Western Ghats, India. Toxicological and Environmental Chemistry, 102(7–8), 305–333. doi.org/10.1080/02772248.2020.1789134

Velluva S (1999), Dynamics of Land Use in Recently settled forest areas-Acase study of Attappady, Kerala, Kerala Forest Research Institute, Peechi and Department of Applied Economics, Cochin University of Science and Technology

Velluva, S. (2006). Land settlement and degradation: Dynamics of land use in recently settled forest areas of Kerala. Serials Publications.

Warner, K., Afifii, T., Henry, K., Rawe, T., Smith, C., & de Sherbinin, A. (2012). Where the Rain Falls: Climate Change, Food and Livelihood Security, and Migration: An 8-Country Study to Understand Rainfall, Food Security, and Human Mobility. 144.

Weeraratna, S. (2022). Climate Change and Land Degradation. 59–65. doi.org/10.1007/978-3-031-12138-8_6

Wei, C., & Pandolfi, M., Querol X., Alastuey A., Jimenez J. L., Jorba O. Day D., Ortega A., Cubison M.J., Comeron A., Sicard M., Mohr C., Prevot A.S.H., Minguillon M.C., Pey J., Baldasano J M. Burkhart J.F., Seco R., Penuelas j., Van Drooge B.L., Artinano B., D I Marc J.J. (2014). Journal of Geophysical Research : Atmospheres. Journal of Geophysical Research, 3, 6578–6595. https://doi.org/10.1002/2013JD020872.Received

Wheeler, L. B. (2017). Modeling Atmosphere-Mountain Interactions : Implications for Stable Isotope-Based Paleoaltimetry.

Whitney, J.B.R. 1987. "Impact of Fuel wood use on Environmental Degradation in the Sudan." In P. Little et al. eds. Lands at Risk in the Third World: Local Level Perspectives. Boulder, Colorado: Westview Press.

Wijitkosum, S. (2016). The impact of land use and spatial changes on desertification risk in degraded areas in Thailand. Sustainable Environment Research, 26(2), 84–92. doi.org/10.1016/j.serj.2015.11.004

Wijitkosum, S. (2021). Factor influencing land degradation sensitivity and desertification in a drought prone watershed in Thailand. International Soil and Water Conservation Research, 9(2), 217–228. https://doi.org/10.1016/j.iswcr.2020.10.005

WMO. (2005). Climate and Land Degradation Climate and Land Degradation (Issue 989). http://www.wmo.int/pages/themes/wmoprod/documents/WMO989E.pdf

Wu J (2008) Land use changes: economic, social and environmental impacts. CHOICES: The magazine of food, farm and resource issues 23(4) : 6-10

Wu, Ma., Lu, Zhai., Alexandria, L., Pivovaroff., Jacquelyn, K., Shuman., P., Buotte., Junyan, Ding., Bradley, O., Christoffersen., Ryan, G., Knox., Max, A., Moritz., Rosie, A., Fisher., Charles, D., Koven., Lara, M., Kueppers., Chonggang, Xu. (2021). Assessing climate change impacts on live fuel moisture and wildfire risk using a hydrodynamic vegetation model. Bio geosciences, 18(13):4005-4020. doi: 10.5194/BG-18-4005-2021

Xian-long, Yang., Yan'an, Tong., Yong-li, Lu., Hai-yang, Ma. (2015). Research advances in the calculating method of nitrogen use efficiency (NUE) in cultivated lands. Journal of Applied Ecology, 26(7):2203-2212.

Ximing, Cai., Dingbao, Wang., Romain, Laurent. (2009). Impact of Climate Change on Crop Yield: A Case Study of Rainfed Corn in Central Illinois. Journal of Applied Meteorology and Climatology, 48(9):1868-1881. doi: 10.1175/2009JAMC1880.1

Y.G., Prasad., O.M., Bambawale. (2010). Effects of Climate Change on Natural Control of Insect Pests. Indian Journal of Dryland Agricultural Research and Development, 25(2):1-12.

Yeneneh, N., Elias, E., & Feyisa, G. L. (2024). Monitoring soil quality of different land use systems: a case study in Suha watershed, northwestern highlands of Ethiopia. 13, 1–17. https://doi.org/10.1186/s40068-024-00336-9

Yones K, Farshad K, Sohaila E (2014) The effect of land use change on soil and water quality in Northern Iran. J. Mt. Sci 9 : 798-816.

Zeng D H, Hu Y L, Chang S X, Fan Z P (2009) Land cover change effects on soil chemical and biological properties after planting Mongolian Pine (Pinus sylvestris var. mongolica) in sandy lands in Keerqin, North Eastern China. Plant and Soil 317(1/2) : 121-133.

Zhang P, Li L, Pan G, Ren J (2006) Soil quality changes in land degradation as indicated by soil chemical, biochemical and microbiological properties in a Karst area of Southwest Guizhou, China. Environ Geol 51 : 609-619

Zheng-Rong, Kan., Jian-Ying, Qi., Xin, Zhao., Xiang-Qian, Zhang., Lu, Zhanyuan., Cheng, Yuchen., Hailin, Zhang. (2020). No-Till Farming Systems in Rain-Fed Areas of China. 477-492. doi: 10.1007/978-3-030-46409-7_27

Zhihui Li, Xiangzheng Deng, Fang Yin, and Cuiyuan Yang. (2014). Analysis of Climate and Land Use Changes Impacts on Land Degradation in the North China Plain" Hindawi Publishing Corporation Advances in Meteorology Volume 2015, Article ID 976370, 11 pages. doi.org/10.1155/2015/976370

Ziervogel, G., & Calder, R. (2003). Climate variability and rural livelihoods: Assessing the impact of seasonal climate forecasts in Lesotho. Area, 35(4), 403–417. doi.org/10.1111/j.0004-0894.2003.00190.x

APPENDIX

Appendix 1. Sub-criteria of each parameter and the pairwise comparison matrix and their weights

Sl.No	Factors	1	2	3	4	5	6	7	8	9	10	CR	Weight (Ri)	$RSI = \sum_{i=1}^{n} Wi * Ri*100$
	Rainfall (in mm)													
	650	1											0.29	8.12
	700	1/2	1										0.19	5.32
	800	1/3	1/2	1									0.15	4.2
	900	1/4	1/3	1/2	1								0.11	3.08
1	1000	1/5	1/4	1/3	1/2	1							0.08	2.24
	1250	1/6	1/5	1/4	1/3	1/2	1						0.07	1.96
	1500	1/6	1/6	1/5	1/4	1/3	1/2	1					0.05	1.4
	2000	1/7	1/7	1/6	1/5	1/4	1/4	1/3	1				0.03	0.84
	3000	1/8	1/8	1/7	1/6	1/5	1/6	1/5	1/3	1			0.02	0.56
	>3000	1/9	1/9	1/8	1/7	1/7	1/8	1/7	1/5	1/5	1	**0.091**	0.01	0.28
	Elevation													
	<500	1											0.41	7.79
2	500-1000	1/2	1										0.37	7.03
	1000-1500	1/3	1/5	1									0.16	3.04
	>1500	1/4	1/7	1/5	1							**0.095**	0.06	1.14
	Wind Speed (10 Meter)													
3	<2.00	1											0.52	8.32
	2.00-2.15	1/3	1										0.30	4.8
	2.15 – 2.30	1/5	1/5	1									0.13	2.08
	2.30-2.41	1/7	1/7	1/5	1							**0.085**	0.05	0.8
4	**Relative Humidity**													
	<76.21	1											0.49	5.39
	76.21 – 77.86	1/2	1									**0.038**	0.30	3.3

	77.86 – 79.55	1/4	1/3	1									0.16	1.76
	79.55 – 81.17	1/7	1/5	1/5	1								0.05	0.55
5	**Temperature**											**0.037**		
	23.76-24.13	1											0.40	3.2
	23.56-23.76	1	1										0.32	2.56
	23.32-23.56	1	1/3	1									0.23	1.84
	23.08-23.32	1/7	1/5	1/5	1								0.05	0.4
6	**LST**											**0.051**		
	24-32	1											0.53	3.71
	22-24	1/3	1										0.31	2.17
	19-22	1/5	1/5	1									0.11	0.77
	14-19	1/7	1/7	1/3	1								0.05	0.35
7	**NDVI**											**0.007**		
	-0.10 – 0.30	1											0.33	1.65
	0.30 – 0.35	1	1										0.32	1.6
	0.35 - 0.39	1	1	1									0.28	1.4
	0.39 – 0.60	1/3	1/5	1/5	1								0.07	0.35
8	**Land Use Land Cover**											**0.096**		
	Crop Land	1											0.46	1.38
	Scrub	1/3	1										0.22	0.66
	Builtup	1/5	1/3	1									0.16	0.48
	Barren	1/7	1/5	1/3	1								0.09	0.27
	Forest	1/8	1/7	1/5	13	1							0.05	0.15
	Water	1/9	1/8	1/7	15	1/5	1						0.02	0.06
9	**SMI**											**0.017**		
	<0.38	1											0.42	0.84
	0.38-0.50	1/2	1										0.26	0.52
	0.50-0.60	1/3	1/2	1									0.16	0.32
	0.60-0.70	1/4	1/3	1/2	1								0.10	0.2
	>0.70	1/5	1/4	1/3	12	1							0.06	0.12
10	**TVPDI**											**0.015**		
	0.40-0.76	1											0.50	0.5
	0.76-0.90	1/3	1										0.27	0.27
	0.90-1.02	1/5	1/3	1									0.13	0.13
	1.02-1.15	1/7	1/5	1/3	1								0.07	0.07
	1.15-1.47	1/9	1/7	1/5	13	1							0.03	0.03

Appendix 2. Effect of influencing factor, relative rates and score for each potential factor

Influencing Factors	Major Effect A	Minor Effect B
Vegetation Type	LULC, Soil, Groundwater Prospects, TWI and Rainfall	Drainage Density, Road Density, Relief and Slope
Soil	Vegetation, Rainfall, LULC, Relief, Slope	Road Density, Groundwater Prospects, TWI, Drainage Density
LULC	Soil, Vegetation Type, Groundwater Prospects, Rainfall, TWI	Road Density, Drainage Density, Slope and Relief
Drainage Density	Groundwater Prospects, Rainfall, Slope, TWI and Soil	LULC, Road Density, Relief, Soil
Rainfall	Vegetation, LULC, TWI, Drainage Density, Soil and Groundwater	Road Density, Slope, Relief
Groundwater	Vegetation, Rainfall, Soil, Drainage Density, TWI, LULC	Road Density, Slope and Relief
TWI	Slope, Relief, Rainfall and Drainage Density	Groundwater Prospects, Vegetation, Soil, Road Density and LULC
Slope	TWI, Soil, Groundwater Prospects, Drainage Density	Rainfall, LULC, Vegetation Type, Relief and Road Density
Relief	TWI, Slope, Drainage Density	Vegetation Type, LULC, Soil, Road Density, Groundwater and Rainfall
Road Density	Slope, Relief, LULC	Rainfall, TWI, Groundwater Prospects, Vegetation Type, Soil, Drainage Density

Appendix 3: Proposed Score for Each Influencing Factors

Influencing Factors	Major Effect A	Minor Effect B	Proposed Relative Rates (A+B)	Proposed Score for Each Influencing Factors
Vegetation Type	1+1+1+1+1	0.5+0.5+0.5+0.5	7	10
Soil	1+1+1+1+1	0.5+0.5+0.5+0.5	7	10
LULC	1+1+1+1+1	0.5+0.5+0.5+0.5	7	10
Drainage Density	1+1+1+1+1	0.5+0.5+0.5+0.5	7	10
Rainfall	1+1+1+1+1+1	0.5+0.5+0.5	7.5	11
Groundwater	1+1+1+1+1+1	0.5+0.5+0.5	7.5	11
TWI	1+1+1+1	0.5+0.5+0.5+0.5+0.5	6.5	10
Slope	1+1+1+1	0.5+0.5+0.5+0.5+0.5	6.5	10
Relief	1+1+1	0.5+0.5+0.5+0.5+0.5+0.5	6	9
Road Density	1+1+1	0.5+0.5+0.5+0.5+0.5+0.5	6	9
SUM			**68**	**100**

Appendix 4. Soil Quality Parameters Laboratory Value

id	Location	Landuse	pH	EC	Nitrogen	Phosphorous	Pottassium	Calcium	Magnesium	Copper	Iron	Zinc	Manganese	Boron	Sulphur
1	Padavayal	Agriculture	5.93	0.00021	220.77	33.97	179.2	1524.75	561.64	3.42	74.35	5.54	5.44	0.249	5.25
2	Tekkupana	Agriculture	6.06	0.00024	234.57	57.31	160.16	1359.75	324.2	2.48	48.39	3.29	3.13	0.257	3.62
3	Bhuthyur	Barren land, no cultivation	6.32	0.00022	193.18	13	124.32	1479.38	467.63	1.29	BDL	0.95	47.19	0.207	24.71
4	Pazhayur(pallayur)	No cultivation	6.16	0.00019	179.38	13.55	86.24	1188.75	303.01	1.44	95.49	3.79	83.85	0.212	3.71
5	Kollapadiga	No cultivation	5.37	0.00089	234.57	24.12	369.6	1564.75	528.91	1.55	10.72	1.81	83.39	0.207	17.71
6	Melle machakandi	No cultivation, coconut in somewhere	5.82	0.00014	179.38	17.21	45.92	396.25	82.83	BDL	23.56	1.08	16.08	0.211	24.94
7	China parabu	Arecanut ,	5.24	0.00022	234.57	11.72	113.12	243.63	94.94	4.11	BDL	1.58	83.67	0.24	32.28
8	Kallamala	Plantain, Arecanut	4.46	0.0004	220.77	152.75	207.2	261.13	65.38	BDL	59.77	2.11	68.81	0.211	7.25
9	Kollamala2	Arecanut, coffee, pepper	6.14	0.00026	220.77	23.84	367.36	637.75	211.19	0.67	30.46	2.93	66.57	0.215	14.55
10	Ommala	Arecanut, pepper, coconut	4.65	0.00042	289.77	13.72	332.64	248.88	126.08	0.91	BDL	0.87	3.17	0.242	3.19
11	Nelliyapathy	Coconut	6.62	0.00038	179.38	87.24	117.6	789.13	100.76	BDL	13.35	8.72	59.81	0.206	4.9
12	Bhoothyvazhi	No cultivation	7.33	0.00045	137.98	48.13	113.12	1033.88	59.63	BDL	7.84	0.72	58.03	0.215	6.01
13	Bhoothvazhi built up area	Built up	7.93	0.00076	179.38	27.74	146.72	3136.75	284.93	BDL	BDL	0	5.27	0.206	7.12
14	Agali	Scrubs, abondan terraced farm	6.39	0.00035	206.98	17.23	112	1537.5	316.48	4.60	26.57	0.84	94.14	0.233	6.71
15	Nakkuppathy uru	No cultivation, thuvara, ground nut	5.83	0.00024	206.98	15.42	292.32	664.75	152.04	BDL	11.06	1.95	87.28	0.227	4.07
16	Sholayur	No cultivation	5.96	0.00043	275.97	11.08	190.4	2011.38	611.58	BDL	52.21	2.52	6.59	0.217	5.54
17	Sholayur	No cultivation	5.91	0.0003	510.54	12.59	156.8	2003.88	552.93	BDL	26.98	0.84	36.02	0.22	5.65
18	Uthukuzhi1	Scrubs	5.89	0.00026	220.77	15.14	113.12	2606.38	529	BDL	24.05	1.09	71.09	0.22	5.95
19	Uthukuzhi 2	Scrub	6.13	0.00019	179.38	14.88	132.16	792.88	205.19	BDL	19.88	0.16	43.2	0.218	3.74
20	Vellakulam	No agriculture	6.27	0.00028	151.78	48.15	101.92	203.25	75.83	BDL	10.14	0.03	34.6	2.144	5.35
21	Vachapathy	No agriculture	6.26	0.00036	220.77	14.82	78.4	1887.75	339.26	0.19	77.38	0.77	77.9	0.229	5.2
22	Anakkatti	Scrubs, Cactus	6.26	0.00063	206.98	16.7	248.64	953.13	257.61	BDL	5.64	0.12	82.54	0.237	7.88
23	Vattalaki	Plantation, scrubs	7.39	0.00095	179.38	29.93	293.44	1399.63	104	BDL	BDL	0.15	73.27	0.24	5.31

24	Kalkandi	Cultivable land	6.83	0.0003	193.18	23.36	171.36	778.5	203.39	BDL	1.85	0.42	67.15	0.223	5.6
25	Mulakombu	Cultivable land	6.09	0.00031	193.18	20.83	347.2	791.13	271.98	0.66	14.43	1.45	2.52	0.245	5.53
26	Mulli	Cultivable	6.84	0.00032	179.38	91.37	182.56	620.25	275.19	BDL	6.50	1.62	84.89	0.257	11.7
27	Pattimalam	Cultivable land	6.28	0.00026	179.38	40.53	293.44	566.5	206.28	BDL	19.94	0.28	63.84	0.253	5.35
28	Anakall	Agricultural, paddy	5.25	0.00092	248.37	41.82	168	1029.88	347.23	BDL	12.53	1.84	4.33	0.244	29

QUESTIONNAIRE

An Appraisal of Rain Shadow Effects and Livelihood Dynamics in the Attappady Hilly Region, Western Ghats, Kerala

The following questions are prepared to study the "An Appraisal of Rain Shadow Effects and Livelihood Dynamics in the Attappady Hilly Region, Western Ghats, Kerala" for the research work in the Department of Geography, Govt. College Chittur.

A. Demographic and Socio-economic status

Name of the Respondent:

1. Location: (Panchayat) 1). Agali 2). Pudur 3) Sholayur
2. Place:
3. Gender 1). Male 2) Female
4. Age:
5. Marital status: 1) Married 2). Unmarried 3). Widow 4.) Widower
6. Household size (No):

7 Education status:

8. Residence status: 1) Native 2) Migrant
9. Category: 1.) ST 2) SC 3) OBC 4.) GENERAL
10. Occupations: (Before 2000)
11. Occupations: (**After** 2000)
12. Income Status 1) BPL 2) APL

13 Annual Income:

B. **Agricultural status**

14 **Livestock status** -(**Before** 2000) .1) Cow 2) Goat 3) Buffalo-4) Poultry 5) Nil

15. Livestock status with number -(**After** 2000) .1) Cow 2) Goat 3) Buffalo 4) Poultry 5) Nil

----

16. **Total cultivated land**-(**Before** 2000) (Acre):

17Total cultivated land-(**After 2000**) (Acre):

18 **At present**. size of the cultivated land 1) Increased 2) Decreased 3) No Change

19. If total cultivated land **decreased**. Specify **reasons:**

---

20. If you have cultivated land, **Farming Land status** -1) Inheritance 2) Rent 3) Buy, 4) Rent and Buy

21 Slope of the plots- 1) Steep 2) Moderate steep 3) Gentle Flat

---

22. **Crops cultivating status** (**Before 2000**)

23. Crops cultivating status (**After 2000**)

24. Labor status used on your farm 1) Family labor, 2) Hired labor 3) Both

25. If farmer, specify farming experience (Years)

C. Climatic Status

26 ***climate of your area*** 1). Hot and Dry 2) Cool 3) Moist

27.Is there any climate change for couple of years 1). Yes 2. No

28.What is rate of climate change? 1)High 2) Moderate 3) Low

29**. Temperature** of your area. 1) High 2). Moderate 3) Low

30 Rate of Temperature amount for last couples of years 1) Increased 2). Decreased.3) No Change

31. How many years of this Temperature change experienced?

32.Which side of Attapady comparatively receives high temperature?

1). East part 2). Western Part

----

33. **Rain** fall of your area 1) High 2) Moderate 3) Low

34 Rate of rainfal**l** amount in your area. 1). Decreased 2). Increased 3). No Change

35 How many years this rainfall change;

36. Rainfall receiving month of your area 1) June –Sept2) Octo-Dember 3) Both

37 Highest rainfalls receiving months- 1) June –Sept 2) Octo-Dember 3) Both

38. Which side of Attapady comparatively receives low rainfall? 1)Eastern part 2). Western Part

----

39 Do you feel that there is the moderate to high level **wind flow** throughout year 1) yes 2) No

40. If yes, mention direction of wind 1) From West to East 2) From East to West 3) Both

41 What is the nature of wind 1) Cool and Dry 2) Hot and Dry 3) Both

42 Do you think that the presence of the western hill ranges reduced the rainfall of your area when compare with western side of the hills (***Rain shadow effect***) 1) Yes 2) No 3) No Opinion

43 **If yes**, what is its effect ….

----

44 What is the general **type of natural vegetation** of your area 1) Long and evergreen type 2) Short scrubs and grass type 3) Both

45.Specify the plants.

----

46 If you agree that there is climate change in your area, **reason** ***of climate change?***

1). Deforestation. 2) Land use change 3). Unscientific agricultural practice. 4). Global warming 5). Population growth 6) All 7) No Opinion

47. According to you, what are the ***impacts of the climate change*** ***on agriculture*** of your area?

1). Water Scarcity 2). Land degradation 3). Reduced crops production 4). Crop conversion 5) More Fallow land 6) Unemployment 7) Loss in Livestock 8) Increased Pests and Diseases 9) All 10) No opinion

---

48 Is there more **land conversion** to fallow land due to climate change in your area1) Yes 2 No

49If yes, where is more land conversion to fallow land in Attappady 1) East 2) West 3) All part

50 Is there more **crop conversion** due to climate change in your area 1) Yes 2) No

51.If yes, Crops more crop conversion to

52 Where is more crop conversion land in Attappady 1) East 2) West 3) All part

53.Mention the period of crop conversion (years)

1) < 5 2) .5-10 3).10-20 4) .20-30 5)30-40 6). Above 40 years

----
-

54.Climate change decreased ***livestock*** number in your area 1) Yes 2) No

55. If yes, which animals mostly affected 1) Cow 2) Goat 3) Buffolo 4) All

56.Climate change caused to any health ***issues*** in your area 1) Yes 2) No 3) No opinion

57 If yes, specify which type of health issue….

----

58. What are the major ***sources of water*** for **domestic** (**before 2000**

59.What are the major ***sources of water*** for domestic (**After2000)**

60. What are the major ***sources of water*** for **agriculture** (**before 2000**)-

61. What are the major ***sources of water*** for agriculture (**After2000**)

62. Have you felt any ***water scarcity*** in your area 1) Yes 2). No

63. Mention time period of water scarcity in your area?
1) . Throughout years 2). Only hot season (feb to May)

64. What are reasons for water scarcity in your area? 1). Low rainfall 2). High temperature 3) Dry up of River 4) All

65. What is the general level of **underground water** of your area 1) Low 2) Moderate 3) High

66.What change you have observed in the Underground ***(water table)*** in the last 25 years? .
1)Decrease 2). Increase 3) No change

67. If decreased, what are the main causes of decline in underground water?
1). Decrease in rainfall 2). Increase in temperature 3). Deforestation 4). More Tube wells
5) Landuse change 6). All

-

68.Have you felt any ***drought condition*** in your area 1) Yes 2) No

69. How much times you have passed from drought condition since 1980? 1) 1. 2) 2 .3) 3. 4) 4

70. Can you mention last drought years, If yes, mention years………

71.What are the main causes of drought in your area? 1)Decrease in rainfall 2). Increase in temperature 3). Decrease in river flow 4) Deforestation 5) All

72.Which part of Attappady has most affected by the drought condition?

1). Eastern part 2). Western part 3) All part

-----

73. What changes observed in **the forests** of your area since 1950?
1) Decreased 2). Increased 3) stable

74. Specify forest decreased area 1) East part 2) West 3) All part

75 Specify Forest increased area 1) East part 2) West 3) All part

D. Land degradation

76. Which **types of soils** are found more in your area?
1) Fertile soil-A). Loamy soil- 2) Infertile B) Laterite soil (sandy and gravels) 3) No opinion.

77. Has **soil fertility declined** in your cultivated land

78 Which parts has more destruction of soil quality

78 Did the soil fertility decline on your cultivated land? 1). Yes 2). No 3). Stable

79. Level of destruction of soil quality in your area?1) Low 2) Moderate 3). High

80. How many years you have observed this change.

81. What is the road density of your area (number of road/ land size) 1) Low 2) Moderate3) High

82 Is there **more building construction** work in your area 1) Yes 2) No

83 If yes, mention the year 1) Before 2000 2) After 2000

84 Mention nature of slope where the building construction occurs

1) Over moderate steep area 2) Over steep area 3) Over gentle flat area

----

85. More **Crop Conversion** in your area **due to Land Degradation**

86 What do you think about the main **cause of soil fertility decline** in your area?

1) High temperature and Low rainfall 2) Deforestation 3). unscientific agricultural practice, 4). Land use changes 5) Population increase 6). Crop conversion 7) Water scarcity 8) All

87. What are the general **impacts of the land degradation on agriculture** in your area?

1) More fallow and barren land 2). Unproductive Agriculture field 3). Unemployment 4). Water Scarcity. 5)Crop conversion 6) All

88 Which **crops were mostly affected by land degradation**?

1)Paddy, 2) Plantain 3) Sugarcane 4) cotton 5) Millets 6) All

89.What are your **suggestions for the reducing of land degradation**?

1) Prevent Deforestation 2) Afforestation 3). crop rotation 4) Organic manure 5) Contour farming 6) Land fallowing g. 7) All

Thank you for your valuable responses

SURESH.P.
Research scholar
Assistant Professor of Geography.
Govt. College Chittur, Palakkad
University of Calicut

RICHARD SCARIA
Research Supervisor
Associate Professor of Geography
Govt. College Chittur, Palakkad
University of Calicut

FIELD PHOTOS







Interview and Focused group discussion with local community

LIST OF RESEARCH PAPERS PUBLISHED

1. Suresh P. and Richard Scaria (2024), "A geospatial framework for rain shadow effect on land degradation: A case study of Attappady Western Ghats region, Kerala": Disaster Advances: (ISSN:0974-262X) scoups index (2025)
2. Suresh P. and Richard Scaria (2025) Assessing Climate Change Impacts on Land Conversion and Land Degradation in the Attappady Region of Western Ghat: International Journal of Emerging Technologies and Innovative Research. (ISSN: 2349-5162). Volume 12 | Issue 6 | 2025-06-11, Page No: c23-c32
3. Suresh P. and Richard Scaria (2025), Assessment of Land Degradation and Ecosystem Resilience in the Attappady Region of Western Ghats of Kerala: International Journal of Research and Analytical Reviews-ISSN 2348-1269, P- ISSN 2349-5138, Volume 12 | Issue 2 | June 2025. Page No: 766-776

DETAILS OF RESEARCH PAPERS PRESENTED IN THE CONFERENCE

1. Paper presented with the title of "**Identification of Rain Shadow Region in Attappady by using Composite Approach of Remote Sensing, Geographical Information Systems and Analytical Hierarchy Process"** in the 5th International Disaster Risk and Vulnerability Conference (DRVC -2023) held on January from 19 to 21, 2023, organised by School of Environmental Sciences, Mahatma Gandhi University, Kottayam, Kerala, India.
2. Paper presented with the title of **"Enhancing Disaster Resilience in Rain Shadow Regions: Geospatial Assessment and Strategies for Attappady in the Context of Climate Change"** in the Three Days National Seminar of Disaster Resilience Through Geospatial Intelligence Innovations and Best Practices, held on November from 08 to 10, 2023, organised by Department of Geography, Govt. Arts and Science College, Tholanur, Palakkad, Kerala, India.
3. Paper presented with the title of **"Land Degradation in the Western Ghats in the context of Climate Change - A Case Study of Attappady Region in India"** in the Three Days International Seminar of Geography for Sustainable Development: Understanding Climate Change Impacts and Navigating Pathways to Resilient Futures held on December from 05 to 07, 2023, organised by PG and Research Department of Geography, Govt. College Chittur, Kerala, India.
4. Paper presented with the title of **"Recent Perspectives in Climate Change Studies"** in the International Seminar of Climate Change and Sustainability Physical Dynamics, Social Vulnerability and Community Resilience, held on February from 04 to 06, 2025, organised by Department of Geography, Kannur University, Kerala, India.