ASSESSMENT AND MODELING OF POLLUTION LOAD IN CHALAKUDY RIVER, KERALA, INDIA

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DOCTOR OF PHILOSOPHY

UNDER THE FACULTY OF ENGINEERING

By

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(Reg. No: DOR/B3/1118/PhD/2012)

Under the Supervision of

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UNIVERSITY OF CALICUT

CERTIFICATE

This is to certify that the work reported in this thesis entitled **ASSESSMENT AND MODELING OF POLLUTION LOAD IN CHALAKUDY RIVER, KERALA, INDIA,** that is being submitted by **Mrs. DIVYA. A. H.** for the award of the Degree of Doctor of Philosophy, to the University of Calicut, is based on the bonafide research work carried out by her under my supervision and guidance in the Department of Chemical Engineering, Government Engineering College, Thrissur, University of Calicut. The results embodied in this thesis have not been included in any other thesis submitted previously for the award of any degree or diploma of any other University or Institution.

Place: Thrissur
Date: 24/04/2019

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The suggestions / corrections from the adjudicators as per Ref. No. 167312/RESEARCH-C-ASST-1/2019/Admn Dated 17.12.2019 from the Director of Research, University of Calicut, have been incorporated in this thesis.

Thrissur

10/01/2020

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DECLARATION

I hereby declare that this thesis entitled **"ASSESSMENT AND MODELING OF POLLUTION LOAD IN CHALAKUDY RIVER, KERALA, INDIA."** submitted to the University of Calicut, for the award of Degree of Doctor of Philosophy under the Faculty of Engineering is an independent work done by me under the supervision and guidance of **Dr. P.A. SOLOMAN**, Professor in Chemical Engineering, Department of Chemical Engineering, Government Engineering College, Thrissur, University of Calicut.

I also declare that this thesis contains no material which has been accepted for the award of any other degree or diploma of any University or Institution and to the best of my knowledge and belief, it contains no material previously published by any other person, except where due references are made in the text of the thesis.

Place: Thrissur
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Date: 10/01/2020

DIVYA. A. H.

Dedicated to my father.............

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ABSTRACT

The physico- chemical and bacteriological parameters analysis enables the assessment of pollution load in water bodies. The present study is carried out to assess and evaluate the load of pollution in water along eight different locations in the Chalakudy river, during the period of November 2013 to October 2018, by the analysis of experimentally collected set of water quality data. The 16 physico- chemical and biological water quality parameters such as Potential Hydrogen (pH), Total dissolved solids (TDS), Temperature (T), Turbidity (TUR), Chemical oxygen demand (COD), Dissolved Oxygen (DO), Electrical conductivity (EC), Nitrates ($NO_3^{-)}$, Phosphates (PO_4^-), Sulphates (SO_4^-), Total Hardness (TH), Biochemical oxygen demand (BOD), Chlorides (Cl^-), Total Coliform (TC), Fecal Coliform (FC), and Organo-chlorine pesticides (OCP's) were analysed in the laboratory using American Public Health Association's (APHA) standard methods (22nd edition). Flow velocity and flow area, discharge, % DO saturation, BOD/COD ratio, and FC/TC ratio were measured. All the experimental and calculated values were consolidated and filtered using Pivot table in Microsoft Excel for the detailed data analysis.

The trend of water quality parameters and seasonal variations of each parameter in the river water samples along the period of study were analysed by the box plots, and graphs using MINITAB 17 software. The significance of site and season on each parameter were identified using ANOVA and the possible reasons for these variations in the parameters were anlysed by Tukey method (post hoc ANOVA). Water Quality Index (WQI) calculation using arithmetic index model was performed and the river water has been classified along the study area based on WQI. The parametric correlation analysis was carried out and correlation coefficient (R) was estimated to evaluate the relation between variables, whether their relation is significant or not. This coefficient provides evidence for the relationship between the 15 analyzed parameters. Correlation coefficient was calculated using Microsoft Excel and the so obtained r-values were listed out between the various pairs of analysed parameters.

The effect of twelve water quality parameters of Chalakudy river water such as pH, Cl^-, % DO, TUR, NO_3^-, SO_4^-, PO_4^-, TDS, BOD, EC, TH and TC which helps in the calculation of water quality index (WQI) was studied. The calculation of WQI using arithmetic index method by keeping the standard value for total coliform as 10 CFU/100ml and 50 CFU/100ml was performed and two sets of water quality indices of Chalakudy river were developed. Chalakudy river water has been classified in to five

based on the WQI indices such as ‘Excellent’, ‘Good’, ‘Poor’, ‘Very poor’ and ‘Not suitable for drinking’. Remedial measures for reducing and controlling the load of pollution in Chalakudy river has been proposed.

Fuzzy dissolved oxygen model (FDOM) model was developed to predict the DO of the river water using four experimentally analysed water quality parameters such as T, COD, NO_3^- and PO_4^- as inputs and DO as output. The prediction model was developed using fuzzy inference system relying on MATLAB 17 software. The predicted DO value by FDOM was found very much closer to the actual experimental values with absolute average relative error (AARE) 3.256 and root mean square error (RMSE) 0.26.

A numerical model for prediction of water quality index (FWQIM) of Chalakudy River was also developed using fuzzy logic tool box in MATLAB 17. Calculated values of WQI by an arithmetic index method using twelve various experimentally estimated water quality parameters pH, Cl^-, % DO, TUR, NO_3^-, SO_4^-, PO_4^-, TDS, BOD, EC, TH and TC were used as inputs to develop FWQIM. Triangular membership function was found be superior than other membership functions for the developments of FDOM and FWQIM . It is applicable to any river system using the same input parameters or using more combinations of inputs. The performance of the model was tested by comparing with calculated values of WQI. The fuzzy model is performing well but takes more time to execute using12 input variables. In this case study, it was identified that the TC value has affected WQI more than other water quality parameters. At all the sites, observed values of TC was out of standard. Most of the other parameters were observed within the prescribed limit. However, the predicted value of WQI was found within the range of same class as per the WQI classification.

Two linear regression models of the WQI of Chalakudy river were developed. This gives the relationship between WQI and TC of the Chalakudy river. The Performance of the two regression models in predicting the WQI has been tested. It was found to be significantly good with an AARE of first model as 0.693 and RMSE of 0.5, and for the second model also found to be significantly good with an AARE 1 and RMSE 0.028.

Among the developed numerical models of Chalakudy river water quality, most adoptable and efficient models for predicting water quality index of Chalakudy river are found to be the arithmetic index model and linear regression models in terms of TC than FWQIM.

CONTENTS

RESULTS AND DISCUSSIONS (CHAPTER 4 - 7)

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS AND ACRONYMS

AARE	-	Absolute Average Relative Error
ANOVA	-	Analysis of Variance
APHA	-	American Public Health Association
BDL	-	Below Detection Limit
BHC	-	Benzene hexachloride
BOD	-	Biochemical oxygen demand,
CFU	-	Colony Forming Unit
Cl	-	Chlorides,
COD	-	Chemical oxygen demand
CWC	-	Central Water Commission
DO	-	Dissolved Oxygen
DDT	-	Dichloro diphenyl trichloro ethane
EC	-	Electrical conductivity
FC	-	Fecal Coliform
FDOM	-	Fuzzy Dissoloved Oxygen Model
FWQIM	-	Fuzzy Water Quality Index Model
GC	-	Gas Chromatograph
IS	-	Indian Standard
KSPCB	-	Kerala State Pollution Control Board
KWA	-	Kerala Water Authority
ND	-	Not Detected
$NO3^-$	-	Nitrates
OCP's	-	Organo- chlorine pesticides
pH	-	Potential Hydrogen
$PO4^-$	-	Phosphates,
RMSE	-	Root Mean Square Error
$SO4^-$	-	Sulphates
T	-	Temperature
TC	-	Total Coliform
TDS	-	Total dissolved solids
TH	-	Total Hardness
TUR	-	Turbidity,
WHO	-	World Health Organization
WQI	-	Water Quality Index

NOMENCLATURE

α	- Configurational (alpha position) position in isomers
β	- Configurational (Beeta position) position in isomers
γ	- Configurational (Gamma position) position in isomers
Σ	- Sum of values

Chapter 1

GENERAL INTRODUCTION

Contents

1. Introduction

Water is an essential part of our life. Water resources play a very important role in maintaining human health and ecosystem, therefore environmental assessement of the quality of water resources is a crucial field. Variations in the availability of the water resources mainly depend upon the local geological attributes and the hydrological structure. Over 70% of the earth is covered by water. Out of this only 3% is available as fresh water and the rest 97% is saline. Of this 3%, 99% is either frozen in glaciers or ice pack in aquifers. Rivers are major among these fresh water sources and only less than 1% is available in rivers and lakes for satisfying the various needs.

Water pollution is a major environmental problem and unless due attention is given to this area and proper measures are undertaken, the situation would be worse in the future. In recent years, due to tremendous development in the field of agriculture and industry, and also an increase in population, water ecosystems have become perceptibly altered in several aspects. Consequently, the rivers are exposed to all local disturbances regardless of their source of occurrence (Venkatesan, 2006). Significantly, improper water management and conservation of water bodies lead to the inevitable water crisis in the entire world. Therefore, the health of the rivers and their biological diversity will be directly related to the health of almost every component of the ecosystem (Ramesh et al., 2007). Again, surface water pollution with chemical, physical and biological contaminants due to anthropogenic activities poses high risk and demands environmental attention (Nkedi et al., 2006). Moreover, constant discharges of domestic and industrial wastewater and seasonal changes like climate, surface runoff also have an important role on the river water quality (Shang, 2003). The increase in the supply of nutrients like phosphate, sulphates, and nitrates enhances the eutrophication process and inversely proportional to the dissolved oxygen level of water. Algal blooms also release toxic chemicals which adversely affect fish and other aquatic life and makes the water body stink. Specifically, the local fishermen who are in the habit of using chemical explosives like dynamite for catching fish added to the gravity of this situation.

Kerala, the God’s own country, rich with unique physiography, varieties of land use pattern, and with climatic combinations of winter, monsoon and summer seasons is blessed with 44 rivers (Maya et al., 2005). Of these 41 rivers flows towards the west and 3 towards the east, with a catchment area more than 10000 km^2. It was this wealth of water in our rivers that resulted in the social, cultural and financial development of the state. In the recent decades the rate of urbanization in the state had become very high. It has increased demand for water in many aspects such as supply for drinking water, irrigation, hydroelectric power plants, transportation and infrastructure, tourism, recreation, and other human or economic uses. But unethical discharge of the untreated wastewater and various pollutants from the urban, industrial and agricultural sources, clay and sand mining from instream areas, damming and hydroelectric projects, have affected the naturality of these rivers. All these human activities have resulted in considerable deterioration of river health. This is mainly due to the so called “development”.

According to the words of the Father of our nation “ There is sufficiency in the world for man’s needbut not for his greed”. All the events resulting in the deterioration of the environment is only due to man’s greed. It is never going to develop the nation, or the development taking place in our neighborhood is not sustainable in nature. This is now evident from the quality of the rivers. Recent incidents such as the flood (August 2018) that occurred in the state, fish death, water-borne diseases etc are the prominent signals of man-enforced impacts on the natural environment. Health of a community can directly be measured by reading the quantity and quality of water available in the nearby river. Water quality monitoring and analysis of quality parameters of the river water have an inevitable role and it also describes the acceptability of surface water sources for human consumption.

As a case study, Chalakudy River in India turned out to be a typical example. Under these circumstances, the water pollution problem in this river has become a challenging risk. Even though the data related to this methodology is derived from much experimental analysis due to its complex nature, the public normally will not be able to comprehend. In this situation the water quality index (WQI) can be used as a good tool to convert the complex data in to simple and understandable form making it feasible for the public to rely upon. Significantly, the WQI is a single measure of overall water quality in a specific location with a special emphasis on the time-based readings of water quality parameters at a given location. Similar types of studies have been done in India by (Pathak, 2015; Chowdhary et al., 2012; Vineeta Kumari et al., 2015). Viewed from this perspective, water quality monitoring and analysis of water quality index are remarkable steps in the process of managing and conserving the entire ecosystem (Smerjit Kaur and Sindhu Singh, 2012). It is useful for making known the overall water quality information to the society. It has become highly essential to closely look at the reasons for deterioration of the health of rivers and take remedial measures.

1.1 Chalakudy River Basin

1.1.1 Origin and Physiography

Chalakudy River is one of the longest rivers in Kerala. The river is located between10^0 05’ to 10^0 35’ North latitude and 76^0 15’ to 76^0 55’ East longitude. This is the longest river in Thrissur district having a length of 145.5 km and the maximum recorded width is 180m. The total drainage area is 1704 sq km, out of which 1404 sq km is in Kerala and the rest 300 sq km in Coimbatore district of Tamil Nadu. The River starts from the Anamalai hills and Nelliampathy ranges of the Western Ghats. In Kerala, it flows westward through Palakkad, Thrissur, and Ernakulam districts. This river basin is separated by Tamil Nadu in the East, Kodungallur Taluk of Thrissur district in the West, MukundapuramTaluk of Thrissur district in the North, Chittur and Alathur Taluks of Palakkad district and, Aluva, Kunnathunad and Paravur

Taluks of Eranakulam district in the South. More than 70% of this river lies in the Thrissur district. Flowing downstream, it joins with the northern tributaries of Periyar, the largest river in Kerala at Elanthikkara near Puthenvelikkara. This is at a distance of 9 km before they end together in the Lakshadweep Sea at Kodungallur estuary (Maya et al, 2005). Chalakudy River is the major source which caters to the needs of Thrissur and Palakkad Districts in Kerala. The map of river basin is shown in Fig.1.1. Annual flow rate of this river is 1858 million m^3.

Fig. 1.1 Map of the Chalakudy River Basin (Courtesy: Wikipedia)

1.1.2 Major Tributaries

Karappara, Kuriarkutty, Peruvarippallam, Thunakadavu and Sholayar rivers are the important tributaries of this river. Many small tributaries also join this stream. Sholayar river originates from the Coimbatore district in Tamil Nadu. It flows for 44.8 km towards west and turns towards the north and joins with Parambikulam River. Sholayar river enters Kerala along the southern side on the Nelliampathy plateau. Parambikulam river coming from the Coimbatore district in Tamil Nadu and joins Kuriarkutty. Kuriarkutty river flows from Anamalai in Kerala and joins Parambikulam River at Kuriarkutty. Karapara River originates from the Nelliyampathy hills of Palakkad district in Kerala and flows west and turns South West till it reaches the mainstream at Orukumbankutty. The place where Karapara river combines with the main stream, the river is called as Chalakkudy River. 'Kannamkuzhithodu,, 'Charpathodu', 'Arurmuzhithodu', 'Parayanthodu', 'Kappathodu', 'Melloorthodu' and

'Perumthodu' are a few important streams that join the river. Until it reaches the plains, the river has a rocky bottom with many rapids and waterfalls. Athirappilly waterfalls and Charpa waterfalls are the most famous and gorgeous waterfalls in this river.

1.1.3 Population

This river basin includes 18 Panchayaths and one municipality (Amithabachan, 2003). It has many lift irrigation schemes and about 37 governments operated drinking water supply schemes. More than 12 lakhs population directly consumes water from this river for various purposes.

1.1.4 Fish diversity

This River is famous for its tremendous fish diversity (Amithabachan, 2003). The survey conducted by the National Bureau of Fish Genetic Resources, Lucknow published that it contains more than 98 species of freshwater fishes out of the 152 types found in Kerala. Fish population mainly depends on the status of physicochemical and biological properties of their habitat.

1.1.5 Major Dams

Peringalkuthu, Sholayar, Upper Sholayar (in Tamil Nadu), Parambikulam, Peruvaripallam, and Thunakadavu are the major six dams constructed across this river. Also there are some small dams along the path of the flow of the river. During summer, these dams restrict the downward flow.

1.1.6 Flow characteristics

A large quantity of water from Chalakkudy River is naturally diverted to nearby tributaries of other rivers. This quantity is more for Chalakudy river in comparison with other rivers of Kerala. Water from Parambikulam group of dams and upper Sholayar are diverted to the Aliyar which is a tributary of the Bharathapuzha reservoir at Tamilnadu. As part of the Edamalayar augmentation scheme water over flowing from Peringalkuthu reservoir is diverted during the monsoon season to a tributary of Periyar river. The donor river and the recipient river absolutely undergo relatively permanent changes as an impact of flows. For irrigation purposes water is transfered through the canals. Along with the alterations in the flow, there could be several changes in water quality like, changes in major nutrients, salinity, temperature and pH, all of which are vital determinants of the health of the river system. The rate of rainfall during monsoon, greatly affects the water flow in the river (June to October). During summer the flow reduced significantly and large amount of water is diverted from the river for domestic, industrial and irrigation purposes. As a result, the river dries off at some parts (February to May).

1.1.7 Forest and tourism spots along the basin

The forest land in the Chalakkudy basin falls within four forest divisions namely, Parambikulam, Vazhachal, Chalakkudy, and Nemmara. Athirapilly, Vazhachal, Malakkapara, Nelliyampathy, and Parambikulam are popular forest and river-related tourism spots. Athirappillywaterfalls,Charpawaterfalls, Thumboormozhi, Dreamworld water theme park, and Siverstormwater theme park are the major recreation spots along the study area.

1.1.8 Possible sources of pollution

Industrial pollution, sewage and garbage pollution, and agricultural runoff are the major sources of pollution in the river basin.

1.1.8.1 Sewage and garbage pollution

The river may directly receive the effluents from Chalakudy municipality. Two famous water theme parks Dreamworld and Silver Storm are situated on the banks of the river. Some cattle farms, fish farms,and poultry farms situated in the nearby areas of the basins also to water pollution. Flats and apartments, hotels, household wastes etc also may lead to pollution issues.

1.1.8.2 Industrial Pollution

The portion from Vettilappara to Pulikkakadavu is an industrial zone situated along the basin of the Chalakudy River and comes under the study area. Major industries located in this region include small scale laundry unit near Kappa thodu, Pariyaram, a medium scale distillery named as Skol breweries at Mellor, Sreesakthi Papermill (shutdown) at Kanjirappilly, and Nitta Gelatin, Kathikudum. All these industries dischrging their treated effluent in to the river.

1.1.8.3 Agriculture runoff

Athirappilly Estate, Vettilappara Estate, and Kalady plantations are the major plantations along the study area. Oil palm and teak are the major plantations along the river margins at Vazhachal and Vettilappara (study area). And the river region is utilized for cultivating crops like paddy, banana, vegetables etc.

1.1.9 Drinking water scarcity affected on the basin

The drinking water scenario in the basin displays that this basin is getting into a serious drinking water crisis. Study area facing serious drinking water scarcity. Main reasons for drinking water scarcity are misuse of water, excess use of water, improper water management, and difficulties faced in water supply and pumping of water from the river during summer. Chalakudy river diversion scheme diverts a good amount of water for irrigation of 14000 ha of agriculture field near Thumboormozhi.

1.1.10 Uses of river stream

Five major hydroelectricpower plants are situated on the upstream of the study area. Steam is being utilized for fishing, navigation, bathing, washing, recreation and for industrial purposes. Fishing is the main activity of the local people in the Vazhachal region. Fishing using unauthorized method such as the use of dynamite is a problem for fish species in this river. At few sites, boats are plying to crossing the river. Majority of the nearby communities use this stream for bathing and cleaning their utensils. The spots in the stream like Athirappilly waterfalls, Charpa waterfalls, Vazhachal, and Thumboormozhi have large recreational value.

1.1.11 Major uses of river water along the study area

The community living near the river basin mainly depends on this river for satisfying their basic requirements. Chalakudy and Kodungallur municipalities utilize this river water as their major drinking water source. Also water in this river is mainly used for domestic, agricultural and industrial uses for Thrissur and in Palakkad Districts. Thirty-one irrigation projects and more than ten water pumping stations are situated in this river along the study area. A water treatment plant has a capacity of 26.1 million m^3 is situated at Vynthala. This drinking water supply scheme supplies water to all the panchayaths and the Chalakudy municipalities along the basin. Some coastal panchayaths such as Eriyad, Methala, Puthenvelikkara and the Kodungallur municipality depends on this scheme for drinking purpose.

1.2 Use of Pesticides in the Basin

Various pesticides are used to eradicate pests and diseases in the agriculture area and in this basin. These Pesticides enter into the environment by agricultural runoff, by misuse of pesticides and by accident. Pesticide spills, improper storage and disposal of pesticide containers can make direct path for the contamination in water or in sediment. These non biodegradable micro pollutants can enter the food chain and become more concentrated at high tropic levels by biomagnifications and adversely affect the entire ecosystem. The pesticides entered in to the environment can remain forever in the sediment or in the atmosphere, which finally reaches the water bodies (Anju et al., 2010). When they reach on the ground, it continues to breakdown, usually much slower than in surface layers of soil (Kihampa 2011). Neurological and reproductive damage, cancer, growth and development of birth defects, endocrine disruptions etc. are the chronic pesticide effects on human health. Therefore pesticide analysis in river water and resources of potable water should be of a great concern.

The factors affecting the persistence of organic pollutants in water are bottom sediment, pH, solubility, temperature and presence of organic matter. The pesticides having important role in connection with river water quality include soil insecticides, persistence herbicide, chlorinated hydrocarbons and its derivatives. In these traces of organochlorine pesticides (OCPs) in water may accumulate progressively in different steps of food chain. Organochlorine pesticides have been extensively used in India for agricultural and public health purposes (Nhapi et al., 2011).The study was intended to monitor the presence of wide range of OCPs in sediment and water of this river.

1.3 Water Quality Index (WQI)

Water quality index (WQI) can be used as a good tool to convert the complex data into a simple and understandable tool making it feasible for the public to rely upon. WQI is a single measure of overall water quality in a specific location with a special emphasis on the time-based readings of water quality parameters. Similar types of studies related to WQI have been conducted in India (Pathak, 2015; Chowdhary et al., 2012; Vineeta Kumari et al., 2015). Viewed from this perspective, water quality monitoring and analysis of water quality index are remarkable steps in the process of managing and conserving the entire ecosystem (Smerjit Kaur and Sindhu Singh, 2012). In the present study WQI models were developed using arithmetic index method, fuzzy water quality index model and regression model and these models were validated.

1.4 Fuzzy Model Developments

Fuzzy logic has shown a good promise in modeling new water quality models (Chang et al., 2001). Prediction modeling involves various environmental control parameters (Cohen et al., 2008). Dissolved oxygen model and water quality index model(Mamdani model) were developed using triangular membership functions by Fuzzy logic in MATLAB software.

1.5 Regression Models

The regression model is a modeling approach which can be used to develop prediction model of a dependent variable as a response of independent variable. In this work, experimentally analysed values of total coliform content have been used to suggest models for predicting quality of river water using linear regression equation by Microsoft Excel.

1.6 Significance of Water Quality Models

Water quality monitoring and analysis of water quality index are very important steps in the process of managing and conserving the entire ecosystem (Smerjit Kaur and Sindhu Singh, 2012). Water quality prediction models address the quality issues of water quality monitoring and assessment. The prediction and estimation of water quality is always a complex affair as it is influenced by many variables and there combinations. Also the collection of data required for the prediction is cumbersome and requires large investment in terms of money and human resource. So, to have a water quality model is very essential for the proper conservation and management of the ecosystem. Various water quality models were developed based on the experimental values along the period of study. This includes Arithmetic index method, Fuzzy dissolved oxygen model, Fuzzy water quality index model and linear regression model.

The WQI can be easily calculated by arithmetic index method putting weightge for each input parameters. The WQI takes arithmetic index of these variables and synthesizes into a single number using twelve various experimentally estimated water quality parameters. For environmental modeling using Fuzzy, water quality index model (FWQIM) using triangular membership function was developed. The models can be extended to any combinations of input parameters, which influence the level of DO directly or indirectly.

Regression model that correlate the load of pollution in terms of Total Coliform with water quality of the river . This linear model is very much useful to predict the water quality index at any site, in the Chalakudy river where there regular monitoring is not possible. All these models are based on the water quality standards and could be feasible in some situations where monitoring is not possible.

1.7 Thesis Outline

The thesis mainly intends to assess the pollution load of water in Chalakudy river during the period of study (November 2013 to October 2018). Sixteen water quality parameters such as Temperature (T), pH, Chlorides (Cl^-), Nitrates (NO_3^-), Chemical Oxygen Demand (COD), Dissolved oxygen (DO), Electrical conductivity (EC), Phosphates (PO_4^-), Sulphates (SO_4^-), Total dissolved solids (TDS), Total hardness (TH), Biochemical oxygen demands (BOD), Turbidity, % DO saturation, Total coliforms (TC), fecal coliforms (FC), and three quantitative parameters such as Cross-sectional area, Velocity and Discharge were also estimated experimentally at eight locations stretching for a distance of about 55 km along the Chalakkudy river basin. The level of organochlorine pesticide in the river water and sediments were also analyzed experimentally during the period January 2014 to December 2016. The estimated physicochemical and biological water quality parameters were also compared with the water quality standards as per WHO and IS in order to quantify the water quality status of the Chalakudy river at present. Experimental data were analyzed using tools (pivot table) available in Microsoft Excel software and statistical analysis was done using two way ANOVA, posthoc ANOVA (Tukey method). For doing the staistical analysis of these parameters, MINITAB 17 statistical software was used. Temporal, spatial and seasonal variations of the above parameters were observed during the study period by plotting box plots and graphs using MINITAB 17. Post-flood sampling and analysis of water samples were carried out during the month of September and October 2018 to identify the impact of the flood on the river.

The organic pollution load of the river was identified in terms of BOD/COD ratio, TC/FC, and % DO saturation .Water quality index of Chalakudy river was calculated along the study area by arithmetic index method. The water quality was classified based on the value of WQI.

Fuzzy logic dissolved oxygen model and WQI model were developed in terms of water quality parameters using MATLAB software. Linear regression model for WQI was developed using Microsoft excel. The possible sources of pollution along the area of study were traced out and appropriate remedial measures were suggested for a specific cause of pollution.

1.7.1 Content of the thesis

The thesis mainly consists of eight chapters:-

Chapter 1**:** General introduction to the river and study area with its location, sampling sites, physiography, population, flow characteristics, the objectives of the study, and thesis outlines are explained.

Chapter 2**:** Literature review on assessment of pollution load in river water using physicochemical and bacteriological water quality parameters, sediment and water sampling and analysis methods, pesticide analysis, Water quality index, and Water quality index models.

Chapter 3: Methodology of sampling and analysis methods of qualitative and quantitative parameters, data computation and data analysis by Pivot table tool of Microsoft Excel, Spatial, temporal and seasonal variations of water quality parameters, two way ANOVA and posthoc ANOVA statistical analysis using MINITAB 17, identification of parametric correlation by analysing correlation coefficient (R), measure of biodegradability by analysing BOD/COD ratio, % saturation of DO, and TC/FC , Organochlorine pesticide analysis in water and sediments, water quality index calculation using arithmetic index method, Validation of these models with experimental data by finding an absolute average relative error (AARE) and root mean square values (RMSE), Developments FDOM and FWQIM (Mamdani model) using fuzzy logic by MATLAB,and WQI regression are also included .

Chapter 4: Qualitative and quantitative parameters of Chalakudy river

Chapter 5: Persistence of organochlorine pesticides in river water and bottom sediment

Chapter 6: Fuzzy Water quality dissolved oxygen (FDOM) prediction Model

Chapter 7: Water Quality Index (WQI) prediction models.

Chapter 8: Conclusions

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Chapter 2

LITERATURE REVIEW

Contents

2.1 Introduction

Knowledge about the health of a river is an important step in developing sustainable management strategies for maintaining the health of the society. Fundamentally, the load of pollution affecting in the river water quality was analysed in terms of physicochemical and biological characteristics, and quantitative parameters like discharge, velocity and area of cross section etc. Before monitoring every parameter, select certain indicator representatives for the main component of a river in the ecosystem so as to obtain a realistic measure of the health of the system and review literature on the problem.

This Chapter focuses on the previous studies that have attempted to identify load of pollution of water and sediment in Chalakudy River. Important aspects of river analysis, standard methodologies for parameter analysis, seasonal variations of quality of water, persistence of pesticides, water quality index, regression modeling and environmental modeling using Fuzzy logic were reviewed in detail. Reviews of previously published papers related to this work are consolidated below.

2.2 Previous Studies on Chalakudy River

Sunny George et al., (2001) reported that for the planning and executing projects related with the development of the society, watershed is the main natural factor out of all units of consideration. Large quantity of pesticide BHC was used in 1991 by the oil plantations in the basin. Most of the areas near the Chalakudy River experienced acute fresh water scarcity and damage to crops.

Amita bachan K H., (2003) studied on the riparian vegetation of the Chalakudy River, especially along the middle and lower zones of the basin. Various methods of inland fishing and species richness in the river basin were specified. It was also found that this river is richest in the case of fish diversity. Author suggested that the watershed awareness program shall be conducted for the conservation of riparian vegetation and regeneration of the streams in Chalakudy River.

Maya K and Seralathan P., (2005) studied the issues related to sediment properties of two important rivers- the Periyar and the Chalakudy river in Kerala. The objectives of the study was to establish the characteristics of texture, mineralogy, transportation and depositional mechanisms of the sediments of the Periyar and the Chalakudy rivers and to analyze the geochemical variability of organic carbon, phosphorus and check some quality parameters like sodium, potassium, calcium, and magnesium in sediment. Reports on the assessment of aquatics and sediment quantity based on riparian vegetation, trace distribution of metals in the sediment in the Chalakudy River and this has been reported by several workers. Not much detail is available regarding the overall water quality status, water quality index and water quality models of Chalakudy river.

Chattopadhyay et al., (2005) monitored the Chalakudy river basin in Kerala. On analysis of water samples spread over the land use based on forest area and agriculture area. basically forest and agriculutral area through correlation analysis of various parameters indicated seasonal effects on river water during four seasons. Chalakudy River has been deteriorating based on the nature of land use. A strong water resource management system is very essential in the basin.

Raghavan, R et al., (2008) identified that there is a strong relationship between the increasing stream orders with the observed richness in fish species in the river. This river is an example for a global biodiversity hotspot in Kerala. Padikkal et al., (2018) used the desktop model, 'Flow Health' software to design e-flows regime for the Chalakudy Sub-basin in Kerala, India. The Chalakudy Sub-basin contains six dams and a major part of Parambikulam Aliyar Project, which is one of the largest inter basin water transfer network in Asia. Estimated the monthly e-flow regimes required to maintain alternate levels of ecosystem conservation. It deals about the additional flood flow volume required for these alternate levels in this river. E-flows and redefining the inter basin water transfer network operations within a broad framework of integrated water resource management are useful for informed decision-making.

2.3 River Pollution Assessments

Rivers constitutes as a main inland water body for various purposes such as large scale use of domestic, industrial and agricultural purposes and often carries municipal sewage, industrial wastewater discharges, and seasonal runoff from agricultural fields (Singh et al., 2004; and Pradhan et al., 2009).

Sewage wastewater is liquid waste from the community carried from residences and buildings that enters the sewerage system operated by local government authorities. Generally this wastewater disposed in to surface water resources such as streams, rivers, lake and sea etc. While discharging sewage in this way most care should be taken that the sewage may not pollute water resource. But it makes unfit for domestic purposes such as drinking, bathing etc. Sewage may contain septage which is the waste out of septic tanks (waste discharge by law, 2010).

Sewage waste contains faecus and surfactants etc. Faecus is the human and animal excreta, which contains pathogens. The faecal pollution is attributed mainly due the absence of toilet facilities, direct discharge of septage, and waste water discharge of cattle farm etc. Spreading of epidemics and disparity of water quality are the indications of faecal pollution (Yudhistra and Vikram., 2009).

Nikedi et al., (2006) found that pollution in surface water caused by chemical, physical and biological substances formed by anthropogenic activities poses high risk and seek environmental attention. Water pollution is a major environmental problem and unless due attention is given to this area and proper measures are not undertaken, the situation would worsen in future. Water ecosystems have become negatively altered due to tremendous development in the field of agriculture, industry, and also due to an increase in population. Consequently, they are exposed to all variations regardless of their source of occurrence.

The river is a very important water supply source for numerous purposes and it enhances the fertility of nearby lands, which in turn helps in the development of thickly populated residential areas (Mouri et al., 2011).

Evans A E et al., (2012) focused on the huge discharge of sewage, industrial and agricultural wastes, in Asia. Many countries are trying to meet better targets in the level of sanitation. Most of the untreated wastes discharged into the water bodies remains in it for a long period. According to this study, it was revealed that the water quality situation is very worst and serious. Moreover, there are various ways to recover to a better situation. Water quality monitoring programs are improving and many countries have systems to guide other nations. The efforts of basin agencies could lead the way to regional assessments.

2.4 Water and Sediment Sampling and Analysis

Suess M J (1985) explained in his book, the techniques of sampling, analysis and monitoring of water pollution measurements in the evaluation of water quality for pollution control. He also deals with design of measurements, data compilation, and data interpretation of biological indicators, laboratory designs, and internationally acceptable procedures, which made comparisons between laboratories in different countries.

Singh et al., (2002) observed the increasing demands according to population explosion have imposed extra tension on natural water bodies like rivers and lakes. These altered physicochemical characteristics of water make serious consequences on fisheries and agricultural growth.

Jarvie H P et al., (2002) delivered information on sampling, storage, and method of analysis of Phosphorous in river water. The effect of physical, chemical and biological constituents on the river was examined and he and analyzed the form of errors related to a sampling of water, preparation of samples, storage and identification of contamination levels. It was identified that the analytical response of river water is different according to physicochemical and biological conditions of storage, and the sensitivities of samples will be higher with the low concentrations and prone to storage and analytical errors. The paper suggests the protocols for sampling, storage, and analysis method according to a few river water quality parameters.

A textbook written by Keith L (2017) dealt with the special techniques needed in planning and carrying out reliable sampling of environmental matrices. Various approaches for sampling are mentioned in the work. According to Keith, improper sample collection procedures results in unrepresentative samples and contribute to errors in analytical results. Moreover, these errors in sampling and analysis cannot be accounted for blank laboratory samples or control samples. Sometimes it can be generated by protocol errors. So sampling procedures should be carried out carefully and documented. Contamination is a general cause of error in environmental measurements. Schemes of sampling and analytical work give numerous opportunities for sample contamination from different sources.

2.5 Water Quality Parameters Trend Analysis

Collett K O., (1978) had performed a statistical analysis on series of electrical conductivity (EC) using one indicator taken over the past sixteen years from eight stations on the River Murray. The objective was to assess the changes in salinity along the river and temporal analysis was done throughout the study area.

Kemp W M and Boynton W R., (1980) studied on the effects of some water quality parameters especially physical and biological parameters on the level of dissolved oxygen (DO) in an ecosystem near Calvert Cliffs, Chesapeake Bay. In several sites of Chesapeake Bay, influence of photosynthesis process and respiration were observed with time-course changes in DO in open sources, in bottled samples and benthic chambers. In deep waters of 3 m depth, the variations in DO appeared to be predominated by biological contamination, however, different values of DO over approximately 10 m depth showed by the influences of physical parameters. To examine possible reasons for variations in DO values oxygen budgets were developed for the 10 m depth stations.

Metcalfe J L., (1989) focused on the assessment of macroinvertebrates in Europe and biological contamination using each of the principal approaches. The results of these principal techniques are strongly influencing in the policy decisions concerning the management of surface water in Europe. These are being used as good tool for managing used of water, ambient quality monitoring, and measuring the effectiveness of pollution control measures. Surface fresh water has an important role in development of society. Monitoring of these physicochemical parameters, quantification of pollution load and sources of pollution are very essential.

Yu Y S et al., (1993) studied on surface water quality data collected from fifteen sampling stations on the four river basins such as Arkansas, Verdigris, Neosho, and Walnut river basins. Trend water quality parameters were analysed by non parametric method. It was then realized that concentrations of total dissolved solids, calcium, total hardness, sodium, potassium, alkalinity, sulphate, chloride, total phosphorus, ammonia plus organic nitrogen, suspended sediment and specific conductance have a commonly downward trend.

Correll D L., (1998) found that Phosphorus (P) is an important element for all life. It is a known mineral nutrient. Only one form of P that can assimilate autotrophs is Orthophosphate. Eutrophication is the way of receiving waters with excessive concentrations mineral nutrients. The results are excessive growth of algae and cyan bacteria. This leads to high bacterial growth and high respiration rates leading to hypoxia or anoxia in slowly mixed bottom waters and in surface waters during calm, hot conditions at night. Low dissolved oxygen is a reason for loss of aquatic animals and release of many materials normally bound to bottom sediments including various forms of Phosphorous. The release of Phosphates enhances the eutrophication. It is the most common cause of eutrophication in freshwater lakes, reservoirs, streams, etc. water present in estuaries and continental shelf are in a transition zone because of problems created by excessive Phosphates and Nitrates. It is best to measure and regulate total Phosphorous inputs into whole aquatic ecosystems.

Olajire and Imeokparia., (2001) revealed the presence of calcium, ammonia, chlorides, nitrates, cyanides, phosphates in the water samples from Osun river, and other select rivers and ground water reservoirs in the area. Some water quality parameters like pH, temperature, and electrical conductivity, measure of total dissolved solids, total hardness, and total carbon dioxide have also been considered in the assessing level of chemical contaminants and pollution in these water sources.

Jonnalagada et al., (2001) Jackher and Rawat (2003), and Shang (2003) stated that water is a very essential and valuable natural resource in the world and has distinctive properties of dissolving and delivering in suspension a wide variety of substances. Hence water can easily become contaminated. Assessment of water quality of any water bodies, mainly used for water supply to domestic, Industrial, agricultural and culture of fish, is very essential. Constant discharge of domestic and industrial wastewater, seasonal changes in climate and surface run-off also have an important role in determination of the river water quality.

Das and Achary., (2003) stated that rivers, lakes, etc. act as best recipient for the discharge of industrial as well as domestic wastewater. Rajasegar M., (2003) studied some physicochemical parameters in relation to farming such as temperature, salinity, pH, dissolved oxygen and nutrients such as total phosphorus, inorganic phosphate, nitrite and silicates. There are many shrimp farms situated on the banks of Vellar estuary. Waste water discharge from these farms into the estuary, which may influence on the water quality. The physicochemical features in relation to shrimp farming were studied in three sites of the estuary. In comparison to the previous data collected from Vellar estuary there was not much difference in physicochemical characteristics by considering shrimp farming.

Ramesh et al., (2007) found that improper water management and conservation of water bodies lead to an inevitable water crisis over entire world. Therefore, the health of rivers and their biological diversity will be directly related to the health of almost every component of the ecosystem. The increase in supply of nutrients like phosphate, sulphates,and nitrates enhances the eutrophication process and is inversely proportional to the dissolved oxygen level in water. Algal blooms also release some toxic chemicals which adversely affect fish and other aquatic life and makes the water body stink. Specifically, the local fisherman who was in habit of using chemical dynamite for catching fish added to the gravity of this situation. All natural water resources are commonly used for various purposes like drinking water supply.

Milovanovic M (2007) determined the spatial and temporal trends by plotting graphs about nitrates, nitrites, ammonium, total phosphorous, BOD_5, cadmium, chromium, zinc, and lead from twenty two sampling stations along the Vardar river. Samples were collected on a monthly basis.

Singh A K et al., (2008) evaluated the major chemistry in water decomposition and suitability of water for domestic, irrigational and industrial uses. The study was made on the water samples collected from natural water resources near Damodar River basin, India. Water quality was analyzed on the parameters such as pH, EC, TDS, F, Cl^-, HCO3, SO4, NO3, Ca, Mg, Na and K. the trend was analysed seasonally.

Singh M R et al., (2010) carried out physicochemical parameter analysis from April 2008 to March 2009 in the samples from four rivers namely the Imphal, the Iril, the Thoubal, and the Manipur located in Manipur, a north-eastern state in India, bordering Myanmar. Sites 1, 4, 5 and 6 were locations of various anthropogenic activities and consisted of urban residential areas while sites 2 and 3, near the Manipur River, were located in a forested watershed and in the area of less anthropogenic activities. Maximum measures of TDS at 870 mg/l, NO_3^-N at 0.550 mg/l, PO_4^-P at 0.068 mg/l, conductivity at 467μS/cm, and K at 9.00 mg/l were observed during monsoon season while a maximum of free CO_2 at 22.3 mg/l, total alkalinity at 168.0 mg/l, hardness at 136.0 mg/l, and total Chloride at 42.63 mg/l were observed during summer from the rivers. This indicated the deterioration of quality of water during rainy season than in summer season. At site V, values of DO were below the minimum permissible limit (4.43 mg/l) and free Carbon dioxide beyond the maximum limit (22.30 mg/l) during summer season. Compaired with other rivers, The values of all the analysed parameters in Thoubal River were high during monsoon. The results indicated that most of the physicochemical parameters from the Manipur river system were within the WHO drinking water limits. So this water may be used for domestic purposes.

Saksena et al., (2008) have studied the physicochemical characteristics of the Chambal river water in the National Chambal Sanctuary in Madhya Pradesh. Three sampling stations were established for the collection of water samples from April 2003 to March 2004. The water quality parameters namely transparency, colour, turbidity, electrical conductivity, total dissolved solids, pH, dissolved oxygen, free carbon dioxide, total alkalinity, total hardness, chloride, nitrate, nitrite, sulphate, phosphate, silicate, biochemical oxygen demand, chemical oxygen demand, ammonia, sodium, and potassium are reflected on the premises of the Chambal river. On the basis of various parameters studied this stretch of the Chambal River slightly polluted by organic matter (oligosaprobic category). The water quality analysis indicated that the river water in the sanctuary area is pollution free and can use as a good water quality for many aquatics species.

Kido et al., (2009) focused on the role of river water for navigation, and economic activities of the citizens in Java and Kalimantan in Indonesia. In many developing countries, including Indonesia, industrial, agricultural and domestic water were disposed directly in to rivers. The study culminates in the evaluation of water quality and a comparison of the levels of environmental pollutants in developing and developed countries. Water quality and presence of endocrine disrupters like alkyl phenol in 64 water samples collected from 53 sites in Indonesia and Japan were measured. The results indicated that the rivers in both the capital cities Jakarta and Tokyo were contaminated due to the incomplete and improper drainage systems. Water in Japan was heavily polluted than the rivers in Indonesia.

Rani N et al., (2011) studied the water quality of three important tributaries of the Ganga in the middle stream, the Gandak, the Ghaghra, and the Sone rivers. Changes in water quality of the rivers were observed seasonally by analyzing parameters such as pH, phosphate, temperature, turbidity, total alkalinity, sodium, and sulphates. During monsoon, several water quality parameters showed noticeable changes due to increased surface water runoff and other seasonal factors. Multivariate discriminate analysis was used to understand the reason and responsible parameter for temporal variations in water quality. Temperature, turbidity, total dissolved solids, calcium and phosphates were important affective parameters for the seasonal discrimination in the water quality of the Sone River. The changes in the water quality of the rivers were due to the seasonal effects and catchment characteristics.

Smith and Shivashankar P (2013) studied the effect of urbanization on water quality of the Kapila (Kabini) river near Nanjangud industrial town in Mysore district of Karnataka, India. Water analysis was accomplished for the parameters like pH, odor, turbidity, temperature, dissolved oxygen (DO), chloride, total hardness, total dissolved solids (TDS), calcium hardness, magnesium hardness, nitrate, and sulphate. The experiments on the quality of water were conducted during the months of March, April and May in 2013. It was found that the level of domestic sewage pollution load increased during month of May.

2.6 Water Quality Assessment Using Statistical Tools

Jones P J and Burt T P., (1993) studied deterioration of water quality by natural and anthropogenic activities in the Panchganga River, which is considered as one of the major rivers in Maharashtra, India. Reason for the scarcity of fresh water along the Panchganga was analysed from March 2011 to February 2013. During the study, various physicochemical parameters at different monitoring sites were assessed and statistically analysed. Seasonal changes in the physicochemical parameters were verified using average values of water quality parameters on the Panchganga. Moreover, it was noted the river was continuously being polluted due to discharge of huge quantities of industrial wastes along with sewage wastes.

Kannan R and Kannan L., (1996) conducted water quality analysis in two different stations of the Palk Bay and it revealed temporal variations in all the hydrographical features observed. Effects of parameters on spatial variations were measured in terms of nutrient concentration, light penetration and dissolved oxygen. Nutrient levels were comparatively higher than those in nearby areas of the other coast, giving evidence for the fertile property of this region.

Vega M et al., (1998) have analyzed 22 physicochemical parameters in water samples collected from three sampling stations every three months, along a stretch of twenty-five kilometers of the river affected by anthropogenic activities and seasonal changes. Exploratory analysis of analysed data have been carried out using box plots display methods, ANOVA, principal component analysis and cluster analysis to establish the variation of water quality. ANOVA of rotated principal components has displayed that mineral contents are significant with seasonal variations and climatic variations. This pointing to a natural origin of organic matter and nutrients originates from agricultural runoff and anthropogenic sources like municipal wastewater.

Simeonov V et al., (2003) studied on the usage of various approaches of multivariate statistical analysis for data interpretation of a large and complex data matrix collected in the duration of surface water monitoring in Northern Greece. This study also presents the requirement and usefulness of multivariate statistical determination of large and complex data sets in order to get necessary information about the quality of surface water.

Singh K P et al., (2005) used multivariate statistical techniques such as cluster analysis, factor analysis, principal component analysis, and discriminate analysis to the data analysis and interpretation on water quality of the Gomti river (India), generated monitoring eight different sites for thirty four parameters in duration of three years (1999–2001). This study presents importance of multivariate statistical techniques for evaluation of large complex water quality data sets. Study convey better information about the identification and apportionment of pollution sources , factors effecting on the water quality and about operational design network for effective management of water resources.

Shrestha and Kazama., (2007) used multivariate statistical techniques such as clus were used for the evaluation of temporal and spatial variations and interpretation of a large complex water quality data of the Fuji river basin. 8 years (1995–2002) data sets were consolidated after monitoring of twelve parameters at thirteen different sites. In this study, specified about the effectiveness of multivariate statistical techniques, water quality assessment, identification of pollution sources and factors, understanding temporal and spatial variations in water quality for analysis. It was also identified that interpretation of complex data sets using multivariate statistical analysis was very useful for Proper River water quality management.

Strobl and Robillard., (2008) found that in recent years, indicate a need for logistically adaptable and cost-effective design network approaches and design practices for water quality monitoring systems. There are so many variables that require being included in the complete monitoring network. A holistic approach towards monitoring objectives, selection of water quality variables, sampling locations, sampling frequencies, logistical constraints are examples.

Iscen et al., (2008) found that assessment of seasonal changes in surface water quality is an important aspect for evaluating temporal variations in river pollution due to natural or anthropogenic inputs from point and non-point sources. In this study, data on surface water quality for sixteen physical and chemical parameters were analyzed. The samples were collected from twenty two monitoring stations in a river in 2004-2005. The principal component analysis technique was employed to evaluate the seasonal correlations of water quality parameters while the principal factor analysis technique was used to extract the parameters that are most important in assessing seasonal variations in river water quality. Statistical analysis found the similarities between sampling sites of different groups. The similarities were observed in their physicochemical properties and contamination levels. Three latent factors were revealed the responsibility data structure, explaining 77.35% of total variance in the data set. The microbiological factor displayed 32.34% of the total variance. The organic nutrients factors displayed 25.46% and physico chemical factors displayed 19.54% of variance respectively.

Juahir H et al., (2011) studied spatial variations of the most significant water quality variable and attempted to determine the origin of pollution through analysis of twenty-three samples. Three spatial cluster analyses were performed on the upstream, middle stream and downstream of the Langat River.

Ramesh and Elango., (2012) assessed the suitability of ground water for agriculture purposes and domestic uses in the Tondiar river basin, Tamil Nadu, India. The study was focused on an area of the region. Ground water is the major source of domestic agriculture activity in this area. Ground water samples were collected from 45 wells during pre-monsoon and post monsoon in 2006. The water samples were analysed for physical and chemical characteristics. Suitability of ground water for irrigation was evaluated on the basis of salinity hazards, sodium percent, sodium adsorption ratio, residual sodium carbonates, plotted Us salinity diagram, Wilcox's diagram, and calculated Kelly's ratio and permeability index. High hardness and electrical conductivity in this area make the ground water unsuitable for drinking and agriculture purposes. Concentration of trace elements such as manganese, copper, zinc, lead, and nickel did not exceed the permissible limit for drinking and agriculture purposes. Majority of the ground water samples were unsuitable for domestic and agriculture purposes, except for 31% and 36% which were suitable for drinking and irrigation purposes, respectively.

Selvam et al., (2014) used Arc GIS 9.2 software and utilized the geographic information to create a map of the spatial distribution of major elements. The classification of the maps as maximum, minimum and desirable limits are compared with the prescribed limits of WHO and found that the values exceed the maximum prescribed limit. The concentrations of alkalis like sodium and potassium ions exceed the alkaline earth calcium and magnesium ions. Seawater intrusion into the freshwater sources towards the study area was identified.

Gao Q et al., (2016) studied the water quality status of Gorges Reservoir, China by analyzing nutrient and biochemical indexes, total nitrogen (TN), total phosphorus(TP), potassium permanganate index (COD), five-day biochemical oxygen demand (BOD_5), fecal coliform, and the load of heavy metals (Cu, Hg, As, Cd, Zn and Pb).The samples were collected from ten sites during the study period from 2008 to 2013. Using multiple analysis approach, spatial and temporal distributions were plotted for all the analyzed parameters and elaborated on the reasons found behind their trends in variation. Principal component analysis was performed to assess the load of pollution of the reservoir.

Dhamodaran A et al., (2016) focused on their study on assessment of seasonal variation in surface water quality of *Cooum* river basin. The samples were collected as pre-monsoon, monsoon and post-monsoon representation during March 2013 to March 2014. Eighteen physicochemical parameters were analysed for eleven samples collected from the C*oou*m river basin. Statistical tools such as correlation analysis scatter plots, box plot and multivariate tools such as cluster analysis and principal component analysis were implemented. From the data sets, the ionic concentration, organic loads exhibits positive correlation (R2>0.7) for all three seasons. Also, box plot and scatter plot results revealed that during post-monsoon season the ionic concentration along with organic and inorganic levels were slightly higher than monsoon and pre-monsoon. PCA indicate that the ionic concentrations and organic load contributed more than 50% of variance and nature of pollutant load among the sites by cluster analysis.

2.7 Mathematical Models of Water Quality Index

Hirsch R M et al., (1982) was developed a regression model of flow, by considering concentrations of parameters as a function of discharge. These flow-adjusted concentrations model were tested for trend seasonally using the seasonal Kendall test.

Bhargava D S (1983) developed a simplified model for the Water Quality Index (WQI) to evaluate the WQI values of the River Ganga for various uses. The use of WQI is exploited for classification and zoning of Ganga. The river standards for pollution control and water quality management is also prescribed in terms of WQI.

Bedient P B et al., (1994) dealt with flow and pollutant transport ways, site investigation processes, flow and transport modeling, and remediation for ground water contamination. The study also specified about groundwater flow and well mechanics, sources and types of groundwater contamination, data collection methods, contaminant transport mechanisms, sorption and other chemical reactions, biodegradation reactions and kinetics, flow and transport in the unsaturated zone, numerical modeling of contaminant transport, non-aqueous-phase liquids, hydrogeological site investigations, groundwater remediation and design, and legal protection of groundwater.

Cude C G et al., (2001) developed Oregon Water Quality Index (OWQI), a single number that expresses water quality by integrating measurements of eight water quality variables (temperature, dissolved oxygen, biochemical oxygen demand, pH, ammonia, nitrate nitrogen, total phosphorus, total solids, and fecal coliform). Its purpose is to provide a simple and concise method to express the ambient water quality of Oregon's streams for general recreational uses, including fishing and swimming.

Bordalo et al., (2001) collected the Bangpakong River Surface water from three different stations per site and analyzed temperature, dissolved oxygen, turbidity, suspended solids, pH, ammonia, fecal coliform, biochemical oxygen demand, chemical oxygen demand, conductivity, phosphate, and heavy metals. The Scottish water quality index (WQI) was adapted to the classification of the river.

Bordalo A A et al., (2006) developed Scottish water quality index using nine water quality parameters to assess the monthly water quality of the Douro River. Sánchez E et al., (2007) investigated the use of the WQI and the DO deficit as simple indicators of water pollution and compared it in the Municipality of Las Rozas (located in North-West of Madrid, Spain). The quality of the water in the Guadarrama and the Manzanares rivers and Paris Park ponds, the main watersheds of this area were investigated during two years, from September 2001 to September 2003. It was found that the WQI was very useful for the classification of the waters monitored.

Kannel P R et al., (2007) used WQI to analyse the trend of spatial and temporal changes in water quality of the Baghmati river basin. The water quality index was developed after considering 18 water quality parameters and minimum and maximum water quality index was calculated by measuring five water quality parameters pH, DO, EC, total suspended and a single parameter DO, $WQI_{DO,}$ was also calculated. The minimum and maximum water quality index and the water quality index using DO could be of particular interest for developing countries because of the minimum analytical cost required.

Avvannavar and Shrihari., (2008) classified the water quality of the Chalakudy river using Bhargava water quality index method and Harmonic mean. WQI method was used to find overall water quality index along the stretch of river basin and a five-point rating scale was adopted to classify the river water quality in the study area.

Samantray P et al., (2009) carried out an assessment of water quality of the Mahanadi and its distributaries, the Atharabanki River and Saldana Canal were studied during the three seasons summer, pre-monsoon and winter. Four parameters viz. pH, Dissolved Oxygen, Biochemical Oxygen Demand, and Fecal Coliform were considered to compute Water Quality Index based on the National Science Foundation studies.

Lermontov et al., (2009) proposed creation of a new water quality index based on fuzzy logic called as the fuzzy water quality index (FWQI). The performance of this index is assessed by a comparison of several water quality indices (WQIs) suggested in the literature and also using data obtained from hydrographic surveys of the Ribeira de Iguape River, in the southwestern part do São Paulo State, Brazil from 2004 to 2006.

Ramakrishna C R et al., (2009) determined WQI for the groundwater of Tumkur taluk. The physicochemical analysis was chosen for the calculation of WQI. It was calculated using 12 parameter such as pH, total hardness, calcium, bicarbonate, nitrate, sulphate, magnesium, total dissolved solids, iron, chloride, manganese, and fluorides. To understand the hydro-geochemical parameters and to develop water quality index in Thirumanimuttar sub basin, a total of 148 ground water samples were collected and cations and anions were analysed. Water quality index was calculated by an assessment of the overall water quality prescribed for human consumption.

Vasanthavigar M et al., (2010) developed WQI using six water quality parameters to be measured at locations along the river basin. The parameters included Dissolved Oxygen, biochemical oxygen demand, total coliform, turbidity, total dissolved solids. Rating curves were drawn based on the tolerance limits of inland water and health point of view.

Reza and Singh (2010) carried out water quality index rating to quantify overall groundwater quality status in Angul-Talcher region of Orissa by using water quality index (WQI). WQI, a technique of rating water quality, is an effective tool to assess spatial and temporal changes in groundwater quality. Twenty four groundwater samples were collected from open and tube wells during summer and post-monsoon seasons.

Chouhan and Singh (2010) studied the physicochemical analysis data of various water samples collected from different locations and this forms the data base. This study was carried out to calculate the water quality index (WQI) for the national river (Ganga) of India at Rishikesh utilized for drinking, recreation, and another purpose by eight water quality parameters like turbidity, DO, BOD, COD, Free CO2, TS, TSS and TDS.

Ganga Action Plan is a program launched by the Government of India in April 1985. It envisioned to reduce the pollution load on the Ganga, but failed to decrease the pollution level, after spending more than 9 billion rupees over a period of 15 years.

Alam and Pathak (2010) assessed WQI in terms of pollution level and the quality of the Ramganga river of Western Uttar Pradesh in India. A computer program was prepared based on the eight physicochemical parameters viz. pH, Biological Oxygen Demand, Dissolved Oxygen, Total Alkalinity, Total Hardness, Total Solids, Total Suspended Solids and Chloride. Water quality index (WQI) is a useful tool for quick estimation of the quality of any water resource.

Pandey and Ali (2013) in their paper dealt with the water quality index assessment of the River Wainganga, which is a tributary in the Godavari system. Water Quality Index was assessed by (WQI) technique. The surface water quality index assessment of the River Wainganga was analyzed according to the procedure provided by the Bureau of Indian standards, the Union Health Ministry, the Government of India and the Indian Council of Medical Research. Eighteen of samples were collected from drainage and sub-drainage of the river. Water quality affects the quality of potable water and the aptitude of the water body to support healthy ecosystems. An endeavor has been made to develop water quality index, using eight water quality parameters such as iron, color, pH, EC, turbidity, alkalinity, TDS and total hardness and these were measured at two different stations along the river from September 2010 to May 2011.

Attempts have been made by Tyagi et al., (2013) to review the WQI criteria for its appropriateness for drinking water sources. WQI depicts effects of various water quality parameters and dish out water quality information to the public and makers of legislation. In spite of the absence of a globally accepted composite index of water quality, some countries have used and are using aggregated water quality data in the development of water quality indices.

Singh P K et al., (2013) studied fourteen surface water samples collected from various rivers and ponds of West Bokaro Coalfield. The quality of water was evaluated by testing various physicochemical parameters such as pH, Total Dissolved Solids, Total Hardness, Turbidity, Bicarbonate, Total Alkalinity, Calcium, Magnesium, Fluoride, Chloride, Nitrate, andSulphate. A maximum WQI value of 125.5 and minimum value of 36.2 was found in the study area. The computed WQI shows that 28.6% of the water sample falls in the good water category. On the other hand, 42.9% of the water samples can be classified as poor category and 28.6 % as very poor category. Water Quality Index of 71.5% of the samples indicated that the water is not suitable for direct consumption.

Dede and Telci (2013) conducted the study on water quality data obtained from ten sampling stations during a year as part of a river monitoring program at Kashmir basin. Forty four water quality parameters in all the water samples were analysed. It was found that dissolved oxygen, biochemical oxygen demands, turbidity, iron phosphate, total coliform, E. coli, iron , manganese , arsenic , aluminum, boron, and barium values, mentioned in the water quality standard, are the major pollutants that affect the water quality of the river basin. Five different water quality index models were applied for the selected parameters. The suitability of these models and its applicability in similar studies are discussed. This study found that the best results would be provided by Canadian water quality index and Oregon water quality index.

Oişte A M et al (2014) considered the water quality index on evaluation of ground water sources used for specific environmental practices and verified the suitability of ground water for drinking purpose. Twenty two ground water resources were monitored and different regimes of parameters inclusive of pH, EC, turbidity, oxygen regime, hardness, alkalinity, nutrients regimes were checked. Nutrient regimes include the level of nitrates, ammonium, and phosphates, which were considered as most important. Water quality indicators utilized for computation revealed poor quality of ground water.

Haider H et al., (2016) reviewed the development and modifications of mathematical models for Dissolved Oxygen (DO). The field and laboratory methods to estimate the kinetics of Carbonaceous Biochemical Oxygen Demand (CBOD) and Nitrogenous Biochemical Oxygen Demand (NBOD) are also presented in the article. This paper was also included the recent approaches of BOD and DO modeling and their applicability to the natural rivers. The frequently available public domain computer models and their applications in real-life projects are also briefly covered. The literature survey reveals that, currently there is more emphasis on solution techniques rather than understanding the mechanisms and processes that control DO in large rivers. The DO modeling software contains inbuilt coefficients and parameters that may not reflect the specific conditions dealt in the study. It is therefore important that the select mathematical and computer models must incorporate the relevant processes that are specific to the river studied and also they should be within the available resources in concern to data collection.

Sutadian A D et al., (2016) informed that WQI is the major factor and support for the government and authorities in the evaluation of river water quality status. Since there are many uncertainties involved in the steps for development and application of water quality index, it was recommended that suggestions and opinions (Delphi method) of local water quality experts should be taken, especially in the course of the first three steps.

Gupta N et al., (2017) developed WQI of the Narmada, considered as a holy river in Madhya Pradesh. Eight parameters viz. pH, T, TDS, Turbidity, NO_3-, PO_4-, BOD DO measure were used at six sampling stations along the river. WQI was developed using these parameters by arithmetic index method.

2.8 Fuzzy and Artificial Neural Network Water Quality Model Development

Beck M B et al., (1987) analyzed the uncertainty in the development of mathematical models of water quality. A lack development of identifiable model has been a major difficulty in interpreting and explaining previously observed system behavior. There is ample evidence to show that the “larger” and more “comprehensive” models easily generate highly uncertain predictions about future behavior. A possibility of progress in the development of novel algorithms for model structure identification is speculated in the future of the subject. A need for new questions towards the problem of prediction and a distinct challenge to conventional views in new forms of knowledge representation and manipulation is novel emergence in field of artificial intelligence.

Kung H T et al., (1992) developed a general methodology for fuzzy clustering analysis and illustrated it with a case study of water quality evaluation for Dianshan Lake, Shanghai, China. Fuzzy clustering analysis may be used whenever a composite classification of water quality incorporates multiple parameters. In such cases, the technique may be used as a compliment or as an alternative to comprehensive assessment. In fuzzy clustering analysis, the classification is determined by a fuzzy relation. After the establishment of a fuzzy similarity matrix and stabilization of the fuzzy relation, a dynamic clustering chart can be developed. On an applicable threshold, the appropriate classification is made possible. The methodology is relatively simple and the results can be interpreted to provide valuable information in decision making and aid water quality management.

Desmet et al., (1996) in their research tried determining the soil erodibility factor using a fuzzy rule base system. Based on the Wischmeier`s homograph method, Sixty samples were collected from sixty homogenous units. After generating the fuzzy rules and calculating the soil erodibility factor, the results were compared with values from the method. The results showed that the values of K- factor generated with the fuzzy system is quite close to the values obtained by the USLE model. Therefore, the fuzzy rule base model was chosen as the most suitable site selection strategy in determining soil erodibility factor.

Mujumdar and Sasikumar (2002) developed a fuzzy optimization model for the seasonal water quality management of river systems. The model showed the uncertainty in a water quality system using a fuzzy probability framework. The occurrence of low water quality was considered as a fuzzy event. Randomness associated with water quality parameters was linked with this fuzzy event. In fuzzy risk approach, a range of risk levels is specified considering a fuzzy set of low risk, instead of using a chance constraint.

Sadiq and Rodriguez (2004) proposed a new indexing method using fuzzy synthetic evaluation to determine the health risk associated with two major groups of Trihalomethanes and Halo acetic acids. Initially, membership functions for cancer and non-cancer risks associated with THMs and HAAs are used to establish the fuzzy evaluation matrices.

Ocampo Duque, et al (2006) studied the relative importance of water quality parameters partaken in the fuzzy inference process and also dealt a multi-attribute decision-aiding method. The use of the fuzzy index has been tested with a case study. Data was collected from the Ebro River (Spain) through environmental protection agencies.

Zhanq and Liang (2005) applied entropy value theory to combine a fuzzy matter-element method and to establish an entropy fuzzy matter-element model for the uncertainty of indexes in evaluation of water quality. The coefficients of weight in this model were derived from the available value in the data on information entropy. The problem of weight allocation can be avoided through this method. The result of calculation is compared with that of the integrated evaluating method and attributes a recognition model. It indicates that the proposed method is reasonable and practical.

Karmakar and Mujumdar (2006) developed a grey fuzzy optimization model for water quality management of the river system and to address the uncertainty involved in fixing the membership functions according to the different goals set by the Pollution Control Agency. The present model, Grey Fuzzy Waste Load Allocation Model has the capability to incorporate the conflicting goals of PCA and dischargers in a decisive framework. The imprecision associated in specifying the water quality criteria and fractional removal levels are modeled on a fuzzy mathematical framework.

Qin et al., (2007) worked on the uncertainties in water quality, pollutant loading, and the system objective was displayed through the developed fuzzy model. The method of piecewise linearization was developed for dealing with the nonlinearity of the objective function. A case study on water quality management was conducted in Changsha section of the Xiangjiang Riverwith the intention of demonstrating the applicability of the developed IFNP model.

Sasikumar and Mujumdar (1998) developed a fuzzy waste-load allocation model for water quality management of a river system using fuzzy multiple, objective optimization. An important feature of this model is its capability to incorporate the aspirations and conflicting objectives proposed by the Pollution Control Agency and dischargers. The membership functions of these fuzzy sets were considered in the representation of variation in satisfaction levels of the pollution control agency and dischargers in attaining their respective goals. Maximization of the bias measure attempts to keep the satisfaction levels of the dischargers away from the minimum and that of the pollution control agency close to the minimum. Most of the conventional water quality management models use waste treatment cost curves that are uncertain and nonlinear. Unlike such models, this model avoided the use of cost curves. The model also provided a scope for the pollution control agency and dischargers to specify their aspirations independently.

Chang N B et al., (2001) conducted a comparative study using three fuzzy synthetic evaluation techniques to assess water quality conditions. The outputs were generated by conventional procedures like Water Quality Index (WQI). Based on the set of data collected at seven sampling stations, a case study was conducted on the Tseng Wen River system in Taiwan and demonstrated its potential for application. The findings clearly indicated that the techniques may successfully harmonize inherent discrepancies and help interpret complex conditions. In addition, the newly developed fuzzy synthetic evaluation approach described in this paper might also become useful in verifying water quality conditions. Maximum Daily Load (TMDL) program and also be helpful in constructing an effective water quality management strategy.

Nasiri et al., (2007) proposed a fuzzy multiple-attribute decision support expert system to compute water quality index and to provide an outline to prioritize alternative plans based on the number of improvements in WQI. WQI provide a comprehensive and easy to use tool to assess and evaluate water quality policies. Due to the abovementioned complexities, there was a necessity of a methodology to not only structure and identify information relevant to the problem but also to help users reach a decision. This issue was tackled by designing a multiple attribute decision support expert system which makes expert knowledge available to non-expert users. Qualitative or linguistic assessments were encountered in the index making process. Thus, the study demonstrated the fuzzy set theory can be applied to recognize inherent fuzziness of such a process. In the end, a case study was conducted to evaluate applicability and usefulness of the proposed methodology.

Lermontov A et al., (2009) focused on intrinsic uncertainties and subjectivities of environmental problems. These have been increasingly dealt with computational methods based on artificial intelligence. In order to evaluate applicability of artificial intelligence, this study proposed the creation of a new water quality index based on fuzzy logic called the fuzzy water quality index (FWQI). Fuzzy-logic-based methods have proven to be appropriate to address uncertainty and subjectivity in environmental problems. In the present study, a methodology based on fuzzy inference systems (FIS) to assess water quality is proposed. A water quality index calculated with fuzzy reasoning has also been developed.

Yan H et al., (2010) used an adaptive neuro-fuzzy inference system to classify water quality status of the river. The study applied several physical and inorganic chemical indicators including dissolved oxygen, chemical oxygen demand, and ammonia-nitrogen. A data set (nine weeks, total 845 observations) was collected from 100 monitoring stations located in all major river basins in China and it was used for training and validating the model.

Huang F et al., (2010) provided an understanding of the spatial distribution and identification of potential sources of water pollution and efficient management of water resources in the study. In this work, 13 water quality variables were collected for analysis during the year 2004 from 46 monitoring sites along the Qiantang River (China). Fuzzy comprehensive analysis categorized the sites into three major pollution zones (low, moderate, and high) based on national quality standards for surface waters prescribed in China. Most sites classified as “low pollution zones” (LP) occurred in the main river channel, whereas those classified as “moderate pollution (MP) and high pollution (HP) zones” occurred in the tributaries. Through factor analysis two potential pollution sources each were identified in the LP and MP and those sources explained 67% and 73% of the total variance in LP and MP, respectively. Three potential pollution sources that explained 80% of the total variance were identified in HP. UNMIX was used to estimate contributions from identified pollution sources into each water quality variable and to each monitoring site. Most of the water quality variables were primarily influenced by the pollution caused by industrial wastewater, agricultural activities and urban runoff.

Gesim N.A. and Okazaki T., (2012), using Fuzzy logic, identified artificial recharge sites of groundwater in Herat city, Afghanistan. Special attention was paid to artificial groundwater recharge in arid and semi-arid regions. Parameters considered in the selection of groundwater artificial recharge locations were diverse and complex. In this study, factors such as slope, infiltration rate, depth to groundwater and electric conductivity (EC) were considered to determine the aquifer area most suitable for groundwater artificial recharge in Herat city. Thematic layers of the above mentioned parameters were prepared, classified, weighted based on centroid method of de-Fuzzification and integrated it in a GIS environment by algebraic product operator of Fuzzy logic. The land use map of the research area was used to filter the artificial recharge map. The results of the study indicated that 17.74% of the study area is suitable and 82.26% is unsuitable for artificial groundwater recharge. A comparison between mean of water level points located in suitable zone of suitability and water level classes was done to validate the model.

Mourhir A et al., (2014) proposed a new water quality index to determine river water quality using fuzzy logic. The propped model comprised of water quality input indicators mainly from the Moroccan and Quebec water legislation. The model combined six input parameters and exhibited discrepancy between two base parameters. This model was implemented for water quality assessment by quantifiable score. Classification of membership function can be of sound support to the policy makers.

Krishnan and Vasantha., (2014) attempted a fuzzy logic-based modeling approach using the universal soil loss equation (USLE) in the selection and application of appropriate coir geotextile in controlling soil erosion. The fuzzy logic model was developed to address issues of soil erosion risk due to constant rainfall intensity. Two simple and efficient fuzzy logic soil erosion models were developed. One was for predicting soil erosion intensity and the other was for selecting an appropriate CG type to control soil erosion according to types of soil in various combinations of slope angle and length, crop cover, rainfall intensity, and so forth. These two models were designed a way that the input data requirement was minimum for model execution. The input parameters considered were ones qualified as main, primary, governing factors that influence soil erosion intensity in the USLE platform. F-SEM and F-CGM were compared with actual field data and found to be closely matching. F-SEM predicts the erosion intensity of an area and F-CGM can be used in the selection of CGs to control erosion.

Zhang et al.,(2016) developed an algorithm based wavelet neural network model using twelve combinations of water quality parameters such as COD, salinity, DO, temperature, EC, alkalinity, ammonia, TDS ,turbidity, sulphates, nitrates and phosphates to forecast the whole water quality index status of Miyun reservoir in Beijing, China. It is a case study to identify the effectiveness of this WNN .And it was revealed that this model is more stable and efficient in the case Miyun river.

Alizedath et al., (2018) performed machine learning model for forecasting of coastal waters in Hilo Bay, Pacific Ocean river using water quality parameters of temperature, salinity, and turbidity as the flow data of Wailuku river. Artificial neural network, extreme earning machine and support vector regression models were used and it was identified that performance of the different machine learning models was very close to each other.

2.9 Organochlorine Pesticide Contamination in Water and Sediment

Iwata H et al., (1994) analyzed the persistent organochlorines in air, river water and sediment samples from eastern and southern Asia (India, Thailand, Vietnam, Malaysia, Indonesia) and Oceania (Papua New Guinea and the Solomon Islands) to elucidate their geographical distribution in a tropical environment. The concentration of organochlorines in the abiotic samples collected from Taiwan, Japan, and Australia were also monitored for comparison. Atmospheric and hydrospheric concentrations of HCHs (hexa chloro cyclo hexanes) and DDTs in the tropical developing countries were apparently higher than those observed in the developed nations, suggesting to the extensive usage of these chemicals in the lower latitudes. CHLs (chlordane compounds) and PCBs (polychlorinated biphenyls) were also occasionally observed at higher levels in the tropics, implying that their usage area extents to the south

Fatoki and Awofolu (2003) were evaluated different extraction methods to determine fifteen organochlorine pesticides in water and sediments. Liquid–liquid extraction was availed for pesticides analyses in water while Soxhlet extraction and microwave assisted extraction methods were employed in sediment. Dichloromethane gave the best results among all the extracting solvents used. Percentage recoveries ranged from 71.03±8.15 (dieldrin) to 101.25±2.17% α-BHC) in water with LLE. In sediments the percentage recoveries with Soxhlet extraction method varied between 88.22±7.85 (endrin) and 109.63±5.10% (β-BHC) and ranged from 74.11±9.82 (2,4 DDT) to 97.50±4.56% (α-BHC) with MAE.

Zhou R et al., (2006) investigated level of 13 organochlorine pesticides in surface water and sediments from the Qiantang River in East China to evaluate potential pollution and risks. A total of 180 surface water samples from 45 sampling sites and 48 sediment samples from 19 sampling stations were collected along the river during four seasons in 2005. Soil samples and wet deposition samples were also collected to provide evidence on the source of OCPs. The total OCP concentration in surface water and sediments were 7.68–269.4 ng/L and 23.11–316.5 ng/g respectively. The concentrations of OCPs in sediments occurred in a range of 8.22–152.1 ng/g-DW for HCHs, 1.14–100.2 ng/g-dw for DDTs, 9.41–69.66 ng/g for other OCPs. Among OCPs, HCHs, DDTs and heptachlor were the most dominant compounds found in the sediments. The dominant OCPs in water were γ-HCH among HCHs, heptachlor among other OCPs and *p*,*p*′-DDE among DDTs.

Zhou R et al., (2006) estimated levels of 13 organochlorine pesticides (OCPs) in surface water and sediments from the Qiantang River in East China and evaluated their potential for pollution and risks. A total of 180 surface water samples from 45 sampling sites and 48 sediment samples from 19 sampling stations were collected along the river in course four seasons in 2005.

Zhou R et al., (2008) measured correlation between the HCH and presence of OCPs in water. The measured OCP concentration in sediments, soils, runoff water from farm land, dry and wet deposition were discussed in relation to the concentrations and patterns found in surface water.

Tan L et al., (2009) investigated the levels of 19 kinds of Organochlorine pesticides in the aqueous phase, suspended particulate matter, sediment and water from the Daliao River of Liaodong Bay (Bohai Sea) in Northeast China and evaluated the risk of pollution. The total concentration of organochlorine in the aqueous phase, SPM, pour water and sediments were 3.7–30.1 ng/ l, 4.6–52.6 ng/ l, 157–830 ng/l and 2.1–21.3 ng/ g dry weight, respectively. The concentrations of OCPs in the Daliao River estuary were in a mid-range, as compared to those reported in other estuaries across the world. The distribution of HCHs and DDTs were different and this indicated the presence of different contamination sources. Lindane is the main type of HCH and continued use in northeast China of ‘pure’ HCH (Lindane) over technical HCH accounts for as the source.

Bao L J et al., (2012) studied the status of drinking water contamination in coastal waters in China caused by persistent organic pollutants (POPs), including organochlorine pesticides (OCPs), polychlorinated biphenyls (PCBs), polybrominateddiphenyl ethers (PBDEs), polychlorinated dibenzo-*p*-dioxins and polychlorinated dibenzofurans, perfluorooctanesulfonate, and perfluorooctanoate.

Akhil and Sujatha (2012) attempted to study contamination levels of organochlorine pesticides in open wells of Kasargod district from 2010 to 2011. Maximum contamination of organochlorine pesticides (OCP's) was caused by endosulfan followed by hexachlorobenzene (BHC). Contamination levels of α-endosulfan were higher at Panathur (58 $\mu g\ L^{-1}$) and Periya (37 $\mu g\ L^{-1}$) in the post monsoon season of 2010.

The chapter contains a detailed literature review on the water quality assessment methods and various water quality modeling aspects of different water sources. The importance of water quality index in terms of water quality parameters to reduce the drinking water scarcity and protect the natural water bodies has been extracted. From these works it was identified that in order to overcome the fresh water crisis in our society, regular water quality monitoring, assessment and development of various water quality prediction models of nearby natural water sources are very essential and is the need of the hour.

2.10 Objectives of the Study

- To assess the water quality and the spatial, temporal and seasonal trend of pollution load by experimental analysis of water quality parameters for a 55km stretch of Chalakudy river from Vazhachal to Palapuzhakadvu.

- To identify the parametric correlation (R) of experimentally analysed pair of parameters and establishment of load of organic pollution and biodegradability in water by measuring BOD/COD ratio and FC/TC ratio.
- To analyse the persistence of organochlorine pesticide and its level of contamination in water and bottom sediment.
- To calculate water quality index using arithmetic index method and classify the water quality according to the values of WQI.
- To develop dissolved oxygen prediction model (FDOM) using fuzzy logic (Mamdani model) using triangular membership functions in MATLAB.
- To develop WQI prediction model (FWQIM) using fuzzy logic (Mamdani model) using triangular membership functions in MATLAB
- To develop regression models for predicting WQI in terms of total coliform content.
- To find the potential sources of pollution of river along the study area and proposed the remedial measures

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Chapter 3

MATERIALS AND METHODS

Contents

3. Introduction

The present study is carried out to assess and evaluate the load of pollution in water along eight different locations in the Chalakudy river, during the period of November 2013 to October 2018, by the analysis of experimentally collected set of water quality data. Using these analysed data, various water quality prediction models were developed and validated. To fulfill the objectives of the study, the following approaches have been adopted. The research work flow sheet is shown in Fig. 3.1.

3.1 Study Area

Chalakudy sub-basin is located between the $76^{o}20'0''$ and $77^{o}0'0''$ E and $10^{o}10'0''$ and $10^{o}30'0''$ N. The present study area starts from Vazhachal10°17’18.34N and 76°31’42.18E (400m above sea level) to Vynthala10°11’33.75N and 76°20’07.24E (Sea level). The length of the river studied is 55km i.e. 38% of the total river length (145.5 km).Upstream from the study area is dense forest area around the Vazhachal region. The river stretch along the study area is shown Fig.3.2.

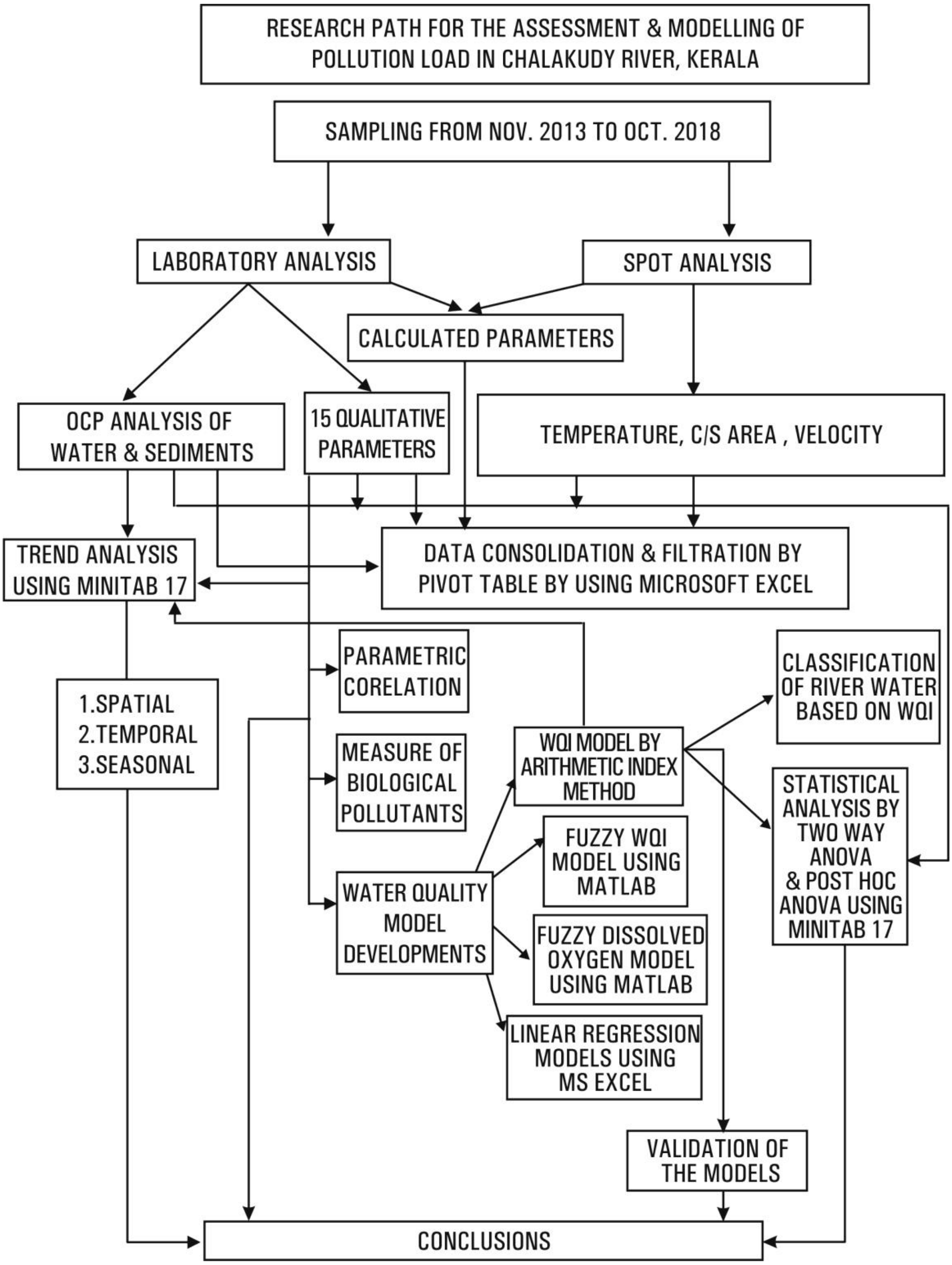

Fig. 3.1: Flow chart

3.2 Sample Collections

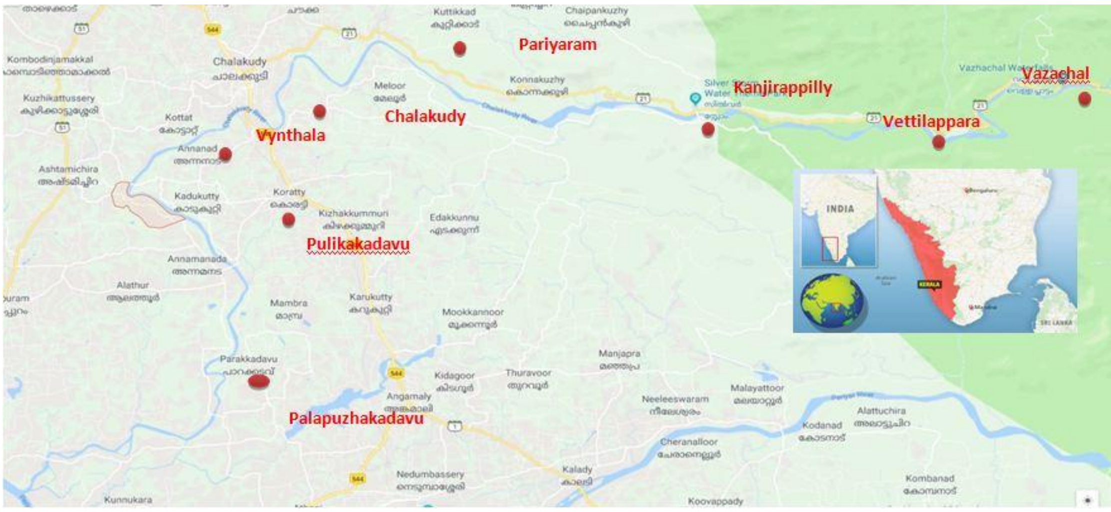

Fig. 3.2: River Stretch along study area

Water samples were collected from eight selected locations in Chalakudy river during November 2013- October 2018, once in a month using the grab sample method. The sampling stations are shown in Table 3.1 and Fig.3.3 to Fig.3.10. The samples were collected from locations where pollution due to human activity could be expected and also are locations from where water used for public consumption.

Samples were collected in 1000 ml HDPE bottles for determination of all the parameters except Biochemical oxygen demand (BOD), Chemical oxygen demand (COD), Total Coliform(TC), Fecal Coliform(FC) and Dissolved oxygen (DO). The plastic bottles were rinsed with 1M HCl and then with distilled water. The bottles were also rinsed thrice with water sample before collection. The collected samples were capped tightly and placed in a cooler box with ice for transportation to the laboratory (Asmaa mouhir et al., 2014).

Sterilized glass bottles for analysis of BOD and DO were filled with water carefully up to the brim along the sides of the bottle without entering air. DO was fixed using manganese sulphate and alkali iodide azide and capped. BOD bottle were wrapped using dark paper to avoid any contact with sunlight. All the samples were labeled by site name and date to avoid any error between sample collection and analysis. The samples were stored in a refrigerator at $4^{o}C$ immediately upon arrival at the laboratory. Bottom Sediments for pesticide analysis were collected using iron mesh shovel at the described points to the depth up to 10 and 15 centimeters from bottom (Haider et al, 2013).

Table 3.1: Sampling stations

site	Place	Activity	longitude and latitude
I	Vazhachal	Tourist spot, Forest division	10°17’18.34N-76°31’42.18E
II	Vettilappara	Water theme park, Agricultural area	10°17’33.86N-76°28’39.32E
III	Kanjirappilly	Paper mill (Presently not working)	10°18’14.59N-76°23’48.29E
IV	Pariyaram	Bathing, Skol breweries	10°17’31.65N-76°21’26.06E
V	Chalakudy	Major town, KWA pumping station, cattle farms	10°17’41.04N-76°20’11.06E
VI	Vynthala	KWA drinking water pumping station with treatment plant.	10°11’33.75N-76°20’07.24E
VII	Pulikkakadavu	DCP plant, agriculture area	10°14’01.75N-76°19’53.29E
VIII	Palapuzhakadavu	Bathing, residential area, Agriculture area	10°14’01.75N-76°20’10.96E

Fig. 3.3: Vazhachal sampling Site

Fig.3.4: Vettilappara sampling site

Fig.3.5: Kanjirappilly sampling site

Fig.3.6: Pariyaram sampling site

Fig.3.7: Chalakudy sampling site

Fig.3.8: Vynthala Sampling Site

Fig.3.9: Pulikkakadavu sampling Site

Fig.3.10: Palapuzhakadavu sampling site

3.3 Laboratory Analysis and Analytical Methods

All the 16 physico- chemical and biological water quality parameters such as Potential Hydrogen (pH), Total dissolved solids (TDS), Temperature (T), Turbidity (Tur), Chemical oxygen demand (COD), dissolved Oxygen (DO), Electrical conductivity (EC), Nitrates (NO_3^-), Phosphates (PO_4^-), Sulphates (SO_4^-),Total Hardness(TH), Biochemical oxygen demand (BOD), Chlorides (Cl^{-}), Total Coliform (TC), Fecal Coliform (FC),and Organo- chlorine pesticides (OCP's)as shown in Table.3.2were analysed in the laboratory using American Public Health Association's (APHA) standard methods(22nd edition) as shown in Table.3.3.Temperature, Velocity and Cross-section are measured at the real time of sampling. The standardization of methods and analysis techniques are very important for water quality monitoring and assessment. In this study American Public Health Association (APHA) standard methods are used to evaluate and quantify the various parameters of water quality. The analysed values were compared with Indian water quality standards (IS.10500; 2012). The standard values as per IS shown in Table 3.4.

Table 3.2: Details of parameters analyzed

Experimentally Analysed Parameters					*Calculated Parameters*
Physical	***Chemical***	***Biological***	***pesticides in Sediment***	***pesticides in Surface water***	***Physico-chemical and biological***
Temperature, °C	pH	Fecal coliform CFU/100ml	Aldrin (µg/kg)	Aldrin (µg/l)	Flow rate m3/s
Total Dissolved Solids, mg/l	COD, mg/l	Total Coliform CFU/100ml	Dicofol (Kethane) (µg/kg)	Dicofol (Kethane) (µg/l)	DO saturation, %
Turbidity NTU	Dissolved Oxygen, mg/l		Dieldrin (µg/kg)	Dieldrin (µg/l)	Saturation DO, mg/l
Velocity, m/s	Electrical Conductivity, µmhos/cm		Op-DDT (µg/kg)	Op-DDT (µg/l)	BOD-COD ratio
Cross sectional area, m^2	Nitrates mg/l		pp- DDT (µg/kg)	pp- DDT (µg/l)	FC-TC ratio
	Phosphates, mg/l		α BHC (µg/kg)	α BHC (µg/l)	WQI, TC limit: 10
	Sulphates, mg/l		α Endosulphan (µg/kg)	α Endosulphan (µg/l)	WQI, TC limit: 50
	Total hardness as $CaCO_3$, mg/l		β Endosulphan (µg/kg)	β Endosulphan (µg/l)	
	Chlorides, mg/l		δ BHC (µg/kg)	δ BHC (µg/l)	
	BOD, mg/l		ϒ BHC(Lindane) (µg/kg)	ϒ BHC(Lindane) (µg/l)	

Table 3.3: Analytical Methods various parameters analyzed

SI .No.	Parameter	Method of analysis	Reference
1	pH	Electronic pH meter	APHA 22nd edition
2	EC	Conductivity meter	APHA 22nd edition
3	Temperature	Mercury Thermometer	APHA 22nd edition
4	TDS	Gravimetric Method	APHA 22nd edition
5	Chloride	Argentometry	APHA 22nd edition 4500-Cl-B
6	Total Hardness	Titration (using EDTA)	APHA 22nd edition 2340C
7	DO	Winkler Method	APHA, 22nd edition, 4500-OBC
8	Turbidity	Nephlometer	APHA 22nd edition2130B
9	Sulphate	Spectrophotometer	-APHA, 22nd edition 4500-SO_4-E
10	BOD	3 day BOD incubation at 27ºC	APHA 22nd edition 5210B
11	COD	Dichromate reflux Method	APHA 22nd edition 5220B
12	Phosphates	Ascorbic acid method	APHA 22nd edition4500P-E
13	Nitrates	Cadmium reduction Method	APHA22nd edition 4500-No_3-E
14	Total Coliform	Membrane filtration Technique	APHA 22nd edition APHA9222B
15	Faecal coliform	Membrane filtration Technique	APHA 22nd edition APHA9222D
16	Organochlorine pesticides (OCPs)	Gas Chromatograph	APHA 22nd edition 6630B,C
17	Velocity(v)	Float method	
18	Cross section(A)	Depth*length	
19	Discharge Q	A*V	

Table 3.4: Drinking water specification IS.10500; 2012

SI. No	Parameter	Desirable limit	Permissible limit in the absence of alternate source
1	pH	6.5- 8.5	No relaxation
2	Turbidity, NTU	5	10
3	DO (mg/l)	6	No relaxation
4	Chlorides (mg/l)	250	1000
5	TDS (mg/l)	500	2000
6	Sulphates (mg/l)	200	400
7	Nitrates as NO_3 (mg/l)	45	No relaxation
8	BOD	3	No relaxation
9	Total hardness as $CaCO_3$ (mg/l)	200	600
10	Total Coliform (CFU/100 ml)	Absent	10 CFU/100ml
11	Fecal Coliform	Absent	No relaxation
12	Aldrine (µg/l)	0.03	No relaxation
13	Dieldrine (µg/l)	0.03	No relaxation
14	alpha BHC (µg/l)	0.01	No relaxation
15	DDT (µg/l)	1	No relaxation
16	Endosulphan (µg/l)	0.4	No relaxation
17	Lindane (µg/l)	2	No relaxation
18	β BHC (µg/l)	0.04	No relaxation

3.3.1 Temperature (^oC)

Temperature was measured on spot using mercuric thermometer ranged between 0^oC to 50^oC.

3.3.2 pH

pH is defined as the negative logarithm of hydrogen ion. Eutech PC 650, electronics pH meter (part of water analyzer instrument), was used to measurethe pH of the samples. The pH meter was calibrated with known pH buffer solutions. Standard buffer solutions: pH = 4, pH=7 and pH=9.2 also were used for calibration of instrument.

3.3.3 Electrical conductivity (EC)

Conductivity is a measure of the ability of aqueous solutions to carry electric current. It was measured using conductivity meter in water analyzer Eutech PC 650 inμmhos/cm. The instrument was calibrated using 0.01 M KCl solution to read the standard value of 1412 μ mhos/cm at 25^0C using the calibration knob.

3.3.4 Turbidity (TUR)

Turbidity was measured using Nephlometer, (Thermo scientific Eutech TN 100, ranged between 0- 800 NTU) by the Nephelometry method. The solutions had turbidity of 0.02 NTU (Nephlometric Turbidity Units), 20 NTU, 100 NTU, 800 NTU and distilled water were used for the calibration of the instrument.

3.3.5 Dissolved oxygen (DO)-Winkler method

Fixed water sample at the time of sampling (spot) using $MnSO_4$followed by alkali iodide in 300 ml B.O.D bottle was used to analyse DO. Manganese hydroxide first precipitated which is immediately oxidized to a hydroxide of higher oxidation state $MnO(OH)_2$ forming a brown precipitate. When conc. H2SO4 is added to this, it liberated iodine equivalent to the original oxygen content of the sample. From the volume of iodine liberated, which is estimated by titrating against 0.025 N Sodiumthiosulphate and starch indicator.

3.3.6 Total suspended solids (TDS)

TDS is the amount of dissolved solids present in a water sample; mostly ionic substances. A well mixed sample is filtered through a weighed standard glass-fiber filter and the residue retained on the filter dried to a constant weight at 103^oC to 105^oC about one hour using a KEMI hot air oven (Temperature ranged $0\text{-}300^oC$). The increased weight of the filter represents the total suspended solids.

3.3.7 Biochemical oxygen demand (BOD)

BOD is the amount of oxygen required for the Biochemical oxidation of organic matter at a specified temperature under aerobic condition. Dissolved oxygen was measured initially and after 3 day incubation at 27^0C. BOD is computed from the difference between initial and final DO. BOD incubator (KEMI, model KBOD3S, Temperature range $5^oC\text{-}60^oC$, 220-230V AC) was used for the incubation.

3.3.8 Total hardness (TH)

Total hardness is the sum of the calcium and magnesium concentrations, both expressed as $CaCo_3$in mg/l. Total hardness was analysed by titration using Ethylene diamine tetra acetic acid (EDTA) and a dye Eriochrome Black T. Calibration was performed by titrating 20 ml of standard calcium solution against the EDTA and determined mg of $CaCO_3$ equivalent to 1.00 ml EDTA.

3.3.9 Chemical oxygen demand (COD)

Chemical Oxygen Demand is the amount of oxygen consumed for the complete oxidation of the sample by a strong oxidizing agent. Dichromate reflux method was adopted for COD analysis.DBK COD digester with Erlenmeyer flasks and condenserswere used for the rapid analysis of COD.

3.3.10 Chlorides (Cl^-)

Chlorides are salt compounds resulting combination of the chlorine and a metal. Excess chlorides can cause human illness and also affects on the growth of tissues.

In a neutral or slightly alkaline solution, potassium chromate can indicate the end point of the silver nitrate titration of chloride. Silver chloride is precipitated quantitatively before red silver chromate is formed.

3.3.11 Phosphates (ascorbic acid method)

UV Spectrophotometer (Model U 2900, Hitachi, wavelength range190- 1100nm, Spectral band pass1.5nm, stray light0.05%, or less, wave length scan speed 10 -3600nm/min) and cuvettes were used for the calibration and analysis of the samples. Ammonium Molybdate and potassium antimonytartrate react in acid medium with orthophosphate to form a hetropoly acid phosphomolybdic that is reduced to intensely colored molybdenum blue by ascorbic acid and measured the absorbance with a wave length 880 nm using spectrophotometer.

3.3.12 Nitrates (NO_3^-)

Nitrate in the sample is reduced to nitrite in presence of cadmium and then determined by diazotizing with sulphanilamide and coupling with NEDA. Cadmium-Reduction Column and UVspectrophotometer (Model U 2900, Hitachi, wavelength range190- 1100nm, Spectral band pass1.5nm, stray light0.05%, or less, wave length scan speed 10 -3600nm/min) were used for the analysis of nitrates in the water sample. The sample was read absorbance at 543 nm using Spectrophotometer. Calibration graph was plotted with absorbance and concentration.

3.3.13 Sulphates (SO_4^-)

Sulphate is precipitated in an acetic acid medium with barium chloride to barium sulphates crystals of uniform size. The light absorbance of $BaSo_4$suspension and calibration with sulphate standard solution was carried out using spectrophotometer (Model U 2900, Hitachi, wavelength range190- 1100nm, Spectral band pass1.5nm, stray light0.05%, or less, wave length scan speed 10 -3600nm/min) and measured with at 420 nm wavelength.

3.3.14 Total coliforms (TC)

The coliform group is defined as those facultative anaerobic, gram negative, non spore forming rod shaped bacteria that develop red colonies with a metallic (golden) sheen within 24h at 35^{0}C on an Endo type medium containing lactose. The Membrane Filtration (MF) Technique was used for the analysis of TC in the water sample. Filtration units attached with laminar flow chamber (Rotek), membrane filter (pore size 0.45μ m), and absorbent pads consist of disks of filter paper, and forceps, incubators (35^{0}C),and culture media M Endo Agar, KEMI hot air oven, digital colony counter and autoclave (Labline AV101) were used for the analysis. TC was calculated using the equation (3.6). Disposed all the culturesafely15 minutes autoclaving at 121^{0}C.

3.3.15 Fecal coliforms (FC)

Bacteria that develop various shades of blue colonies an M-FC Medium at 44.5 + 0.2^{o}C are considered as fecal coliform. The fecal coliform MF Technique used an enriched medium and incubation temperature of 44.5+ 0.2^{0}C for selectively.

3.3.16 % DO saturation

Based on the analysed value of DO and T, DO saturation was calculated using the eqn. (3.1), (Benson and Krause., 1984). Then % DO saturation was calculated.

$$lnCs = Yint + \frac{a}{T} - \frac{b}{T2} + \frac{c}{T3} - \frac{d}{T4} - chl \times \left(e - \frac{f}{T} + \frac{g}{T2}\right) \qquad \textit{eqn. (3.1)}$$

3.3.17 Organo Chlorine Pesticides (OCP's)

Persistence of organochlorine pesticide in surface water and bottom sediment of Chalakudy River was analysed using Gas Chromatographic techniques during the period of January 2014- December 2016.

OCPs are strong long lasting, hydrophobic pesticides with low water solubility (Govinda swami et. al 2000). Organochlorine pesticides have strong bonds between their chlorine and carbon molecules and are attracted to fats and highly insoluble in water.

This is a big problem that once OCPs entered; residue can remain for a long time, in human or animal body via diet, in the water supply or in the soil. OCPs are widely used as insecticide. Since OCPs don't breakdown easily in fatty tissue, this can cause persistent organic pollution (Derek Muir and Rainer. 2013).

The pesticide analysis was done as per the method APHA6630B using Gas Chromatograph (GC) Perkin Elmer clarus 500 model with an electron capture detector (ECD) at 300^{o}C, column Elite -5 [30m x 0.53mm x 0.5µm], oven at 200 ^{o}C/ 5 min (5^{o}C /min to 220^{o}C), injection port at 250^{o}C, 4 psi nitrogen (carrier gas) flow and 0.2 µliters of split less injection. Detection limit of this equipment was 0.04 µg/l. The instrument was calibrated using the standards of the components to be analyzed. The Retention Time (R.T) for the pesticides analyzed by the Gas Chromatograph is shown in Table 3.5.

3.3.17.1 Extraction of pesticides from surface water and sediment

The pesticides were extracted from the water and sediment samples using the suitable organic solvents. Hexane was used for extraction of pesticide from water sample. Both hexane and acetone were used for the extracting pesticides from sediment samples. The following procedure was adopted for this. 1 liter of water sample filtered using a 0.45 µm Whattman glass-fiber filter paper. In order to maintain the pH at 7, phosphate buffer solution was added to the water sample. 25 ml of n-Hexane and 25 ml diethyl ether was added to the same sample and the whole solution was transferred to a separating funnel and shake thoroughly for 5 minutes. This was then kept undisturbed for phases to get separated. The extract was collected completely and it was passed through anhydrous sodium sulphate for dehydration of solvents. This extract was then concentrated into about 5 ml using a vacuum rotary evaporator. The concentrate was analyzed using GC.

For sediment analysis, soil sample was dried below 60^{o}c using an oven and then ground using mortar and pestle to obtain a size of 20 mesh sieve. 10ml n hexane and 10ml acetone were added in to a 4gm fine sample and allow mixing using Microwave digester (UV) for about 30 minutes. The extract was then collected completely and was passed through anhydrous sodium sulphate.

This was then concentrated to 5 ml by passing through a vacuum rotary evaporator. By keeping the degree of dilution, 2µl sample was injected from the transparent solution to the GC for pesticide analysis .The extracted samples were stored at +4°C. The extracts of OCPs were performed within a time period of 48 h.

The chromatogram obtained during the analysis of pesticides in a sediment sample is shown Fig.3.11. Retention time for each pesticide is shown in Table.3.5.

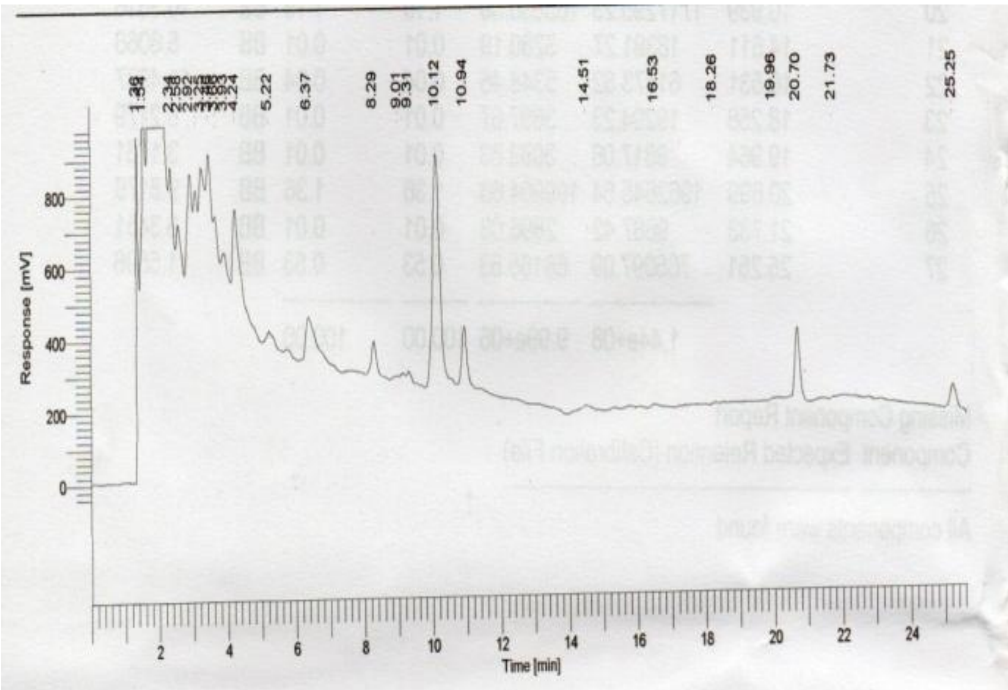

Fig. 3.11: The chromatogram obtained at time of calibration of GC

Table 3.5: Retention time of each pesticide

Sl. No.	Name of Pesticide	Retention Time (min)
1	α BHC	5.8
2	ϒ BHC (Lindane)	6.8
3	δ BHC	7.6
4	Aldrin	10.7
5	Dialdrin	16.5
6	Dicofol (Kethane)	11.1
7	α Endosulphan	14.9
8	β Endosulphan	18.2
9	Op-DDT	18.9
10	pp- DDT	20.7

Using area of standard, concentration of pesticide (μg/l) =

$$\frac{peak\ area\ of sample \times vol.\ of std inj(\mu l) \times conc.\ of std \left(\frac{pg}{\mu l}\right) \times Vol of extract\ (ml) \times Dil.\ fctor}{peak\ area\ of std \times vol.\ of sample\ inj(\mu l) \times vol of sample\ (ml)}$$

eqn. (3.2)

3.4 Determination of Quantitative Parameters (Spot Analysis)

3.4.1 Determination of average Flow velocity (v) using single floats

Single float method was used to measure the surface velocity at each site of the river. First measured the time taken by the float (thermocol cube) to travel a particular distance (5m) along each section of the river, Surface velocity was calculated by dividing the distance travelled by the float by the time taken (using stopwatch) to reach the distance. This surface velocity at same section is then converted in to an average velocity.

3.4.2 Determination of cross section area(A) by single segment method

In this method, the whole width of the river at a particular site was divided into number of segments at length L1, L2, L3 etc and at depth such as D1, D2, and D3 etc. The area of flow is the sum of all area of segment.

3.4.3 Determination of river discharge (Q)

The river discharge is the total volume of water flowing through a river bed at any given point in m^3/sec. It was calculated using the measured area and flow velocity using the eqn. (3.3).

$$Q = A \times V \qquad \text{eqn. (3.3)}$$

3.5 Data Analysis

3.5.1 Pivot Table analysis using Microsoft Excel

Microsoft Excel was used for the analysis of calculated parameters of all the qualitative and quantitative data set. The data were initially arranged according to the year, site, month, season (summer, winter, and monsoon), type (quantitative, qualitative, experimental, and calculated), parameter and value of monitoring. Pivot table was used to process the necessary combinations of data from the entire data table.

All the measured and calculated values at all the sampling points during the study period were consolidated in single excel sheet and processed using pivot table. Totally 13745 number of data were analyzed using pivot table.

3.5.2 Two Way analysis of Variance (ANOVA) using Minitab 17 Software

Regarding the physico- chemical, bacteriological, pesticide data and water quality index, the two way analysis of variance (ANOVA) was performed using Minitab 17 statistical software, to assess the significant differences in the qualitative parameters in the river between sampling sites and season. Prior to analysis, data were verified for normality. Post hoc ANOVA analysis (Tukey method) was performed to examine the relationship between the sampling stations and seasons. This was related to the distribution of water quality parameters analysed and with calculated water quality index.

3.5.3 Parametric correlation using Microsoft Excel

The parametric correlation analysis was carried out and correlation coefficient (r) was estimated to evaluate the relation between variables, whether their relation is significant or not significant. This coefficient provides evidence for the relationship between the 15 analyzed parameters. Information and reason regarding the correlated water quality parameters must be found from the study area. Correlation coefficient was calculated using Microsoft Excel and the so obtained r values were listed out between the various pairs of analysed parameters.

3.5.4 Trend analysis using box plots

The simplest way to represent the trend of parameters is graphical method. The trend can be analysed spatially, temporally and seasonally. Box plots were plotted to analyze the spatial, temporal and seasonal variations of each parameters with site, year and season respectively. This plot gives the spread of each parameter in terms of mean, minimum and maximum over a site and over a season.

3.6 Fuzzy Dissolved Oxygen Model (FDOM)

Fuzzy logic is a good promise in modeling of water quality studies (Chang et al., 2001). Thus fuzzy prediction modeling involves various environmental control parameters (Cohen et al., 2008). Fuzzy DO model (FDOM) Mamdani model was developed to predict the DO of the river water using four experimentally analysed water quality parameters such as T, COD, NO_3- and PO_4- are inputs and DO as output. The temperature dependency and eutrophication effects on DO was considered for the selection of input parameters (Young et al, 1998). This prediction model was developed using fuzzy inference system relying on MATLAB software. The next model, Fuzzy water quality index model (FWQIM) was developed using twelve water quality parameters such as pH,EC, TDS, Chloride, Total Hardness as $CaCO_3$, DO, Nitrate, COD, BOD, Phosphate, Sulphate and TC are inputs and considered WQI as output.

3.6.1 Model Development Using Fuzzy logic in MATLAB

Steps involved in fuzzy modeling (Mamdani) for fuzzy water quality models using triangular membership functions are shown in Fig. 3.11 and Fig. 3.12.respectively.The rules were developed for each factor by MATLAB programming which can execute a series of statements (Gesim and Okazaki.,2018) . Further values corresponding to the input variables generated were subdivided and recorded into groups with specific ranges and symbols such as E, G, VG, P, VP, andSP. This helped in creating the membership functions for fuzzy modeling within the permitted range. Triangular membership functions of each parameter were generated as these are considered to be more reliable and efficient in the case of water quality modeling.

3.6.2 Fuzzy modeling comprises the following steps.

3.6.2.1 Fuzzification

Fuzzification is the process of transforming the input data with the rule conditions to determine how the conditions of each rule will match that particular instance. The first step of the modeling is to define the inputs and determine the degree to which each linguistic term belongs to each of the appropriate fuzzy sets and that too through membership functions (Asmaa Mouhir, 2014).In this work, the fuzzy sets were quantitatively defined by membership functions for creating discrete membership functions.

It was essential to define the range of experimental values of each input values at every site as shown in Table 3.6, Table 3.8. and Table 3.9. Inorder to increase system accuracy, a large number of membership functions (within the range) overlapping are required. Triangular membership functions were found to increase the model accuracy of environmental problems. The fuzzyfier takes input values and determines the degree to which they belong to each of the fuzzy set through these triangular membership functions (Kido.M.et.al, 2009). For any given indicators, the rules are derived automatically based on the number of variables as well as the membership functions.

Table 3.6: Range of values of input and output Parameters for FDOM

Fuzzy set labels	P (mg/l)	T in °C	COD (mg/l)	NO_3-N (mg/l)	DO (mg/l)
Excellent(E)	0 - 0.5	25 – 26	0 - 0.5	0 - 0.5	10.1 – 11
Very Good(VG)	0.6 - 1	26.1 – 27	0.6 - 1	0.51 - 0.7	9.1 - 10
Good(G)	1.1 -1.5	27.1- 28	1.1 -1.5	0.71 -0.9	8.1 – 9
Moderately Good(MG)	1.6 - 2	28.1 – 29	1.6 - 2	0.91 - 1	7.1 – 8
Moderately poor(MP)	2.1 - 3	29.1 – 30	2.1 - 3	1.1 -1. 3	6.1 -7
Poor(P)	3.1 - 4	30.1 – 31	3.1 - 4	1.31 - 1.5	5.1 – 6
Very Poor(VP)	4.1 - 5	31.1 – 32	4.1 - 5	1.5.1 - 1.8	4.1 – 5
Severely Poor(SP)	5.1 - 5.5	32.1 -33	5.1 - 5.5	1.81 - 2	3 - 4

The steps involved in the model development are described below as diagrammatically in the Fig. 3.12.FDOM using triangular membership functions is developed with overlapping for all four input parameters and DO level (output) in the fuzzy system was shown in Fig.3.13. The fuzzyfier develops the rules to map an input space to output space 'if-then' statements called rules. Aggregation is the process by which the fuzzy steps are combined in to a single fuzzy set (Krishnan, B., & Vasantha, P. A., 2014).

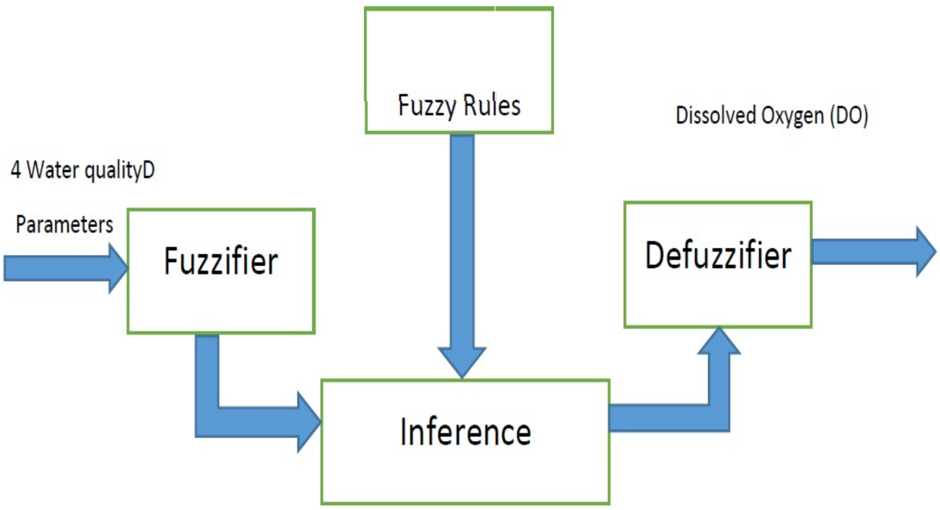

Fig.3.12: Steps involved in FDOM

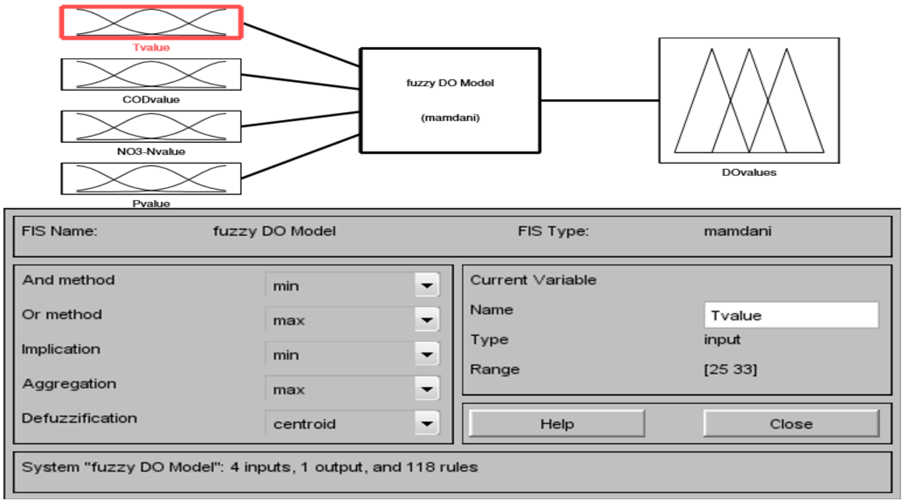

Fig.3.13: FDOM of Chalakudy River

3.6.2.2 Defuzzification

The last step for fuzzy model development is defuzzification (Chang.et al., 2001). Related to this, the defuzzification fuzzy set assigned to a control output variable at first, and then they get to transform into crisp values by comparing all the inputs within the range by centroid calculation which returns the center of the area under the triangular membership functions. Predicted DO will be obtained as an output crisp value from the defuzzifier.

3.7 Water Quality Index (WQI) Model using Arithmetic Indexmethod

Arithmetic WQImodel ofriver using empirical equations which in turn based on arithmetic index method was attempted using the experimental data obtained during the period of study (November 2013 to October 2018). In order to determine the quality of water for drinking and public use, twelve water quality parameters pH,EC, TDS, Chloride, Total Hardness, DO saturtion %, Nitrate, BOD, Phosphate, Sulphate, Turbidity and TC were analysed and WQI was calculated.

3.7.1 Water quality index (WQI) Calculation

WQI calculation was done according to the purity of the water using arithmetic index method. The method has been used by many researchers (Rao et al., 2010). It is to be noted that, WQI is the number representation of the relative value with respect to the standard values of Bureau of Indian standard (BIS).

Among these, eleven physicochemical and one bactriological (TC) parameters were considered for calculation of WQI. Therefore, the index is very reliable to assess the level of pollution to a considerably accurate level. In these, TC, BOD and DO are strong indicators of the WQI. But obviously, control of these parameters is necessary through the regular water quality monitoring. Factors which have higher permissible limits are less harmful in lower levels. But they can harm the quality of drinking water if they are present in very high quantity (Vatkar et al., 2013). In fact, these numerical models interpret the reality by means of the experimental values that can be accepted to quantify the various phenomena and their components (Marcello Benadine et al., 2013).Eqns. (3.4 to 3.7) was used to calculate WQI by arithmetic index method.

$$WQI = \sum Qn\, Wn \qquad \textit{eqn. (3.4)}$$

Water quality rating **(Qn)** of each parameter is calculated using the relationship

$$Q_{n} = \frac{100 * (Vn - Vi)}{(Vs - Vi)} \qquad \textit{eqn. (3.5)}$$

Here V_n is the observed value of n th parameter, V_s is the standard value of each parameter and $V_i$is the ideal value of the n^{th} parameter in pure water. All the ideal values except pH and DO are taken as zero. Ideal value for pH=7, and for DO saturation % =100. If Qn = 0**,** it indicates the complete absence of pollutants. While $0 < Q_n < 100$implies that, the pollutants are within the prescribed standard. When $Q_n > 100$**,** it means that the pollutants are above the standard (Mohanty et al., 2014).

$$Wn = \frac{K}{Vs} \qquad \textit{eqn. (3.6)}$$

Where Wn is unit weight, n is the number of standard values

$$Where\ K = \frac{1}{\frac{1}{Vs1} + \frac{1}{Vs2} + \frac{1}{Vs3} + \frac{1}{Vs4} \ldots\ldots \frac{1}{Vsn}} \qquad \textit{eqn. (3.7)}$$

3.7.2 Classification of river water according to the WQI

The river water was classified in to five categories based on the value of WQI as shown in Table 3.7.

Table 3.7: Classification according to WQI value (Ramakrishna et.al. 2009)

WQI Value	***Water quality***
WQI < 50	Excellent
50 <WQI <100	Good
100 < WQI<200	Poor
200<WQI <300	Very Poor
WQI >300	Not suitable for drinking

3.8 Fuzzy Water Quality Index Model (FWQIM)

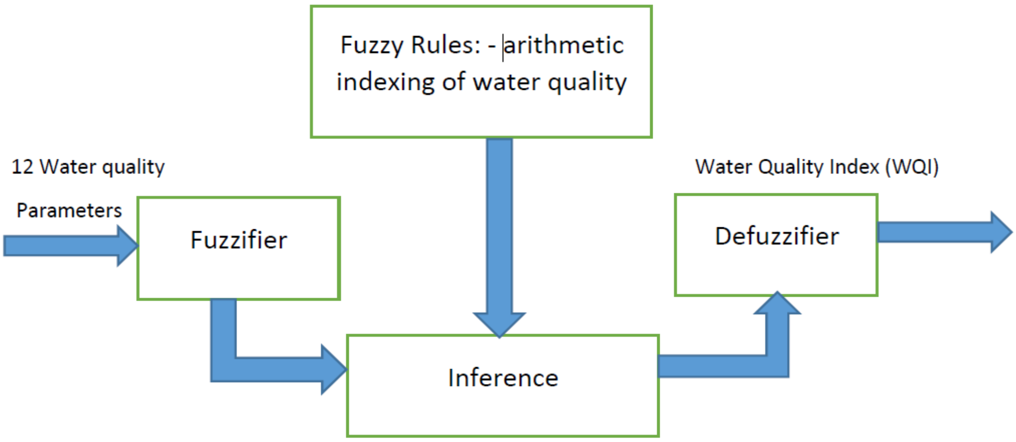

Fig. 3.14: The process of fuzzy Modeling of WQI

Determination and prediction of water quality index model of river water using the twelve input parameters,pH,EC, TDS, Chloride, Total Hardness as $CaCO_3$, DO, Nitrate, COD, BOD, Phosphate, Sulphate and TC was developed using fuzzy inference system. Mamdani model using triangular membership functions were applied to develop fuzzy WQI prediction model as shown in Fig. 3.14. From the above equations of WQI by arithmetic index method, it was found that there is a strong relationship between all the input parameters with the output parameter (WQI).

Each input variables were classified into different ranges as shown in the Table.3.8. & Table. 3.9. All the values except pH, TC, DO saturation and EC are expressed in mg/l. EC expressed in the unit µmhos/ cm, DO saturation in % and TC in CFU/100 ml. WQI is a dimensionless index.

Table 3.8: The range of values for the fuzzy input data set for FWQIM

Group	pH	Do saturation %	BOD (mg/l)	TC (CFU/100ml)	TDS (mg/l)	EC (µmhos/cm)
Excellent (E)	7	80-100	0-0.5	0- 10	0-10	0-10
Very Good (VG)	6.9≤ 7 ≥7.1	70-80	0.51-1	Oct-20	10.1-30	10.1-50
Moderately good (MG)	6.8≤ 6.9,7.1≥7.2	60-70	1.1-1.5	15-20	30.1-80	50.1-100
Good (G)	6.7≤ 6.8,8.3≥8.5	50-60	1.5-2	20-25	80.1-150	100.1-150
Poor (P)	6.3≤ 6.4,7.3≥8.6	40-50	2.1-2.5	25-30	151.1-200	150.1-200
Moderately Poor (MP)	6.4<6 .5 , 8.6 >8.5	30-40	2.5 - 3	30-35	200.1-300	200.1-250
Very Poor (VP)	4.5<5, 9.5 >9	20-30	3.51-5	35-50	300.1-500	250.1-300
Severely poor(SP)	<4.5, >9.5	≤ 20	>5	>50	>500	>300

Table.3.9: The range of values for the fuzzy input and output data set for FWQIM

Group	Cl^-(mg/l)	NO_3^- (mg/l)	PO_4^- (mg/l)	TH (mg/l)	SO_4^- (mg/l)	Tur (NTU)	WQI
Excellent (E)	0-5	0-0.5	0-0.5	0-10	0-5	0-0.5	0-25
Very Good (VG)	5.1-10	0.51-5	0.51-1	10.1-50	5.1-10	0.5-1	25-50
Moderately good MG)	10.1-25	5.1-10	1.1-2	50.1-100	10.1-25	1-1.5	50-75
Good (G)	25.1-50	10.1-20	2.1-3	100.1-150	25.1-50	1.5-2	75-100
Poor (P)	50.1-100	20.1-30	3.1-4	150.1-200	50.1-100	2-2.5	100-200
Moderately Poor (MP)	100.1-150	30.1-40	4.1-5	200.1-250	100.1-150	2.5-3.5	200-400
Very Poor (VP)	150.1-250	40.1-45	5.1-6	250.1-300	150.1-250	3.5-5	400-800
Severely poor (SP)	>250	>45	>6	>300	>250	>5	800-1000

The FWQIM developed for predicting WQI of the river system is shown in Fig.3.15 with twelve inputs and WQI as output.

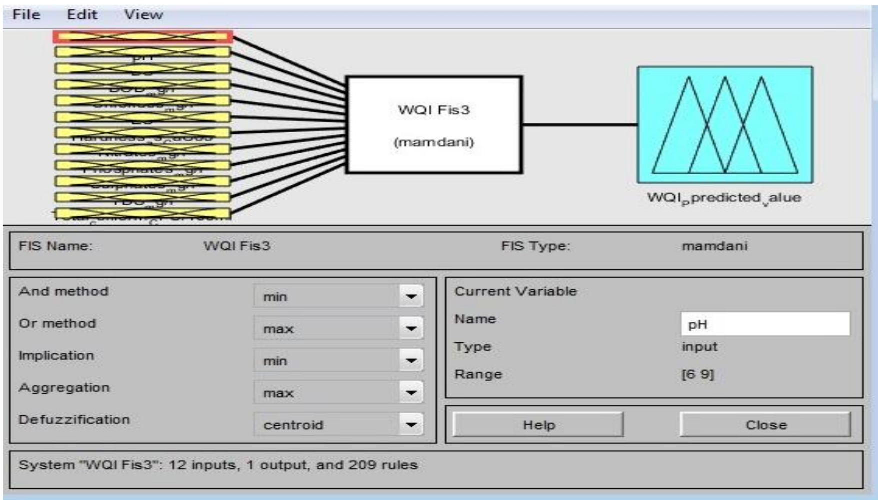

Fig. 3.15: FWQIM Model

3.9 Regression Model

A collective set of data of five years to assess and determine WQI, a precise technique of linear regression were used as a good tool for surface water quality modeling. Using Microsoft Excel, regression equations were generated between the variables TC and WQI. Experimentally analysed values of TC were used as independent variable. Two sets of values of WQI calculated using twelve water quality parameters (two standard limits for TC, 10 CFU/100ml and 50CFU/100ml) by arithmetic index method were taken as dependent variable. Two regression models of WQI in terms of TC were culminated to develop two linear regression equations with regression coefficients R^2.This regression equation gives the relation between the significantly correlated river water quality parameters TC and WQI.

3.10 Validation of the Models

Predicted values of FDOM, FWQIM and regression models were tabulated to evaluate their performance. Hence the models can be extended to any combinations of input parameters which are influencing the level of output parameter directly or indirectly. Interestingly, the model was found to be agreeing with the experimental findings statistically with average absolute relative error (AARE) and root mean square error RMSE values using (eqn.3.8) and (eqn.3.9).

$$AARE\ \% = \frac{1}{n}\sum_{i=0}^{n}\frac{(E_i - P_i)}{E_i} \times 100 \qquad \text{eqn. (3.8)}$$

$$RMSE = \left[\frac{1}{n}\sum_{i=0}^{n}\frac{(E_i - P_i)^2}{E_i}\right]^{\frac{1}{2}} \qquad \text{eqn. (3.9)}$$

Where E_i is experimental, P_i is the predicted value obtained from the fuzzy inference system.

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Chapter 4

QUALITATIVE AND QUANTITATIVE PARAMETERS OF CHALAKUDY RIVER

Contents

4.1 Introduction

The physicochemical and biological characteristics of surface water can give a clear idea about the water quality of any water body. The sixteen physico-chemical and biological characteristics such as Temperature, pH, Chlorides, Nitrates, Chemical Oxygen Demand, Dissolved Oxygen, Electrical Conductivity, Phosphates, Sulphates, Total Dissolved Solids, Total Hardness, Biochemical Oxygen Demand, Turbidity, % DO saturation, Total Coliform and Fecal Coliform of Chalakudy river water were analyzed during the period of study from November 2013 to October 2018 along the study area. Quantitative parameters such as cross-section area (A), velocity (v), and rate of flow (Q) at each site were also analyzed. Persistence of organo chlorine pesticides in water and sediment were also analysed during the period from January 2014 to December 2016. The experimentally analyzed qualitative and quantitative parameters of the Chalakudy River during the study period, at each sampling stations from Vazhachal to Palapuzhakadavu, are shown in Table 4.1 to 4.48. Analysis of all the data were carried out using Pivot table using Microsoft Excel, Two way ANOVA and posthoc ANOVA (Tukey method) using MINITAB . These tools will helps in assessing the nature of water quality and a load of pollution in the river during the period of study. Spatial and temporal distribution, parametric correlation between fifteen pairs of parameters, biodegradability measure by BOD/COD ratio and FC/TC ratio were also analysed. Based on the analyzed water quality parameters, various WQI prediction models such as arithmetic index model, DO and WQI models using fuzzy logic in MATLAB, and two regression models were developed. Validations of these models are performed to choose the most suitable model. All the results obtained during the period of study are summarized and discussed in this chapter as follows: -

Table 4.1: Qualitative and quantitative characteristics of surface water at Vazhachal Site during 2013

	Parameters	Nov-13	Dec-13
Experimental	BOD, mg/l	0.55	0.78
	Chlorides, mg/l	12	14
	COD, mg/l	1.3	2.3
	Dissolved Oxygen, mg/l	7.4	7.68
	Electrical Conductivity, µmhos/cm	43	86
	Fecal coliform CFU/100ml	50	130
	Nitrates mg/l	0.77	0.5
	pH	7.1	7.05
	Phosphates, mg/l	0.335	1.2
	Sulphates, mg/l	1.195	0
	Temperature, ^{o}C	26	27.8
	Total Coliform CFU/100ml	220	670
	Total Dissolved Solids, mg/l	41	39.5
	Total hardness as $CaCO_3$, mg/l	16	20
	Turbidity NTU	0.16	0.35
	Velocity, m/s	0.1	0.056
	Cross sectional area, m^2	542	339
Calculated	DO saturation, %	91.2	97.8
	FC-TC ratio	0.23	0.19
	Flow rate, m^3/s	54.1	18.9
	Saturation DO, mg/l	8.11	7.85
	BOD-COD ratio	0.42	0.34

Table.4.2: Qualitative and quantitative characteristics of surface water at Vazhachal site during the year 2014

	Parameters	Jan-14	Feb-14	Mar-14	Apr-14	May-14	Jun-14	Jul-14	Aug-14	Sep-14	Oct-14	Nov-14	Dec-14
Experimental	BOD, mg/l	0.53	0.78	1.32	1.05	1.25	0.67	2.3	0.93	0.5	1.2	0.79	0.48
	Chlorides, mg/l	18	50	58.5	40	32	74	10	11	27	19	14	14
	COD, mg/l	0.76	2.1	2.15	3.7	3	2.8	2.9	2.05	1.8	2.6	3.5	2.25
	Dissolved Oxygen, mg/l	7.1	7.5	6.8	5.7	7.19	6.5	7.5	7.1	7.3	6.9	7.6	7.3
	Electrical Conductivity, µmhos/ cm	60	82	87	146	96	94	42	84	89	62.5	41.5	71.5
	Fecal coliform, CFU/100ml	40	20	50	80	50	50	40	160	50	60	40	100
	Nitrates, mg/l	0.38	0.04	0.31	0.255	0.2	0.08	0.36	0.25	0.235	0.13	0.495	0.53
	pH	6.5	7.2	7.1	6.6	7.2	6.7	6.45	7.2	6.85	6.7	6.85	7.1
	Phosphates, mg/l	0	0.6	1	0.27	0	0	0.32	0.05	0.08	0.035	0	2.4
	Sulphates, mg/l	0	0.82	0	0.88	0	0	0.78	1.1	1	0.1	0	1.23
	Temperature, °C	27	26.8	28	28.5	30	27.33	27.7	25.5	25.8	27.6	26.7	27.9
	Total Coliform, CFU/100ml	520	440	120	940	790	740	960	520	510	1030	660	710
	Total Dissolved Solids, mg/l	55	95	109	132	107	98	27	36	27	36	120.6	30.5
	Total hardness, mg/l	37.5	36	58.5	48	20	44	12.5	19	18	22	23	16
	Turbidity, NTU	0.45	1.23	1.56	2.5	0.4	1.44	1.5	0.4	0.43	0.77	1.78	0.4
	Velocity, m/s	0.046	0.08	0.077	0.08	0.2	0.338	0.316	0.175	0.248	0.179	0.091	0.1
	Cross sectional area, m^2	344	235	182	149	165	936	940	928	759	912	651	320
Calculated	DO saturation, %	89.2	93.9	87	73.5	95.2	82.2	95.4	86.8	89.7	87.6	95	93.2
	FC-TC ratio	0.08	0.05	0.42	0.09	0.06	0.07	0.04	0.31	0.1	0.06	0.06	0.14
	Flow rate, m^3/s	15.8	18.9	14	11.9	33	316.1	296.6	162.8	188.3	162.9	59	32
	Saturation DO, mg/l	7.96	7.99	7.82	7.75	7.55	7.91	7.86	8.18	8.14	7.88	8	7.83
	BOD-COD ratio	0.7	0.37	0.61	0.28	0.42	0.24	0.79	0.45	0.28	0.46	0.23	0.21

Table 4.3: Qualitative and quantitative characteristics of surface water at Vazhachal site during the year 2015

	Parameters	Jan-15	Feb-15	Mar-15	Apr-15	May-15	Jun-15	Jul-15	Aug-15	Sep-15	Oct-15	Nov-15	Dec-15
Experimental	BOD, mg/l	1.06	1.22	1.42	1.6	1.09	1.43	2.78	0.77	1.88	1.96	1.78	2.9
	Chlorides, mg/l	20	13	28	18.49	30.56	12.5	23.5	20.45	18.5	20.45	7.8	22.35
	COD, mg/l	1.6	1.6	3.4	2.5	5.7	4.3	2.8	2.24	2.06	2.4	1.97	4.9
	Dissolved Oxygen, mg/l	7.3	6.95	6.7	7.1	6.44	7.1	7.54	6.1	6.3	7.5	6.9	6.2
	Electrical Conductivity, µmhos/cm	65	89	65	89.5	185	70.34	48	34	76.56	34	76.56	40
	Fecal coliform CFU/100ml	120	170	120	170	20	100	130	120	300	130	90	140
	Nitrates mg/l	0.01	0.01	0.28	0.01	0.34	0.34	0.25	0.78	0.89	0.78	0.89	0.34
	pH	6.7	6.7	7	6.8	7.2	6.8	7.5	7.5	6.8	7.5	6.8	6.7
	Phosphates, mg/l	2.1	0.07	0.67	1.09	0.77	0.24	0.12	0.22	0.17	0.22	0.17	0.16
	Sulphates, mg/l	0.84	0.92	0.23	0.48	1.03	1.56	1.2	0.897	0.675	0.897	0.675	0.342
	Temperature, °C	27.8	27	28.4	29.65	30.2	27.9	27.2	26.3	26.8	27.9	26.9	28
	Total Coliform CFU/100ml	840	360	520	480	120	600	1020	420	1320	810	560	500
	Total Dissolved Solids, mg/l	45	69	92.36	82.1	97.8	89.3	123.65	109.78	121	98.4	71.2	82.3
	Total hardness as $CaCO_3$, mg/l	14	19	84.55	31.6	89	123.45	111.8	129.5	89.5	73.36	77.7	65.67
	Turbidity NTU	0.33	0.67	0.8	1.8	2.9	1.43	0.32	1.32	0.81	1.23	0.4	1.2
	Velocity, m/s	0.054	0.084	0	0.096	0.176	0.178	0.384	0.135	0.071	0.102	0.077	0.098
	Cross sectional area, m^2	333	239	197	157	199	1695	1016	1453	1148	744	686	349
Calculated	DO saturation, %	93	87.3	86.2	93.4	85.5	90.7	95.1	75.7	78.8	95.8	86.5	79.3
	FC-TC ratio	0.14	0.47	0.23	0.35	0.17	0.17	0.13	0.29	0.23	0.16	0.16	0.28
	Flow rate, m^3/s	18	20	0	15.1	35	302.4	390.3	196.7	81.7	76	52.7	34.2
	Saturation DO, mg/l	7.85	7.96	7.77	7.6	7.53	7.83	7.93	8.06	7.99	7.83	7.98	7.82
	BOD-COD ratio	0.66	0.76	0.42	0.64	0.19	0.33	0.99	0.34	0.91	0.82	0.9	0.59

Table.4.4: Quantitative and qualitative characteristics of surface water at Vazhachal site during the year 2016

	Parameters	Jan-16	Feb-16	Mar-16	Apr-16	May-16	Jun-16	Jul-16	Aug-16	Sep-16	Oct-16	Nov-16	Dec-16
Experimental	BOD, mg/l	1.5	1.06	1.6	2.56	2.56	0.89	1.06	0.54	1.87	2.7	1.4	2.6
	Chlorides, mg/l	18	26	28	18.49	28.78	30.56	28.78	30.56	20.45	7.8	23.23	22.35
	COD, mg/l	4.8	3.98	2.24	2.96	2.67	5.2	1.3	5.2	4.9	3.6	3.05	3.6
	Dissolved Oxygen, mg/l	7.4	7.7	6.7	6.58	6.82	7.1	7.23	7.6	6.3	7.5	6.9	6.2
	Electrical Conductivity, μmhos/ cm	78.67	70	65	89.5	89.5	106.4	70.34	106.4	76.56	121.6	65	40
	Fecal coliform CFU/100ml	100	120	120	100	90	140	230	120	300	130	140	130
	Nitrates mg/l	1.28	0.33	0.28	0.34	0.34	0.25	0.34	0.78	0.89	0.34	0.33	0.89
	pH	6.6	6.6	7	6.8	6.8	7.5	6.8	7.5	7.5	6.8	6.4	6.7
	Phosphates, mg/l	0.5	0.52	0.67	1.09	1.09	0.77	0.89	0.77	0.22	0.17	0.32	0.16
	Sulphates, mg/l	0.13	0.22	0.23	0.345	0.672	1.2	1.56	1.03	0.897	0.675	0.621	0.342
	Temperature, °C	28.2	26.5	28	30.6	30.5	26.7	25.6	26.8	27	28.2	27.2	28.4
	Total Coliform CFU/100ml	480	910	800	430	400	400	340	590	700	780	380	790
	Total Dissolved Solids, mg/l	69.4	65.34	92.36	82.1	92.34	173.45	118.6	100.6	118.6	89.56	67.3	82.3
	Total hardness as $CaCO_3$, mg/l	56	102	84.55	31.6	78	89.67	123.45	89	77.7	77.7	76.56	65.67
	Turbidity NTU	3.01	4.85	2.05	0.33	0.67	0.77	1.78	0.4	0.33	0.67	0.5	0.77
	Velocity, m/s	0.051	0.012	0.007	0.01	0.017	0.157	0.212	0.112	0.172	0.029	0.018	0.019
	Cross sectional area, m^2	395	692	609	410	987	1263	1238	1144	749	1620	1529	422
Calculated	DO saturation, %	95	95.9	85.7	88.1	91.1	88.8	88.5	95.1	79.1	96.3	87	79.8
	FC-TC ratio	0.21	0.13	0.15	0.23	0.23	0.35	0.68	0.2	0.43	0.17	0.37	0.16
	Flow rate, m^3/s	20.1	8	4.2	4.2	16.3	198	263	127.9	128.7	46.3	28.1	8
	Saturation DO, mg/l	7.79	8.03	7.82	7.47	7.49	8	8.17	7.99	7.96	7.79	7.93	7.77
	BOD-COD ratio	0.31	0.27	0.71	0.86	0.96	0.17	0.82	0.1	0.38	0.75	0.46	0.72

Table.4.5: Qualitative and quantitative characteristics of surface water at Vazhachal site during the year 2017

	Parameters	Jan-17	Feb-17	Mar-17	Apr-17	May-17	Jun-17	Jul-17	Aug-17	Sep-17	Oct-17	Nov-17	Dec-17
Experimental	BOD, mg/l	2.89	1.87	2.55	2.74	3.4	0.86	3.43	2.3	2.3	1.92	1.8	1.89
	Chlorides, mg/l	18	26	28	18.49	28.78	30.56	12.5	1.67	7.8	6.8	25	22.35
	COD, mg/l	5.2	2.07	3.8	4.3	3.8	3.5	4.7	3.26	3	4.5	2.3	3.43
	Dissolved Oxygen, mg/l	6.94	7.68	6.9	6.56	7.12	7.1	5.8	6.1	7.2	6.8	6.9	6.2
	Electrical Conductivity, μmhos/cm	78.67	70	65	89.5	46	106.4	70.34	48	48	48	70.73	40
	Fecal coliform CFU/100ml	140	230	150	120	120	130	120	100	100	230	120	120
	Nitrates mg/l	0.54	0.003	1.85	0.35	0.98	1.34	1.34	0.22	0.22	0.22	0.71	0.45
	pH	6.6	6.6	7	6.8	6.8	7.2	6.8	7.5	7.5	7.2	7	6.7
	Phosphates, mg/l	0.5	0.52	0.67	1.09	0.89	0.77	0.24	0.12	0.17	0.23	0.03	0.16
	Sulphates, mg/l	0.13	0.22	0.23	0.345	0.672	0.67	1.06	0.56	0.72	0.34	0.56	0.342
	Temperature, °C	28	27.3	28.5	31.2	31.4	25.6	29.6	26.4	26.3	27.2	27.3	26.5
	Total Coliform CFU/100ml	590	1200	970	630	700	200	140	560	480	400	340	590
	Total Dissolved Solids, mg/l	69.4	65.34	92.36	82.1	92.34	91.4	89.3	73.3	89.5	105.5	58.5	82.3
	Total hardness as $CaCO_3$, mg/l	56	102	84.55	31.6	78	89	123.45	89.67	89.67	89.67	18.6	65.67
	Turbidity NTU	2.5	0.4	0.4	2.9	1.43	0.32	1.32	0.81	1.23	0.4	1.2	3.01
	Velocity, m/s	0.029	0.046	0.047	0.064	0.091	0.362	0.204	0.167	0.104	0.093	0.058	0.034
	Cross sectional area, m^2	314	127	199	178	196	834	972	923	894	1006	1154	970
Calculated	DO saturation, %	88.7	97	89	88.6	96.6	86.9	76.3	75.8	89.3	85.8	87.1	77.2
	FC-TC ratio	0.24	0.19	0.15	0.19	0.17	0.65	0.86	0.18	0.21	0.58	0.35	0.2
	Flow rate, m^3/s	9.2	5.9	9.3	11.4	17.8	301.8	198.2	153.7	93.3	93.6	67.2	33
	Saturation DO, mg/l	7.82	7.92	7.75	7.4	7.37	8.17	7.6	8.05	8.06	7.93	7.92	8.03
	BOD-COD ratio	0.56	0.9	0.67	0.64	0.89	0.25	0.73	0.71	0.77	0.43	0.78	0.55

Table.4.6 qualitative and quantitative characteristics of surface water at Vazhachal site during the year 2018

	Parameters	Jan-18	Feb-18	Mar-18	Apr-18	May-18	Sep-18	Oct-18
Experimental	BOD, mg/l	2.33	2.54	3.21	3	2.78	1.2	1.05
	Chlorides, mg/l	18	26	28	18.49	28.78	59.7	58
	COD, mg/l	4.35	3.86	4.1	4.9	2.88	4.5	1.8
	Dissolved Oxygen, mg/l	6.55	6.42	5.2	6.45	6.9	6.3	6.8
	Electrical Conductivity, μmhos/cm	78.67	70	65	89.5	46	159.6	87
	Fecal coliform CFU/100ml	130	140	50	230	240	1000	600
	Nitrates mg/l	0.54	0.003	1.85	0.35	0.98	1.23	0.71
	pH	6.6	6.6	6.9	6.8	6.8	6.9	7.1
	Phosphates, mg/l	0.5	0.52	0.67	1.09	0.89	1.06	1.06
	Sulphates, mg/l	0.65	1.07	0.23	0.345	0.672	1.05	0.45
	Temperature, °C	28.9	29.3	29.6	29.3	30.4	28	29.7
	Total Coliform CFU/100ml	700	700	210	610	780	1800	1200
	Total Dissolved Solids, mg/l	69.4	70	92.36	82.1	90	138	83.7
	Total hardness as $CaCO_3$, mg/l	56	102	73	31.6	59.45	99.2	68.9
	Turbidity NTU	0.5	0.77	2.5	0.4	0.67	2.8	1.9
	Velocity, m/s	0.009	0.03	0.043	0.061	0.062	0.097	0.093
	Cross sectional area, m^2	280	140	191	150	123	927	876
Calculated	DO saturation, %	85.1	84	68.4	84.4	92	80.6	89.6
	FC-TC ratio	0.19	0.2	0.24	0.38	0.31	0.56	0.5
	Flow rate, m^3/s	2.6	4.2	8.3	9.1	7.6	89.8	81.8
	Saturation DO, mg/l	7.7	7.64	7.6	7.64	7.5	7.82	7.59
	BOD-COD ratio	0.54	0.66	0.78	0.61	0.97	0.27	0.58

Table.4.7: Qualitative and quantitative characteristics of surface water at Vettilappara Site during 2013

	Parameters	Nov-13	Dec-13
Experimental	BOD, mg/l	1.4	2.2
	Chlorides, mg/l	40	29
	COD, mg/l	2.8	3.2
	Dissolved Oxygen, mg/l	7.75	7.68
	Electrical Conductivity, μmhos/cm	60	55
	Fecal coliform CFU/100ml	160	160
	Nitrates mg/l	0.79	0.445
	pH	7.5	7.05
	Phosphates, mg/l	0	0
	Sulphates, mg/l	7	3.5
	Temperature, °C	26	28
	Total Coliform CFU/100ml	740	720
	Total Dissolved Solids, mg/l	86	69
	Total hardness as $CaCO_3$, mg/l	28	22
	Turbidity NTU	0.42	0.4
	Velocity, m/s	0.075	0.049
	Cross sectional area, m^2	692	406
Calculated	DO saturation, %	95.6	98.2
	FC-TC ratio	0.22	0.22
	Flow rate, m^3/s	51.775	20.045
	Saturation DO, mg/l	8.11	7.82
	BOD-COD ratio	0.5	0.69

Table.4.8: Qualitative and quantitative characteristics of surface water at Vettilappara Site during 2014

	Parameters	Jan-14	Feb-14	Mar-14	Apr-14	May-14	Jun-14	Jul-14	Aug-14	Sep-14	Oct-14	Nov-14	Dec-14
Experimental	BOD, mg/l	1.15	2.5	2.1	2.3	2.55	0.8	1.2	2.9	2.85	2.95	2.8	2.15
	Chlorides, mg/l	17	73.5	27.5	62.5	31	46	16.5	29	15.5	38	48	25
	COD, mg/l	1.68	3.2	3.35	4.2	3.3	2.8	2.9	3.8	3.2	3.1	3.05	3.4
	Dissolved Oxygen, mg/l	5.6	7.5	7.6	7.5	7.19	6.8	7.05	7.13	7.05	7.1	7.3	7.6
	Electrical Conductivity, μmhos/ cm	84	42	66	102	88.5	99	34.5	78	56	53	42	68
	Fecal coliform CFU/100ml	240	70	90	190	280	80	50	100	80	70	60	210
	Nitrates mg/l	0.54	0.03	0.255	0.24	0.1	0.135	0.225	0.19	0.315	0.0625	0.1	0.52
	pH	7.05	6.9	7.2	7	6.5	6.75	6.9	7.2	6.85	6.65	6.6	7.1
	Phosphates, mg/l	1.15	0.3	5.4	0	0	0.1	0	0	0.15	0.15	0	2.3
	Sulphates, mg/l	0	0	0	1.315	0	0	0.215	2.5	0.316	1	2.33	1.8
	Temperature, °C	27.4	26.9	28.3	28.6	30.2	27.67	27.9	25.6	25.9	27.8	27	27.5
	Total coliform CFU/100ml	740	420	180	640	490	510	610	630	480	720	840	780
	Total Dissolved Solids, mg/l	47	153.5	79	110.5	48	76.5	47.5	31	35.5	62	94	40
	Total hardness as $CaCO_3$, mg/l	19	47	24	55	30	42.5	16.5	26	18.5	25.5	30	15
	Turbidity NTU	0.56	1.03	1.77	1.04	0.4	2.9	1.43	0.32	1.32	0.81	1.23	0.4
	Velocity, m/s	0.037	0.045	0.042	0.051	0.161	0.133	0.237	0.21	0.167	0.167	0.074	0.07
	Cross sectional area, m^2	416	272	226	186	202	1183	1214	793	979	882	795	442
Calculated	DO saturation, %	70.9	94	97.7	96.9	95.5	86.4	90	87.3	86.8	90.4	91.7	96.3
	FC-TC ratio	0.32	0.17	0.5	0.3	0.57	0.16	0.08	0.16	0.17	0.1	0.07	0.27
	Flow rate, m^3/s	15.295	12.255	9.595	9.5	32.585	156.845	287.47	166.44	163.21	147.25	58.71	30.875
	Saturation DO, mg/l	7.9	7.98	7.78	7.74	7.53	7.87	7.83	8.17	8.12	7.85	7.96	7.89
	BOD-COD ratio	0.68	0.78	0.63	0.55	0.77	0.29	0.41	0.76	0.89	0.95	0.92	0.63

Table.4.9: Qualitative and quantitative characteristics of surface water at Vettilappara Site during 2015

	Parameters	Jan-15	Feb-15	Mar-15	Apr-15	May-15	Jun-15	Jul-15	Aug-15	Sep-15	Oct-15	Nov-15	Dec-15
Experimental	BOD, mg/l	2.3	2.8	2.8	4.8	3.9	4.5	4.8	2.6	4.9	1.05	4.21	2.67
	Chlorides, mg/l	22	42	21	12.45	24	22.34	57.67	23.45	3.56	1.76	20.45	12.33
	COD, mg/l	3.4	3.6	4.7	5.3	5.6	4.9	7.9	4.4	5.8	3.9	5.2	5.7
	Dissolved Oxygen, mg/l	7.45	6.8	6.85	6.9	6.7	5.8	6.8	6.9	7.1	7.66	7	5.6
	Electrical Conductivity, μmhos/ cm	50	44	219	46	102.43	68	105.65	96.09	109	34	67.6	46
	Fecal coliform CFU/100ml	80	60	80	60	40	90	140	100	90	140	210	230
	Nitrates mg/l	0.52	0.36	0.02	1.06	4.8	0.38	0.78	1.43	0.45	0.76	0.22	0.78
	pH	7.1	8	6.9	6.5	6.4	6.7	6.8	6.7	7.3	8.1	6.4	6.2
	Phosphates, mg/l	2.3	0.89	0.79	0.65	0.59	0.98	1.43	1.72	0.45	0.86	0.54	0.42
	Sulphates, mg/l	0	0.45	0.78	0.894	2	2.43	2.18	1.43	1.21	0.56	0.66	0.32
	Temperature, °C	27.68	27.24	28.4	29.8	31.2	28.3	28.5	26.5	26.9	28.2	27.1	28.3
	Total Coliform CFU/100ml	570	420	980	520	130	870	1180	220	960	1020	780	550
	Total Dissolved Solids, mg/l	46	81.27	60.3	78.67	87.45	112.23	102.2	95.67	78.8	85.6	89.77	93.5
	Total hardness as $CaCO_3$, mg/l	18	87	79.3	40.88	67.56	43.67	172	76.55	32	37.54	39.3	56.56
	Turbidity NTU	1.2	3.01	0.5	0.77	2.5	0.4	0.44	0.36	1.03	1.43	4.85	2.05
	Velocity, m/s	0.044	0.041	0.047	0.074	0.139	0.165	0.287	0.089	0.056	0.083	0.062	0.076
	Cross sectional area, m^2	407	302	232	194	236	1772	1344	1843	1500	870	839	441
Calculated	DO saturation, %	94.7	85.8	88.2	91	90.5	74.6	87.7	85.9	89	98.3	88.1	72
	FC-TC ratio	0.14	0.14	0.08	0.12	0.31	0.1	0.12	0.45	0.09	0.14	0.27	0.42
	Flow rate, m^3/s	17.86	12.255	10.925	14.345	32.87	291.555	385.605	163.115	83.505	71.915	51.965	33.725
	Saturation DO, mg/l	7.87	7.93	7.77	7.58	7.4	7.78	7.75	8.03	7.98	7.79	7.95	7.78
	BOD-COD ratio	0.68	0.78	0.6	0.91	0.7	0.92	0.61	0.59	0.84	0.27	0.81	0.47

Table 4.10: Qualitative and quantitative characteristics of surface water at Vettilappara Site during 2016

	Parameters	Jan-16	Feb-16	Mar-16	Apr-16	May-16	Jun-16	Jul-16	Aug-16	Sep-16	Oct-16	Nov-16	Dec-16
Experimental	BOD, mg/l	4.6	3.43	1.5	2.33	2.7	6.1	4.4	2.8	3.9	0.55	2.3	1.3
	Chlorides, mg/l	17.34	21	12.45	24	22.34	57.67	23.45	3.56	1.76	20.45	12.33	17.34
	COD, mg/l	4.9	4.7	5.3	3.9	4.9	7.9	5.3	5.8	5.3	4.21	2.67	4.6
	Dissolved Oxygen, mg/l	7.2	6.9	7.5	7.29	5.8	6.9	7.57	7.62	6.2	7	6	6.8
	Electrical Conductivity, μmhos/ cm	54	73.77	46	102.43	68	105.65	96.09	109	34	67.6	46	54
	Fecal coliform CFU/100ml	90	70	130	90	210	230	150	100	90	140	330	100
	Nitrates mg/l	0.33	0.67	1.06	1.53	0.38	0.78	1.43	0.45	0.76	0.78	1.07	2.7
	pH	6.4	6.8	6.5	6.4	6.7	6.8	6.7	7.3	8.1	6.4	6.2	6.4
	Phosphates, mg/l	0.46	0.77	0.65	0.59	0.98	1.43	1.72	0.45	0.86	0.54	0.42	0.46
	Sulphates, mg/l	1.04	1.09	0.894	2	2.43	2.18	1.43	1.21	0.56	0.66	0.32	1.04
	Temperature, °C	28.4	26.7	28.4	31	31.2	29.2	28.6	27	26.4	28.5	27.8	28.5
	Total Coliform CFU/100ml	1210	930	540	380	860	790	290	610	660	700	570	510
	Total Dissolved Solids, mg/l	90.7	126	78.67	87.45	112.23	102.2	95.67	78.8	85.6	89.77	93.5	90.7
	Total hardness as $CaCO_3$, mg/l	32	49.78	40.88	67.56	43.67	172	76.55	32	37.54	39.3	56.56	32
	Turbidity NTU	1.4	2.78	2.08	1.2	3.01	0.81	1.23	0.4	1.2	3.01	0.8	0.92
	Velocity, m/s	0.055	0.011	0.006	0.009	0.013	0.121	0.169	0.093	0.136	0.027	0.017	0.017
	Cross sectional area, m^2	516	836	761	518	1335	1669	1495	1338	959	1501	1467	494
Calculated	DO saturation, %	92.7	86.3	96.5	98.2	78.4	90.1	97.8	95.7	77	90.3	76.4	87.7
	FC-TC ratio	0.07	0.08	0.24	0.24	0.24	0.29	0.52	0.16	0.14	0.2	0.58	0.2
	Flow rate, m^3/s	28.215	9.405	4.56	4.465	16.91	202.35	252.51	124.355	129.96	40.375	24.51	8.55
	Saturation DO, mg/l	7.77	8	7.77	7.42	7.4	7.66	7.74	7.96	8.05	7.75	7.85	7.75
	BOD-COD ratio	0.94	0.73	0.28	0.6	0.55	0.77	0.83	0.48	0.74	0.13	0.86	0.28

Table 4.11: Qualitative and quantitative characteristics of Vettilappara Site during 2017

	Parameters	Jan-17	Feb-17	Mar-17	Apr-17	May-17	Jun-17	Jul-17	Aug-17	Sep-17	Oct-17	Nov-17	Dec-17
Experimental	BOD, mg/l	2.8	4.7	5.3	3.9	2.05	5.2	4.4	0.78	0.54	1.34	2.67	2.8
	Chlorides, mg/l	42	21	12.45	24	22.34	57.67	23.45	30.56	19.5	24.7	16.39	17.34
	COD, mg/l	4.4	6.2	5.6	5.9	4.9	7.9	4.5	5.8	3.9	4.21	2.9	4.6
	Dissolved Oxygen, mg/l	6.7	6.6	7	6.9	5.8	7.3	7.26	7.54	7.73	6.2	6.5	6.8
	Electrical Conductivity, μmhos/ cm	44	219	46	102.43	68	105.65	96.09	109	34	67.6	46	54
	Fecal coliform CFU/100ml	150	280	120	300	130	140	160	160	270	200	290	130
	Nitrates mg/l	1.2	0.25	1.37	0.08	1.21	0.87	1.31	0.34	0.22	1.08	0.94	0.76
	pH	8	6.9	6.5	6.4	6.7	6.8	6.7	7.3	8.1	6.8	6.7	6.5
	Phosphates, mg/l	0.89	0.79	0.65	0.59	0.98	1.43	1.72	0.45	0.86	1.76	0.48	0.46
	Sulphates, mg/l	0.45	0.78	0.894	2	2.43	2.18	1.43	1.21	0.56	0.66	0.32	1.04
	Temperature, °C	28.4	27.6	28.8	31.9	32	29.1	29.8	27.5	26.78	27.43	29.2	26.8
	Total Coliform CFU/100ml	700	590	140	490	340	400	330	650	400	790	300	610
	Total Dissolved Solids, mg/l	81.27	60.3	78.67	87.45	112.23	102.2	95.67	78.8	85.6	106.56	91.635	90.7
	Total hardness as $CaCO_3$, mg/l	87	79.3	40.88	67.56	43.67	172	76.55	32	37.54	53.24	47.93	32
	Turbidity NTU	4.03	0.4	0.67	2.5	0.4	0.44	0.36	1.03	1.43	4.85	2.05	3.55
	Velocity, m/s	0.006	0.033	0.033	0.048	0.07	0.402	0.13	0.123	0.066	0.061	0.044	0.026
	Cross sectional area, m^2	411	169	254	214	235	759	1271	1128	1181	1258	1427	1253
Calculated	DO saturation, %	86.2	83.8	90.8	94.4	79.5	95.2	95.8	95.6	96.7	78.5	84.9	85.1
	FC-TC ratio	0.21	0.47	0.86	0.61	0.38	0.35	0.48	0.25	0.68	0.25	0.97	0.21
	Flow rate, m^3/s	2.66	5.51	8.36	10.355	16.435	304.76	164.92	138.415	78.47	76.38	63.46	32.965
	Saturation DO, mg/l	7.77	7.88	7.71	7.31	7.3	7.67	7.58	7.89	7.99	7.9	7.66	7.99
	BOD-COD ratio	0.64	0.76	0.95	0.66	0.42	0.66	0.98	0.13	0.14	0.32	0.92	0.61

Table 4.12: Qualitative and quantitative characteristics of surface water at Vettilappara Site during 2018

	Parameters	Jan-18	Feb-18	Mar-18	Apr-18	May-18	Sep-18	Oct-18
Experimental	BOD, mg/l	2.8	4.7	4.1	3.9	4.23	1.8	1.8
	Chlorides, mg/l	42	21	12.45	24	22.34	60.44	64
	COD, mg/l	3.34	5.3	5.3	4.9	4.9	4.58	1.93
	Dissolved Oxygen, mg/l	6.8	6.7	5.6	7.3	5.8	6.3	6.8
	Electrical Conductivity, µmhos/cm	44	219	46	102.43	68	200.4	96.8
	Fecal coliform CFU/100ml	180	60	120	90	280	1100	750
	Nitrates mg/l	1.2	0.25	1.37	0.08	1.21	2.94	1.06
	pH	8	6.9	6.5	6.4	6.5	6.8	6.9
	Phosphates, mg/l	0.89	0.79	0.65	2.7	3.18	2.18	1.02
	Sulphates, mg/l	1.7	0.78	0.894	2	2.43	1.95	1.42
	Temperature, °C	29.2	29.5	30.2	30.5	30.8	28.3	29.9
	Total Coliform CFU/100ml	630	450	490	420	900	2100	1400
	Total Dissolved Solids, mg/l	95	120	116.9	190.43	186	180	110.6
	Total hardness as $CaCO_3$, mg/l	112	94	107.88	67.56	84.33	107.8	73.5
	Turbidity NTU	0.8	0.92	4.03	0.4	2.23	3	2.3
	Velocity, m/s	0.007	0.024	0.034	0.052	0.053	0.067	0.073
	Cross sectional area, m^2	366	178	218	188	153	1049	1133
Calculated	DO saturation, %	88.8	87.9	74.4	97.5	77.9	81	89.8
	FC-TC ratio	0.29	0.13	0.24	0.21	0.31	0.52	0.54
	Flow rate, m^3/s	2.66	4.275	7.41	9.69	8.17	70.205	82.27
	Saturation DO, mg/l	7.66	7.62	7.53	7.49	7.45	7.78	7.57
	BOD-COD ratio	0.84	0.89	0.77	0.8	0.86	0.39	0.93

Table 4.13: Qualitative and quantitative characteristics of Kanjirappilly Site during 2013

	Parameters	Nov-13	Dec-13
Experimental	BOD, mg/l	2.4	3.8
	Chlorides, mg/l	14	14
	COD, mg/l	6.4	5.6
	Dissolved Oxygen, mg/l	6.4	6.4
	Electrical Conductivity, µmhos/cm	80	80
	Fecal coliform CFU/100ml	100	280
	Nitrates mg/l	0.63	0.52
	pH	6.9	7.1
	Phosphates, mg/l	1.07	0.2
	Sulphates, mg/l	0.088	0
	Temperature, °C	27	28.2
	Total Coliform CFU/100ml	610	1300
	Total Dissolved Solids, mg/l	50	48
	Total hardness as $CaCO_3$, mg/l	20	24
	Turbidity NTU	0.1	0.8
	Velocity, m/s	0.085	0.05
	Cross sectional area, m^2	602	365
Calculated	DO saturation, %	80.4	82.2
	FC-TC ratio	0.16	0.22
	Flow rate, m^3/s	51.3	18.24
	Saturation DO, mg/l	7.96	7.79
	BOD-COD ratio	0.38	0.68

Table 4.14: Qualitative and quantitative characteristics of surface water at Kanjirappilly Site during 2014

	Parameters	Jan-14	Feb-14	Mar-14	Apr-14	May-14	Jun-14	Jul-14	Aug-14	Sep-14	Oct-14	Nov-14	Dec-14
Experimental	BOD, mg/l	0.9	0.9	2.8	2.7	4.6	3.2	2.6	3.2	2.06	1.33	1.5	1.8
	Chlorides, mg/l	12	54	121	54	52	84	22	50	8	68	25	29
	COD, mg/l	3.2	3.2	4.6	4.78	6.2	3.6	2.9	3.2	3.2	3.2	3	3.8
	Dissolved Oxygen, mg/l	5.6	7.5	7.6	7.74	7.2	7.5	7.3	7.85	6.9	7.85	7.6	7.1
	Electrical Conductivity, µmhos/ cm	58	30	240	190	102	136	56	169	43	68	36	80
	Fecal coliform CFU/100ml	170	120	180	200	230	260	110	120	160	80	170	210
	Nitrates mg/l	0.42	0.73	0.55	0.6	0.26	0.14	0.11	0.43	1.43	0.38	0.74	0.52
	pH	7.4	7.4	6.8	7.1	6.8	6.7	7.3	7	6.8	6.5	7.5	7.1
	Phosphates, mg/l	0	1.5	0	0	0	0.3	0	0.1	0.1	0	0	0.2
	Sulphates, mg/l	0	0	0	1.8	1.2	0.3	0	4	4	3.6	0	0
	Temperature, ^{o}C	27.5	27	28.5	29	30.6	28.4	28.3	26	26.4	28.2	27.5	27.9
	Total Coliform CFU/100ml	260	840	860	870	540	1060	900	510	970	520	680	1320
	Total Dissolved Solids, mg/l	80	140	143	125	320	125	40	106	38	110	45	61
	Total hardness as $CaCO_3$, mg/l	62	16	45	68	32	56	20	12	37	32	24	32
	Turbidity NTU	0.23	0.97	4.6	2.2	1.8	1.9	1.1	1.05	0.67	0.86	0.43	0.4
	Velocity, m/s	0.032	0.033	0.059	0.054	0.16	0.276	0.264	0.144	0.201	0.141	0.082	0.082
	Cross sectional area, m2	366	253	194	173	190	1017	1068	1080	843	1048	700	376
Calculated	DO saturation, %	71	94.2	98.1	100	96.4	96.5	93.8	96.8	85.7	100	96.3	90.7
	FC-TC ratio	0.65	0.14	0.21	0.23	0.43	0.25	0.12	0.24	0.16	0.15	0.25	0.16
	Flow rate, m^3/s	11.59	8.455	11.4	9.405	30.4	280.44	282.245	155.04	169.29	147.25	57.475	30.78
	Saturation DO, mg/l	7.89	7.96	7.75	7.68	7.47	7.77	7.78	8.11	8.05	7.79	7.89	7.83
	BOD-COD ratio	0.28	0.28	0.61	0.56	0.74	0.89	0.9	1	0.64	0.42	0.5	0.47

Table 4.15 Qualitative and quantitative characteristics of surface water at Kanjirappilly Site during 2015

	Parameters	Jan-15	Feb-15	Mar-15	Apr-15	May-15	Jun-15	Jul-15	Aug-15	Sep-15	Oct-15	Nov-15	Dec-15
Experimental	BOD, mg/l	2.8	2.8	3.8	1.43	1.24	1.89	3.7	4	2.33	2.66	2.7	3.4
	Chlorides, mg/l	24	8	12	34.5	25.45	15.76	27.66	22	25	25	16.66	18.4
	COD, mg/l	3.2	2.8	4.6	1.78	5.3	4.9	4.5	4.3	2.8	4.2	5.1	4.9
	Dissolved Oxygen, mg/l	7.5	6.8	6.9	7.5	6.5	5.8	7.3	7.2	7.3	7.79	7	6.9
	Electrical Conductivity, µmhos/ cm	68	68	59.66	106	62.33	65	48	45.7	56	28	35.22	106
	Fecal coliform CFU/100ml	130	70	130	70	110	200	140	270	260	140	270	230
	Nitrates mg/l	0.38	0.38	0.75	0.03	0.23	1.23	1.04	0.23	0.63	0.76	0.87	0.12
	pH	6.5	6.5	6.9	7.2	7.2	7.3	7.2	7.8	7.4	7.2	7.3	7.2
	Phosphates, mg/l	0.2	0	0.04	0.07	0.05	0.13	0.12	0.34	0.54	0.03	0.56	0.67
	Sulphates, mg/l	0	0	0.067	0.094	0.27	0.54	0.77	0.56	0.72	0.67	0.34	0.53
	Temperature, °C	28.3	27.6	28.7	30.2	31.45	28.7	29.2	27.2	27.4	28.8	27.5	28.5
	Total Coliform CFU/100ml	960	490	860	590	750	870	740	420	750	250	900	780
	Total Dissolved Solids, mg/l	79.66	93.24	56.4	47.4	52.3	40.8	51.2	47.8	45	58.5	50.2	35.3
	Total hardness as $CaCO_3$, mg/l	32	32	37.6	29.56	18.88	28.3	63.3	46.67	20	18.6	31.3	29.56
	Turbidity NTU	2.01	1.32	2.07	0.35	1.22	1.74	1.5	0.81	0.51	1.32	1.05	2.05
	Velocity, m/s	0.046	0.065	0.051	0.084	0.15	0.248	0.269	0.091	0.065	0.088	0.07	0.082
	Cross sectional area, m^2	383	278	216	171	219	1503	1142	1690	1290	818	738	410
Calculated	DO saturation, %	96.4	86.3	89.3	99.6	88.2	75	95.3	90.8	92.4	100	88.7	89
	FC-TC ratio	0.14	0.14	0.15	0.12	0.15	0.23	0.19	0.64	0.35	0.56	0.3	0.29
	Flow rate, m^3/s	17.765	17.955	10.925	14.345	32.87	372.305	307.42	154.565	83.505	71.915	51.965	33.725
	Saturation DO, mg/l	7.78	7.88	7.73	7.53	7.37	7.73	7.66	7.93	7.9	7.71	7.89	7.75
	BOD-COD ratio	0.88	1	0.83	0.8	0.23	0.39	0.82	0.93	0.83	0.63	0.53	0.69

Table 4.16: Qualitative and quantitative characteristics of surface water at Kanjirappilly Site during 2016

	Parameters	Jan-16	Feb-16	Mar-16	Apr-16	May-16	Jun-16	Jul-16	Aug-16	Sep-16	Oct-16	Nov-16	Dec-16
Experimental	BOD, mg/l	1.2	1.33	2.4	0.67	0.87	1.33	2.9	2.9	3.6	2.4	0.89	1.6
	Chlorides, mg/l	0.16	32	12	1.43	25.45	15.76	27.66	22	25	25	16.66	8.4
	COD, mg/l	3.8	1.98	2.8	2.9	0.89	2.8	3.44	3	4.1	2.8	2.9	3.02
	Dissolved Oxygen, mg/l	7.06	6.9	7.5	7.3	5.8	6.9	7.5	7.2	7.3	7	6	6.8
	Electrical Conductivity, μmhos/ cm	6.2	54	59.66	106	62.33	65	48	45.7	56	28	35.22	106
	Fecal coliform CFU/100ml	90	340	260	150	140	330	100	120	260	330	180	130
	Nitrates mg/l	0.23	0.03	0.23	1.23	1.04	0.23	0.63	0.76	0.87	0.12	0.89	0.77
	pH	4.2	7.2	6.9	7.2	7.2	7.3	7.2	7.8	7.4	7.2	7.3	7.2
	Phosphates, mg/l	0.32	0.22	0.04	0.07	0.05	0.13	0.12	0.34	0.54	0.03	0.56	0.67
	Sulphates, mg/l	0.44	0.07	0.067	0.094	0.27	0.54	0.77	0.56	0.72	0.67	0.34	0.53
	Temperature, °C	28.7	27.3	28.9	31.4	32.8	30.7	29.8	28.3	28.6	28.8	28.3	29
	Total Coliform CFU/100ml	150	1430	730	560	720	500	400	560	560	520	560	320
	Total Dissolved Solids, mg/l	32.4	65	56.4	47.4	52.3	40.8	51.2	47.8	45	58.5	50.2	35.3
	Total hardness as $CaCO_3$, mg/l	7.6	33	37.6	29.56	18.88	28.3	63.3	46.67	20	18.6	31.3	29.56
	Turbidity NTU	0.66	1.5	2.06	2.01	1.32	1.05	0.43	0.4	2.01	1.32	1.05	0.4
	Velocity, m/s	0.063	0.014	0.007	0.01	0.011	0.138	0.19	0.1	0.144	0.034	0.013	0.019
	Cross sectional area, m^2	449	736	677	466	1148	1469	1331	1244	815	1241	1243	454
Calculated	DO saturation, %	91.3	87.1	97.4	99.1	80.6	92.5	98.9	92.5	94.3	90.8	77.1	88.5
	FC-TC ratio	0.6	0.24	0.36	0.27	0.19	0.66	0.25	0.21	0.46	0.63	0.32	0.41
	Flow rate, m^3/s	28.215	10.165	4.56	4.465	13.015	202.35	252.51	124.355	117.515	41.99	15.675	8.74
	Saturation DO, mg/l	7.73	7.92	7.7	7.37	7.2	7.46	7.58	7.78	7.74	7.71	7.78	7.68
	BOD-COD ratio	0.32	0.67	0.86	0.23	0.98	0.48	0.84	0.97	0.88	0.86	0.31	0.53

Table 4.17: Qualitative and quantitative characteristics of surface water at Kanjirappilly Site during 2017

	Parameters	Jan-17	Feb-17	Mar-17	Apr-17	May-17	Jun-17	Jul-17	Aug-17	Sep-17	Oct-17	Nov-17	Dec-17
Experimental	BOD, mg/l	2.45	1.8	1.33	1.78	2.06	2.1	2.06	1.7	0.6	1.2	1.4	0.45
	Chlorides, mg/l	32	32	12	1.43	25.45	15.76	27.66	22	25	25	16.66	8.4
	COD, mg/l	2.9	1.98	4.3	2.7	4.1	3.3	3.2	2.8	3.1	3.6	2.9	3.9
	Dissolved Oxygen, mg/l	6.8	6.9	7.5	7.3	5.8	6.9	7.5	7.2	7.3	7.3	6.5	6.8
	Electrical Conductivity, μmhos/ cm	62	54	59.66	106	62.33	65	48	45.7	56	28	35.22	106
	Fecal coliform CFU/100ml	140	90	140	140	380	140	120	130	140	230	140	380
	Nitrates mg/l	1.22	0.52	0.1	0.56	0.06	0.55	0.04	0.04	0.26	0.14	0.12	0.12
	pH	7.6	7.2	6.9	7.2	7.2	7.3	7.2	7.8	7.4	7.2	7.3	7.2
	Phosphates, mg/l	0.24	0.22	0.04	0.07	0.05	0.13	0.12	0.34	0.54	0.03	0.56	0.67
	Sulphates, mg/l	0.44	0.07	0.067	0.094	0.27	0.54	0.77	0.56	0.72	0.67	0.34	0.53
	Temperature, °C	29.2	28.3	29.3	32.1	32.8	30.2	30.6	28.9	27.7	28.5	29.7	27.4
	Total Coliform CFU/100ml	720	570	890	590	800	430	420	490	340	400	400	560
	Total Dissolved Solids, mg/l	44.25	65	56.4	47.4	52.3	40.8	51.2	47.8	45	58.5	50.2	35.3
	Total hardness as $CaCO^3$, mg/l	20	33	37.6	29.56	18.88	28.3	63.3	46.67	20	18.6	31.3	29.56
	Turbidity NTU	0.32	6.5	1.05	3.67	1.74	1.5	0.81	0.51	1.32	1.05	2.05	0.66
	Velocity, m/s	0.023	0.038	0.037	0.061	0.081	0.25	0.138	0.132	0.075	0.071	0.054	0.029
	Cross sectional area, m^2	353	144	226	193	212	1143	1144	1049	1040	1082	1241	1128
Calculated	DO saturation, %	88.8	88.7	98.2	100	80.6	91.6	100	93.5	92.9	94.2	85.6	86.1
	FC-TC ratio	0.19	0.16	0.16	0.24	0.48	0.33	0.29	0.27	0.41	0.58	0.35	0.68
	Flow rate, m^3/s	8.265	5.51	8.455	11.78	17.1	285.57	157.415	138.415	78.09	76.38	67.07	33.06
	Saturation DO, mg/l	7.66	7.78	7.64	7.29	7.2	7.53	7.47	7.7	7.86	7.75	7.59	7.9
	BOD-COD ratio	0.84	0.91	0.31	0.66	0.5	0.64	0.64	0.61	0.19	0.33	0.48	0.12

Table 4.18: Qualitative and quantitative characteristics of surface water at Kanjirappilly Site during 2018

	Parameters	Jan-18	Feb-18	Mar-18	Apr-18	May-18	Sep-18	Oct-18
Experimental	BOD, mg/l	1.76	1.98	4.6	1.78	5.39	3	1.92
	Chlorides, mg/l	35.55	32	12	1.43	25.45	110	94
	COD, mg/l	3.98	4.33	4.78	5.67	5.4	4.4	2.7
	Dissolved Oxygen, mg/l	6.5	6.9	7.5	6.85	5.8	6.4	6.8
	Electrical Conductivity, μmhos/cm	6.3	54	59.66	106	62.33	267.8	218
	Fecal coliform CFU/100ml	210	230	210	220	130	1300	1000
	Nitrates mg/l	0.21	0.52	0.1	0.56	0.06	1.65	1.04
	pH	6.8	7.2	6.9	7.2	6.9	6.7	6.9
	Phosphates, mg/l	0.65	0.22	0.04	0.07	0.05	2.51	0.69
	Sulphates, mg/l	0.13	0.87	0.067	0.094	0.27	1.88	0.7
	Temperature, °C	30.1	30.2	30.5	30.6	31	29	30.5
	Total Coliform CFU/100ml	560	1010	1200	510	530	2600	1700
	Total Dissolved Solids, mg/l	172.84	65	56.4	47.4	52.3	260	210
	Total hardness as $CaCO_3$, mg/l	6.9	33	37.6	29.56	18.88	158	139
	Turbidity NTU	3.05	0.4	0.32	3.26	5.4	4.78	2.7
	Velocity, m/s	0.014	0.031	0.042	0.063	0.018	0.08	0.082
	Cross sectional area, m^2	326	155	205	165	831	986	1031
Calculated	DO saturation, %	86.2	91.6	100	91.7	78.2	83.3	90.8
	FC-TC ratio	0.38	0.23	0.18	0.43	0.25	0.5	0.59
	Flow rate, m^3/s	4.56	4.75	8.55	10.355	15.2	79.23	84.93
	Saturation DO, mg/l	7.54	7.53	7.49	7.47	7.42	7.68	7.49
	BOD-COD ratio	0.44	0.46	0.96	0.31	1	0.68	0.71

Table 4.19: Qualitative and quantitative characteristics of surface water at Pariyaram Site during 2013

	Parameters	Nov-13	Dec-13
Experimental	BOD, mg/l	1.9	3.8
	Chlorides, mg/l	19	14
	COD, mg/l	3.2	5.6
	Dissolved Oxygen, mg/l	7.92	6.4
	Electrical Conductivity, µmhos/cm	62	80
	Fecal coliform CFU/100ml	160	120
	Nitrates mg/l	0.75	0.52
	pH	7.5	7.1
	Phosphates, mg/l	0	0.2
	Sulphates, mg/l	0	0
	Temperature, ^{o}C	27.3	28.5
	Total Coliform CFU/100ml	920	560
	Total Dissolved Solids, mg/l	48	48
	Total hardness as $CaCO_3$, mg/l	12	24
	Turbidity NTU	0.3	0.8
	Velocity, m/s	0.086	0.035
	Cross sectional area, m2	560	343
Calculated	DO saturation, %	100	82.6
	FC-TC ratio	0.17	0.21
	Flow rate, m^3/s	47.9	12.1
	Saturation DO, mg/l	7.92	7.75
	BOD-COD ratio	0.59	0.68

Table 4.20: Qualitative and quantitative characteristics of surface water at Pariyaram site during 2014

	Parameters	Jan-14	Feb-14	Mar-14	Apr-14	May-14	Jun-14	Jul-14	Aug-14	Sep-14	Oct-14	Nov-14	Dec-14
Experimental	BOD, mg/l	0.9	0.9	2.8	2.7	1.8	3.2	1.45	3.2	3.2	1.9	1.5	1.8
	Chlorides, mg/l	12	54	121	54	52	84	22	50	8	68	25	29
	COD, mg/l	3.2	3.2	4.6	4.78	4.6	5.8	2.6	3.2	3.2	3.2	3	3.8
	Dissolved Oxygen, mg/l	7.85	7.9	7.6	7.64	7.2	7.5	7.3	7.99	6.9	7.77	7.88	7.1
	Electrical Conductivity, µmhos/cm	58	30	240	190	102	136	56	169	43	68	36	80
	Fecal coliform CFU/100ml	170	160	120	140	180	120	100	200	110	100	180	180
	Nitrates mg/l	0.42	0.73	0.55	0.6	0.26	0.14	0.11	0.43	0.43	0.38	0.74	0.52
	pH	7.4	7.4	6.8	7.1	6.8	6.7	7.3	7	6.8	6.5	7.5	7.1
	Phosphates, mg/l	0	1.5	0	0	0	0.3	0	0.1	0.1	0	0	0.2
	Sulphates, mg/l	0	0	0	1.8	1.2	0.3	0	4	4	3.6	0	0.8
	Temperature, °C	27.8	27.4	28.8	29.4	31.1	29	29.2	26.8	27.2	28.4	27.6	28
	Total Coliform CFU/100ml	390	900	480	760	680	1160	860	490	1100	960	690	1450
	Total Dissolved Solids, mg/l	80	140	143	125	320	125	40	106	38	110	45	61
	Total hardness as $CaCO_3$, mg/l	62	16	45	68	32	56	20	12	12	32	24	32
	Turbidity NTU	0.33	0.9	1.32	1.44	1.5	3.14	1.8	1.43	1.03	1.89	0.36	1.5
	Velocity, m/s	0.03	0.05	0.034	0.025	0.117	0.17	0.294	0.158	0.175	0.115	0.082	0.041
	Cross sectional area, m^2	311	238	182	163	163	875	961	960	777	944	623	320
Calculated	DO saturation, %	100	100	98.6	100	97.2	97.7	95.3	100	87	100	100	90.8
	FC-TC ratio	0.44	0.18	0.25	0.18	0.26	0.1	0.12	0.41	0.1	0.1	0.26	0.12
	Flow rate, m^3/s	9.2	12	6.1	4.1	19	148.5	282.2	151.5	136.2	108.6	51.3	13.1
	Saturation DO, mg/l	7.85	7.9	7.71	7.63	7.41	7.68	7.66	7.99	7.93	7.77	7.88	7.82
	BOD-COD ratio	0.28	0.28	0.61	0.56	0.39	0.55	0.56	1	1	0.59	0.5	0.47

Table 4.21: Qualitative and quantitative characteristics of surface water at Pariyaram Site during 2015

	Parameters	Jan-15	Feb-15	Mar-15	Apr-15	May-15	Jun-15	Jul-15	Aug-15	Sep-15	Oct-15	Nov-15	Dec-15
Experimental	BOD, mg/l	3.66	5.4	1.76	2.12	2.9	2.8	3.2	4.67	2.07	4.8	3.8	3.8
	Chlorides, mg/l	42.25	15.45	36	20.67	7.9	1.67	38.56	28.24	12.66	17	19.45	31.22
	COD, mg/l	4.3	5.4	5.4	3.2	4.1	4.2	6.6	5.8	7.8	4.8	4.5	9
	Dissolved Oxygen, mg/l	7.5	6.9	7.7	7.46	7.32	7.3	6.9	7.1	6.9	7.6	6.9	7.75
	Electrical Conductivity, μmhos/ cm	60.33	76.5	203	56.7	70	89.45	66.7	59	87	87	89	56
	Fecal coliform CFU/100ml	80	410	80	340	210	70	100	120	230	100	120	120
	Nitrates mg/l	0.78	1.07	1.85	0.35	0.98	1.34	1.34	0.22	0.55	0.59	0.79	0.45
	pH	7.1	7.2	7	6.5	7.1	7	7.2	7.5	7.5	7.3	6.9	8.1
	Phosphates, mg/l	0.89	0.02	1.3	1.3	1.3	0.09	1.15	1.03	0.76	0.34	0.66	0.91
	Sulphates, mg/l	0.07	0.078	0.86	0.89	0.67	1.34	2.67	1.54	0.67	0.8	0.234	0.14
	Temperature, °C	28.4	27.9	28.9	30.8	31.9	29	27	27.7	27.6	29.3	27.8	28.5
	Total Coliform CFU/100ml	750	1100	160	410	620	600	1000	360	320	650	830	200
	Total Dissolved Solids, mg/l	62.66	104.55	89.56	70.54	88.67	89.3	75.45	64.45	68.9	69.5	62.1	83.3
	Total hardness as CaCO3, mg/l	64	76	59	53.77	71.3	72.24	92.6	89	65.45	87	89.67	60.33
	Turbidity NTU	2.06	3.04	3.18	5.9	1.05	1.05	0.4	0.22	0.9	2.03	1.43	1.05
	Velocity, m/s	0.03	0.046	0.03	0.033	0.112	0.185	0.379	0.097	0.062	0.078	0.081	0.093
	Cross sectional area, m^2	337	259	197	152	188	1569	1051	1572	1187	769	642	353
Calculated	DO saturation, %	96.5	88.1	100	100	100	95.1	86.7	90.3	87.6	99.5	87.9	100
	FC-TC ratio	0.11	0.37	0.5	0.83	0.34	0.12	0.1	0.33	0.72	0.15	0.14	0.6
	Flow rate, m^3/s	10	12	6	5	21	289.9	397.9	151.8	73.1	60.2	52.2	32.8
	Saturation DO, mg/l	7.77	7.83	7.7	7.45	7.31	7.68	7.96	7.86	7.88	7.64	7.85	7.75
	BOD-COD ratio	0.85	1	0.33	0.66	0.71	0.67	0.48	0.81	0.27	1	0.84	0.42

Table 4.22: Qualitative and quantitative characteristics of surface water at Pariyaram Site during 2016

	Parameters	Jan-16	Feb-16	Mar-16	Apr-16	May-16	Jun-16	Jul-16	Aug-16	Sep-16	Oct-16	Nov-16	Dec-16
Experimental	BOD, mg/l	3.67	2.56	2.9	1.33	2.3	2.56	4.3	2.7	3.2	1.7	2.4	1.2
	Chlorides, mg/l	42.25	15.45	36	20.67	7.9	1.67	38.56	28.24	12.66	17	19.45	31.22
	COD, mg/l	4.3	5.4	5.4	3.2	2.9	2.8	6.6	5.8	7.8	4.8	3.8	9
	Dissolved Oxygen, mg/l	7.5	6.9	7.68	7.37	7.27	7.3	6.9	7.1	6.9	7.6	6.7	7.66
	Electrical Conductivity, μmhos/ cm	60.33	76.5	203	56.7	70	89.45	66.7	59	87	87	89	56
	Fecal coliform CFU/100ml	70	140	230	150	120	120	130	120	230	100	210	130
	Nitrates mg/l	1.85	0.35	0.98	1.34	1.34	0.22	0.55	0.59	0.79	0.45	0.65	1.7
	pH	7.1	7.2	7	6.5	7.1	7	7.2	7.5	7.5	7.3	6.9	8.1
	Phosphates, mg/l	0.89	0.02	1.3	1.3	1.3	0.09	1.15	1.03	0.76	0.34	0.66	0.91
	Sulphates, mg/l	0.07	0.078	0.86	0.89	0.67	1.34	2.67	1.54	0.67	0.8	0.234	0.14
	Temperature, °C	28.8	27.5	29.1	31.5	32.3	31	30	29.2	29	29.4	29.5	29.2
	Total Coliform CFU/100ml	550	670	940	300	420	700	900	390	510	540	280	480
	Total Dissolved Solids, mg/l	62.66	58.67	89.56	70.54	88.67	89.3	75.45	64.45	68.9	69.5	62.1	83.3
	Total hardness as $CaCO_3$, mg/l	64	76	59	53.77	71.3	72.24	92.6	89	65.45	87	89.67	60.33
	Turbidity NTU	2.43	0.4	0.33	2.06	3.04	1.89	0.36	1.5	2.06	3.04	0.5	5.3
	Velocity, m/s	0.048	0.008	0.006	0.012	0.008	0.275	0.167	0.089	0.113	0.015	0.013	0.022
	Cross sectional area, m^2	400	633	575	429	1010	1293	1225	1057	733	1638	1229	404
Calculated	DO saturation, %	97.3	87.5	100	100	100	98.4	91.4	92.7	89.8	99.6	87.9	100
	FC-TC ratio	0.13	0.21	0.24	0.5	0.29	0.17	0.14	0.31	0.45	0.19	0.75	0.27
	Flow rate, m^3/s	19	4.8	3.7	5.1	7.9	356	204.2	94.2	82.5	25.3	16.5	9
	Saturation DO, mg/l	7.71	7.89	7.67	7.36	7.26	7.42	7.55	7.66	7.68	7.63	7.62	7.66
	BOD-COD ratio	0.85	0.47	0.54	0.42	0.79	0.91	0.65	0.47	0.41	0.35	0.63	0.13

Table 4.23: Qualitative and quantitative characteristics of surface water at Pariyaram Site during 2017

	Parameters	Jan-17	Feb-17	Mar-17	Apr-17	May-17	Jun-17	Jul-17	Aug-17	Sep-17	Oct-17	Nov-17	Dec-17
Experimental	BOD, mg/l	4.3	4.3	4.7	3.2	2.9	2.3	5.2	0.67	0.88	2	2.3	2.33
	Chlorides, mg/l	42.25	15.45	36	20.67	46	1.67	38.56	28.24	12.66	21.33	19.45	31.22
	COD, mg/l	4.5	5.4	5.4	4.5	4.5	2.8	6.6	5.8	7.8	4.8	3.8	9
	Dissolved Oxygen, mg/l	7.5	6.9	7.63	7.23	7.19	7.3	6.9	7.1	6.9	6.9	6.85	6.6
	Electrical Conductivity, μmhos/ cm	60.33	76.5	203	56.7	70	89.45	66.7	59	87	87	89	56
	Fecal coliform CFU/100ml	340	260	150	140	330	100	140	230	140	100	140	330
	Nitrates mg/l	0.55	0.04	0.23	0.03	0.23	1.23	1.04	0.23	0.63	0.76	0.87	0.12
	pH	7.1	7.2	7	6.5	7.1	7	7.2	7.5	7.5	7.3	6.9	8.1
	Phosphates, mg/l	0.89	0.02	1.3	1.3	1.3	0.09	1.15	1.03	0.76	0.09	0.66	0.91
	Sulphates, mg/l	0.07	0.078	0.86	0.89	0.67	1.34	2.67	1.54	0.67	0.8	0.234	0.14
	Temperature, °C	29.4	28.6	29.5	32.7	33	31.1	32	29.4	28.2	28.7	30.2	28
	Total Coliform CFU/100ml	730	1510	700	370	650	400	520	340	560	300	900	390
	Total Dissolved Solids, mg/l	62.66	58.67	89.56	70.54	88.67	89.3	75.45	64.45	68.9	89.66	62.1	83.3
	Total hardness as $CaCO_3$, mg/l	64	76	59	53.77	71.3	72.24	92.6	89	65.45	109.56	89.67	60.33
	Turbidity NTU	1.44	1.5	1.43	1.92	1.05	0.4	0.22	0.9	2.03	1.43	1.05	2.43
	Velocity, m/s	0.008	0.015	0.023	0.032	0.074	0.345	0.113	0.106	0.085	0.074	0.046	0.02
	Cross sectional area, m^2	300	127	210	174	191	633	995	934	935	963	1092	1015
Calculated	DO saturation, %	98.3	89.1	100	100	100	98.5	94.5	93.1	88.6	89.3	91	84.4
	FC-TC ratio	0.47	0.17	0.21	0.38	0.51	0.25	0.27	0.68	0.25	0.33	0.16	0.85
	Flow rate, m^3/s	2.3	1.9	4.8	5.5	14.2	218.7	112.4	98.6	79.3	71.2	49.7	20.2
	Saturation DO, mg/l	7.63	7.74	7.62	7.21	7.18	7.41	7.3	7.63	7.79	7.73	7.53	7.82
	BOD-COD ratio	0.96	0.8	0.87	0.71	0.64	0.82	0.79	0.12	0.11	0.42	0.61	0.26

Table 4.24: Qualitative and quantitative characteristics of surface water at Pariyaram Site during 2018

	Parameters	Jan-18	Feb-18	Mar-18	Apr-18	May-18	Sep-18	Oct-18
Experimental	BOD, mg/l	4.1	4.9	4.3	3.2	2.9	3.5	2.34
	Chlorides, mg/l	42.25	15.45	36	20.67	7.9	89	65
	COD, mg/l	4.3	5.4	5.4	3.9	4.7	5.8	3.8
	Dissolved Oxygen, mg/l	7.44	6.9	7.3	7.4	7.34	6.4	6.9
	Electrical Conductivity, μmhos/cm	60.33	76.5	203	56.7	70	280.8	230
	Fecal coliform CFU/100ml	180	130	280	160	100	1400	900
	Nitrates mg/l	0.55	0.04	0.23	0.03	0.23	1.45	0.66
	pH	7.1	7.2	7.1	6.5	7.1	6.7	6.8
	Phosphates, mg/l	0.89	0.02	1.3	1.3	1.2	2.66	0.55
	Sulphates, mg/l	0.07	1	0.86	0.89	0.67	2.33	1.4
	Temperature, °C	31	30.7	30.8	31.3	31.8	29	30
	Total Coliform CFU/100ml	580	820	790	470	370	2800	1600
	Total Dissolved Solids, mg/l	62.66	58.67	78.56	70.54	88.67	230	169
	Total hardness as $CaCO_3$, mg/l	64	76	61	53.77	71.3	162.6	100.6
	Turbidity NTU	0.5	5.3	1.44	1.5	0.78	3.67	2.9
	Velocity, m/s	0.007	0.016	0.023	0.038	0.116	0.094	0.069
	Cross sectional area, m^2	300	141	185	149	121	848	907
Calculated	DO saturation, %	100	92.5	98	100	100	83.3	91.4
	FC-TC ratio	0.31	0.16	0.35	0.34	0.27	0.5	0.56
	Flow rate, m^3/s	2.1	2.2	4.2	5.7	14	79.7	63
	Saturation DO, mg/l	7.42	7.46	7.45	7.39	7.32	7.68	7.55
	BOD-COD ratio	0.95	0.91	0.8	0.82	0.62	0.6	0.62

Table 4.25: Qualitative and quantitative characteristics of surface water at Chalakudy Site during 2013

	Parameters	Nov-13	Dec-13
Experimental	BOD, mg/l	3.84	0.78
	Chlorides, mg/l	20	12
	COD, mg/l	3.9	2.1
	Dissolved Oxygen, mg/l	7.2	7.1
	Electrical Conductivity, µmhos/cm	60	77
	Fecal coliform CFU/100ml	190	600
	Nitrates mg/l	0.8	0.53
	pH	6.8	7
	Phosphates, mg/l	0	0.85
	Sulphates, mg/l	2.95	0.208
	Temperature, °C	27.5	28.9
	Total Coliform CFU/100ml	380	1100
	Total Dissolved Solids, mg/l	87.9	67.54
	Total hardness as CaCO3, mg/l	22	45
	Turbidity NTU	0.2	0.5
	Velocity, m/s	0.053	0.038
	Cross sectional area, m2	843	318
Calculated	DO saturation, %	91.3	92.2
	FC-TC ratio	0.5	0.55
	Flow rate, m^3/s	44.8	12
	Saturation DO, mg/l	7.89	7.7
	BOD-COD ratio	0.98	0.37

Table 4.26: Qualitative and quantitative characteristics of surface water at Chalakudy Site during 2014

	Parameters	Jan-14	Feb-14	Mar-14	Apr-14	May-14	Jun-14	Jul-14	Aug-14	Sep-14	Oct-14	Nov-14	Dec-14
Experimental	BOD, mg/l	1.07	1.2	1.3	4.8	3.2	3.87	1.24	1.8	3.1	1.56	1.9	2.8
	Chlorides, mg/l	42	112	86	62	44	52	14	16	13	30	30	12
	COD, mg/l	3.8	2.8	4.2	5.67	4.9	5.8	3.06	4.11	4.67	4.9	3.65	4.6
	Dissolved Oxygen, mg/l	7.5	7.5	7.1	6.8	6.9	6.7	6.3	7.2	5.8	7.1	7.9	7.6
	Electrical Conductivity, µmhos/ cm	125	380	290	220	95	90	40	56	34	72	70	90
	Fecal coliform CFU/100ml	180	240	200	145	310	210	180	300	290	110	210	270
	Nitrates mg/l	0.44	0.81	0.58	0.52	0.21	0.15	0.16	0.2	0.39	0.28	0.28	0.68
	pH	7	6.6	7.2	7	7	7.8	7.65	7.3	7	7.1	6.8	7.3
	Phosphates, mg/l	2.3	0.6	2.3	0.54	0	0.2	0	0	0	0	0.2	1.2
	Sulphates, mg/l	0.3	0	0	0	0	9	0	0	0	0	0	0.4
	Temperature, °C	28	27.6	28.8	29.4	33	30.4	30	26.8	28	28.4	27.6	28
	Total Coliform CFU/100ml	800	700	340	160	980	890	540	1030	1210	380	1160	1110
	Total Dissolved Solids, mg/l	70	245	190	240	60	55	30	30	38	38	42	24
	Total hardness as, mg/l	54	144	106	82	37	79.76	15	14	12	40	40	20
	Turbidity NTU	0.52	1.33	1.52	3.5	1.74	2.23	4.03	0.4	4.14	0.74	0.22	0.4
	Velocity, m/s	0.026	0.062	0.03	0.02	0.086	0.254	0.189	0.177	0.202	0.119	0.056	0.036
	Cross sectional area, m2	352	191	203	204	223	542	1425	856	672	920	855	335
Calculated	DO saturation, %	95.9	95.2	92.1	89.1	96.1	89.3	83.4	90.1	74.2	91.4	100	97.2
	FC-TC ratio	0.23	0.34	0.59	0.6	0.32	0.24	0.33	0.29	0.24	0.29	0.18	0.24
	Flow rate, m3/s	9	11.9	6	4.1	19.1	137.4	269.1	151.7	135.7	109.5	48	12.2
	Saturation DO, mg/l	7.82	7.88	7.71	7.63	7.18	7.5	7.55	7.99	7.82	7.77	7.88	7.82
	BOD-COD ratio	0.28	0.43	0.31	0.85	0.65	0.67	0.41	0.44	0.66	0.32	0.52	0.61

Table 4.27: Qualitative and quantitative characteristics of surface water at Chalakudy Site during 2015

	Parameters	Jan-15	Feb-15	Mar-15	Apr-15	May-15	Jun-15	Jul-15	Aug-15	Sep-15	Oct-15	Nov-15	Dec-15
Experimental	BOD, mg/l	4	3.2	4.94	4.2	3.3	2.9	2.87	3.8	1.01	2.95	3.05	2.15
	Chlorides, mg/l	17	73.5	27.5	62.5	31	46	16.5	29	15.5	38	48	25
	COD, mg/l	5.18	3.7	5.32	4.3	4.73	6.82	5.9	4.51	4.3	3.1	4.65	3.4
	Dissolved Oxygen, mg/l	5.6	6.95	5.3	7.6	7.1	6.4	7.45	7.53	7.55	7.83	6.5	6.6
	Electrical Conductivity, µmhos/cm	84	42	66	102	88.5	99	34.5	78	56	53	42	68
	Fecal coliform CFU/100ml	170	270	170	270	260	270	260	150	140	260	150	140
	Nitrates mg/l	0.54	0.03	0.255	0.24	0.1	0.135	0.225	0.19	0.315	0.0625	0.1	0.52
	pH	7.05	6.9	7.2	7	7	6.75	6.9	7.2	6.85	6.65	6.6	7.1
	Phosphates, mg/l	1.15	0.3	5.4	0	0	0.1	0	0	0.15	0.15	0	2.3
	Sulphates, mg/l	0	0	0	1.315	0	0	0.215	2.5	0.316	1	2.33	1.8
	Temperature, °C	29.6	28	29.2	31.2	32.1	29.8	30.2	27.7	27.6	29.3	27.8	28.5
	Total Coliform CFU/100ml	510	970	850	1370	1200	900	800	330	450	900	890	880
	Total Dissolved Solids, mg/l	47	153.5	79	110.5	48	76.5	47.5	31	35.5	62	94	40
	Total hardness as CaCO3, mg/l	19	47	24	55	30	42.5	16.5	26	18.5	25.5	30	15
	Turbidity NTU	2.78	2.08	4.06	0.3	1.05	1.1	1.05	0.67	0.86	0.43	0.4	2.01
	Velocity, m/s	0.028	0.057	0.027	0.023	0.078	0.266	0.235	0.09	0.053	0.075	0.031	0.047
	Cross sectional area, m2	356	210	216	219	256	1115	1658	1687	1371	752	1741	660
Calculated	DO saturation, %	73.7	88.9	69.2	100	97.4	84.4	98.9	95.8	95.8	100	82.8	85.2
	FC-TC ratio	0.33	0.28	0.2	0.2	0.22	0.3	0.33	0.45	0.31	0.29	0.17	0.16
	Flow rate, m3/s	10.1	11.9	5.9	5	19.9	296.5	389.9	152.5	72.8	56.1	53.3	31.1
	Saturation DO, mg/l	7.6	7.82	7.66	7.4	7.29	7.58	7.53	7.86	7.88	7.64	7.85	7.75
	BOD-COD ratio	0.77	0.86	0.93	0.98	0.7	0.43	0.49	0.84	0.23	0.95	0.66	0.63

Table 4.28: Qualitative and quantitative characteristics of surface water at Chalakudy Site during 2016

	Parameters	Jan-16	Feb-16	Mar-16	Apr-16	May-16	Jun-16	Jul-16	Aug-16	Sep-16	Oct-16	Nov-16	Dec-16
Experimental	BOD, mg/l	6.5	2.55	2.2	4.6	4.76	6.23	5.8	3.33	5.06	5.2	4.5	3.56
	Chlorides, mg/l	0.22	16	3.44	24	14.33	31.55	36	42.22	42.22	16.66	4.65	4.33
	COD, mg/l	9.65	3.3	2.87	4.8	6.56	6.82	5.93	3.8	5.2	5.4	5	4.6
	Dissolved Oxygen, mg/l	6.9	7.3	6.9	6.2	6.33	6.12	6.72	6.9	6.46	6.9	6.67	6.2
	Electrical Conductivity, µmhos/cm	6	48	48	48	126	111.6	60.6	60.6	212	78	78	48
	Fecal coliform CFU/100ml	270	460	400	230	460	140	330	150	140	260	220	120
	Nitrates mg/l	1.68	0.8	1.45	1.23	1.23	0.45	0.76	1.05	0.32	0.54	0.56	1.2
	pH	7.6	7.5	7.6	7.2	7.3	7.3	7.3	7.3	7.7	7.7	7.4	7.3
	Phosphates, mg/l	1.9	0.6	0.18	0.12	0.78	0.12	0.12	0.78	0.55	0.65	0.42	0.44
	Sulphates, mg/l	0.78	1.54	0.78	0.67	0.67	1.33	0.98	1.78	0.77	0.56	0.654	0.345
	Temperature, °C	29.2	27.5	29.1	32.2	32.5	31.5	30	29.6	29	29.4	29.5	29.2
	Total Coliform CFU/100ml	1020	1830	1560	350	1620	530	1030	760	400	730	950	670
	Total Dissolved Solids, mg/l	45.3	55	43	69	46	75	77	68.7	60.44	62.33	62.45	59.45
	Total hardness as CaCO3, mg/l	72	58	49	41.33	42.45	50.44	98.3	65.7	49.67	43.22	49.5	78.54
	Turbidity NTU	1.32	1.05	2.05	2.78	2.08	0.4	0.22	0.4	2.78	2.08	0.4	0.35
	Velocity, m/s	0.042	0.01	0.006	0.01	0.014	0.195	0.16	0.088	0.088	0.017	0.013	0.008
	Cross sectional area, m2	432	530	622	514	567	1695	1276	1047	884	1487	1271	1131
Calculated	DO saturation, %	90.1	92.5	90	85.3	87.4	83.2	89	90.8	84.1	90.4	87.5	80.9
	FC-TC ratio	0.26	0.25	0.26	0.66	0.28	0.26	0.32	0.2	0.35	0.36	0.23	0.18
	Flow rate, m3/s	18	5.1	4	5.1	8.1	331	204.6	92	78.2	24.6	16	8.9
	Saturation DO, mg/l	7.66	7.89	7.67	7.27	7.24	7.36	7.55	7.6	7.68	7.63	7.62	7.66
	BOD-COD ratio	0.67	0.77	0.77	0.96	0.73	0.91	0.98	0.88	0.97	0.96	0.9	0.77

Table 4.29: Qualitative and quantitative characteristics of surface water at Chalakudy Site during 2017

	parameters	Jan-17	Feb-17	Mar-17	Apr-17	May-17	Jun-17	Jul-17	Aug-17	Sep-17	Oct-17	Nov-17	Dec-17
Experimental	BOD, mg/l	2.96	3.3	2.2	4.6	3.43	5.84	5.04	4.07	5.77	0.65	3.5	2
	Chlorides, mg/l	22	16	3.44	24	14.33	31.55	36	42.22	42.22	16.66	4.65	4.33
	COD, mg/l	5.06	4.67	4.99	5.45	6.8	7.9	5.88	8.9	9.6	5.4	4.5	3.56
	Dissolved Oxygen, mg/l	6.4	6.9	6.9	6.2	7	7.1	6.9	6.7	6.6	6.9	7.4	6.5
	Electrical Conductivity, µmhos/cm	56	48	48	48	126	111.6	60.6	60.6	212	78	78	48
	Fecal coliform CFU/100ml	130	70	380	280	370	230	150	270	130	360	280	370
	Nitrates mg/l	1.68	0.8	1.45	1.23	1.23	0.45	0.76	1.05	0.32	0.54	0.56	1.2
	pH	7.16	7.5	7.6	7.2	7.3	7.3	7.3	7.3	7.7	7.7	7.4	7.3
	Phosphates, mg/l	0.67	0.6	0.18	0.12	0.78	0.12	0.12	0.78	0.55	0.65	0.42	0.44
	Sulphates, mg/l	0.78	1.54	0.78	0.67	0.67	1.33	0.98	1.78	0.77	0.56	0.654	0.345
	Temperature, °C	29.4	29	29.5	32.7	33.6	31.7	32.4	30	28.8	28.7	30.5	28
	Total Coliform CFU/100ml	1300	520	1780	1250	1340	560	300	630	700	1210	370	760
	Total Dissolved Solids, mg/l	82.4	97.56	67.88	69	46	175	210	68.7	60.44	62.33	62.45	59.45
	Total hardness as CaCO3, mg/l	7.2	58	49	41.33	42.45	50.44	48.3	65.7	49.67	43.22	49.5	78.54
	Turbidity NTU	1.22	1.74	1.5	1.9	1.1	1.05	0.67	0.86	0.43	0.4	2.01	1.32
	Velocity, m/s	0.003	0.003	0.007	0.006	0.014	0.138	0.07	0.048	0.105	0.076	0.08	0.038
	Cross sectional area, m2	759	640	686	924	1016	1562	1605	1971	700	890	614	532
Calculated	DO saturation, %	83.9	89.8	90.6	86	98.5	96.7	95.2	88.7	85.6	89.3	98.8	83.1
	FC-TC ratio	0.1	0.13	0.21	0.22	0.28	0.41	0.5	0.43	0.19	0.3	0.76	0.49
	Flow rate, m3/s	2.1	2	5	5.9	13.9	215.2	112.4	95.3	73.6	67.4	49.1	20.3
	Saturation DO, mg/l	7.63	7.68	7.62	7.21	7.11	7.34	7.25	7.55	7.71	7.73	7.49	7.82
	BOD-COD ratio	0.58	0.71	0.44	0.84	0.5	0.74	0.86	0.46	0.6	0.12	0.78	0.56

Table 4.30: Qualitative and quantitative characteristics of surface water at Chalakudy Site during 2018

	Parameters	Jan-18	Feb-18	Mar-18	Apr-18	May-18	Sep-18	Oct-18
Experimental	BOD, mg/l	2.6	3.06	3.44	3.77	4.06	2.8	1.34
	Chlorides, mg/l	3.55	3.3	2.2	4.6	6.8	90	78
	COD, mg/l	7.9	8	8	6.2	7	7.9	4.8
	Dissolved Oxygen, mg/l	6.55	6.56	6.88	6.4	6.5	6.1	6.7
	Electrical Conductivity, μmhos/cm	76	63	49	41.33	42.45	390.37	280
	Fecal coliform CFU/100ml	420	280	310	300	310	1800	1300
	Nitrates mg/l	0.98	0.66	2.54	1.06	1.95	2.89	1.23
	pH	6.8	6.5	6.4	6.9	6.5	6.7	6.9
	Phosphates, mg/l	0.12	1.54	0.78	0.67	0.67	0.86	1.22
	Sulphates, mg/l	0.78	0.55	0.65	0.42	0.44	2.3	1.5
	Temperature, °C	31	31.7	31.2	31.4	32	29.5	30
	Total Coliform CFU/100ml	1200	1100	1900	890	930	3600	2100
	Total Dissolved Solids, mg/l	133	55	43	69	145	350	280
	Total hardness as CaCO3, mg/l	45.66	76	190	36	120	210	167
	Turbidity NTU	2.07	0.35	1.22	1.74	1.05	5.2	3.2
	Velocity, m/s	0.003	0.004	0.007	0.006	0.009	0.118	0.065
	Cross sectional area, m2	691	538	597	952	1555	672	926
Calculated	DO saturation, %	88.3	89.4	93	86.8	89	68.2	76.8
	FC-TC ratio	0.35	0.25	0.16	0.34	0.33	0.5	0.62
	Flow rate, m3/s	2.1	2	4.1	6	14	79.2	59.9
	Saturation DO, mg/l	7.42	7.34	7.4	7.37	7.3	7.62	7.55
	BOD-COD ratio	0.33	0.38	0.43	0.61	0.58	0.35	0.28

Table 4.31: Qualitative and quantitative characteristics of surface water at Vynthala Site during 2013

	Parameters	Nov-13	Dec-13
Experimental	BOD, mg/l	1.8	2.9
	Chlorides, mg/l	12	19
	COD, mg/l	3.2	6.4
	Dissolved Oxygen, mg/l	7.8	7.68
	Electrical Conductivity, µmhos/cm	33	47
	Fecal coliform CFU/100ml	260	230
	Nitrates mg/l	0.95	0.23
	pH	7.4	7
	Phosphates, mg/l	0	0.32
	Sulphates, mg/l	1.96	0.06
	Temperature, °C	27.6	29
	Total Coliform CFU/100ml	900	900
	Total Dissolved Solids, mg/l	25	48
	Total hardness, mg/l	10	12
	Turbidity NTU	0.2	0.4
	Velocity, m/s	0.042	0.035
	Cross sectional area, m2	846	321
Calculated	DO saturation, %	99	100
	FC-TC ratio	0.29	0.26
	Flow rate, m3/s	35.862	11.094
	Saturation DO, mg/l	7.88	7.68
	BOD-COD ratio	0.56	0.45

Table 4.32: Qualitative and quantitative characteristics of surface water at Vynthala Site during 2014

	Parameter	Jan-14	Feb-14	Mar-14	Apr-14	May-14	Jun-14	Jul-14	Aug-14	Sep-14	Oct-14	Nov-14	Dec-14
Experimental	BOD, mg/l	3.2	1.4	0.8	2.9	3.2	3.2	2.8	1.8	0.4	0.2	1.67	0.78
	Chlorides, mg/l	23	39.56	12	12.66	20	18.9	8	10	18.9	20	20	54
	COD, mg/l	4.3	3.2	3.2	3.2	4.33	5.1	3.2	3.2	3.2	3.2	3.2	3.3
	Dissolved Oxygen, mg/l	7.79	7.7	7.7	7.63	7.1	7.1	7.1	6.9	6.3	7.1	7.3	7.2
	Electrical Conductivity, µmhos/cm	39	38	40	41	43	35	28	35	45	60	45	60
	Fecal coliform CFU/100ml	130	40	100	130	360	260	100	140	180	150	140	200
	Nitrates mg/l	0.21	0.14	0.16	0.2	0.95	0.14	0.11	0.02	0.03	0.09	0.09	0.2
	pH	6.4	6.6	6.8	7.2	7.8	7	7.4	7.2	6.8	8	7.1	7.8
	Phosphates, mg/l	0	5.5	0	0	0	0.3	0	0	0	0	0	0.12
	Sulphates, mg/l	0	0	0	0	0	0	0	0	2	0	0	2.1
	Temperature, °C	28.2	27.7	28.9	29.5	33	30.2	30	26.9	28.2	28.4	27.6	28
	Total Coliform CFU/100ml	360	210	520	1080	1040	820	990	860	520	990	960	900
	Total Dissolved Solids, mg/l	22	25	26	26	29	20	20	25	35	20	39.88	124
	Total hardness, mg/l	12	16	28	12	14	18	10	12	45	28	28	14
	Turbidity NTU	0.78	1.43	1.2	1.1	0.67	2.5	0.4	0.44	0.36	1.03	1.43	4.85
	Velocity, m/s	0.018	0.055	0.024	0.017	0.061	0.109	0.153	0.153	0.138	0.092	0.043	0.024
	Cross sectional area, m2	377	189	217	206	239	1137	1454	866	866	1058	881	352
Calculated	DO saturation, %	100	98	100	100	98.9	94.3	94	86.5	80.9	91.4	92.6	92.1
	FC-TC ratio	0.36	0.19	0.19	0.12	0.35	0.32	0.1	0.16	0.35	0.15	0.15	0.22
	Flow rate, m3/s	6.794	10.32	5.16	3.44	14.62	123.926	222.31	132.44	119.196	97.266	38.098	8.514
	Saturation DO, mg/l	7.79	7.86	7.7	7.62	7.18	7.53	7.55	7.98	7.79	7.77	7.88	7.82
	BOD-COD ratio	0.74	0.44	0.25	0.91	0.74	0.63	0.88	0.56	0.13	0.06	0.52	0.24

Table 4.33: Qualitative and quantitative characteristics of surface water at Vynthala Site during 2015

	Parameters	Jan-15	Feb-15	Mar-15	Apr-15	May-15	Jun-15	Jul-15	Aug-15	Sep-15	Oct-15	Nov-15	Dec-15
Experimental	BOD, mg/l	1.8	3.6	3.6	3.25	4.97	4.3	3.2	4.96	1.45	0.57	4.1	2.87
	Chlorides, mg/l	2.86	36	17.66	18.56	22.4	36.35	38.56	19.67	4.65	1.76	31.22	14.25
	COD, mg/l	4.8	4.6	3.9	4.8	5.3	5.34	4.65	5.8	3.5	2.67	4.54	3.5
	Dissolved Oxygen, mg/l	7.68	7.2	6.1	7.4	6.8	6.6	7.5	7.3	6.2	7.3	5.2	6.5
	Electrical Conductivity, μmhos/ cm	28.45	60	68	33.45	46.45	87	90.66	76	56	49.99	68	38
	Fecal coliform CFU/100ml	180	120	180	120	150	210	230	90	210	230	260	150
	Nitrates mg/l	1.34	0.78	0.56	0.06	0.55	0.04	0.04	0.26	0.14	0.12	0.12	0.16
	pH	7.2	7	7.5	7.1	7.2	7	7.6	7.8	7.8	7.6	7.6	7.9
	Phosphates, mg/l	0.88	0.32	0.06	0.79	0.88	0.98	1.03	0.76	0.44	0.67	0.77	0.89
	Sulphates, mg/l	0.33	0.67	0.78	0.34	0.55	0.56	0.43	0.55	0.12	0.07	0.76	0.22
	Temperature, °C	29	28	29.2	31.3	32.1	29.8	30.2	27.7	27.6	29.3	27.8	28.5
	Total Coliform CFU/100ml	720	570	1110	980	320	940	1210	180	860	960	1020	160
	Total Dissolved Solids, mg/l	120	38	53	38	67	58	78	58	50	67	54	63
	Total hardness as CaCO3, mg/l	48	38.89	34.22	26.65	31.3	47.34	45.7	30.65	18.33	24.87	45.66	32.53
	Turbidity NTU	2.05	3.55	0.8	0.92	4.03	0.4	4.14	0.74	0.22	0.4	2.78	2.08
	Velocity, m/s	0.019	0.053	0.023	0.019	0.06	0.216	0.182	0.066	0.041	0.056	0.025	0.037
	Cross sectional area, m2	360	210	220	232	271	1182	1675	1788	1426	760	1758	648
Calculated	DO saturation, %	100	92.1	79.6	100	93.3	87.1	99.6	92.9	78.7	95.5	66.2	83.9
	FC-TC ratio	0.25	0.21	0.16	0.12	0.47	0.22	0.19	0.5	0.24	0.24	0.25	0.94
	Flow rate, m3/s	6.88	11.094	5.074	4.3	16.254	255.076	304.956	118.68	57.964	42.226	43.688	23.994
	Saturation DO, mg/l	7.68	7.82	7.66	7.39	7.29	7.58	7.53	7.86	7.88	7.64	7.85	7.75
	BOD-COD ratio	0.38	0.78	0.92	0.68	0.94	0.81	0.69	0.86	0.41	0.21	0.9	0.82

Table 4.34: Qualitative and quantitative characteristics of surface water at Vynthala site during 2016

	Parameters	Jan-16	Feb-16	Mar-16	Apr-16	May-16	Jun-16	Jul-16	Aug-16	Sep-16	Oct-16	Nov-16	Dec-16
Experimental	BOD, mg/l	1.8	3.6	3.6	3.5	4.5	4.3	2.4	1.3	1.88	2.4	1.55	1.6
	Chlorides, mg/l	2.86	36	17.66	18.56	22.4	36.35	38.56	19.67	18.99	39.67	16.49	14.25
	COD, mg/l	4	5.3	4.7	4.8	5.3	4.7	7.4	5.8	3.5	2.67	4.1	3.5
	Dissolved Oxygen, mg/l	7.66	7.2	6.1	7.29	6.8	6.6	7.57	7.3	7.5	7.3	6.65	6.5
	Electrical Conductivity, μmhos/cm	28.45	60	68	33.45	46.45	87	90.66	76	56	49.99	68	38
	Fecal coliform CFU/100ml	140	90	140	140	380	140	190	90	210	230	100	270
	Nitrates mg/l	0.09	0.09	0.28	0.01	0.28	0.34	0.34	0.25	0.78	0.89	0.57	0.34
	pH	7.2	7	7.5	7.1	7.2	7	7.6	7.8	7.8	7.6	7.6	7.9
	Phosphates, mg/l	0.88	0.32	0.06	0.79	0.88	0.98	1.03	0.76	0.44	0.78	0.72	0.89
	Sulphates, mg/l	0.33	0.67	0.78	0.34	0.55	0.56	0.43	0.55	0.12	0.07	0.76	0.22
	Temperature, °C	29.2	27.5	29.1	32.2	32.5	31.5	30	29.6	29	29.4	29.5	29.2
	Total Coliform CFU/100ml	780	620	710	580	1400	200	300	420	450	600	560	560
	Total Dissolved Solids, mg/l	45	38	53	38	67	58	78	58	78.9	107.54	60.5	63
	Total hardness as CaCO3, mg/l	48	38.89	34.22	26.65	31.3	47.34	45.7	30.65	18.33	42.66	35.265	32.53
	Turbidity NTU	0.4	2.01	4.85	2.05	0.4	1.03	1.43	4.85	2.05	0.4	0.3	1.05
	Velocity, m/s	0.029	0.007	0.006	0.008	0.011	0.154	0.14	0.071	0.068	0.011	0.008	0.006
	Cross sectional area, m2	445	562	659	550	595	1678	1289	1057	947	1661	1548	1142
Calculated	DO saturation, %	100	91.3	79.5	100	93.9	89.7	100	96.1	97.7	95.7	87.3	84.9
	FC-TC ratio	0.18	0.15	0.2	0.24	0.27	0.7	0.63	0.21	0.47	0.38	0.18	0.48
	Flow rate, m3/s	12.9	4.128	3.698	4.214	6.794	258.516	181.03	74.734	64.414	18.146	11.868	6.88
	Saturation DO, mg/l	7.66	7.89	7.67	7.27	7.24	7.36	7.55	7.6	7.68	7.63	7.62	7.66
	BOD-COD ratio	0.45	0.68	0.77	0.73	0.85	0.91	0.32	0.22	0.54	0.9	0.38	0.46

Table 4.35: Qualitative and quantitative characteristics of surface water at Vynthala site during 2017

	Parameters	Jan-17	Feb-17	Mar-17	Apr-17	May-17	Jun-17	Jul-17	Aug-17	Sep-17	Oct-17	Nov-17	Dec-17
Experimental	BOD, mg/l	1.8	3.6	3.6	4.8	1.07	2.6	2.5	4.21	2.67	2.8	2.8	1.87
	Chlorides, mg/l	2.86	36	76.6	18.56	22.4	30.56	19.5	24.7	16.39	17.34	42	21
	COD, mg/l	2.76	3.88	4.13	4.88	5.3	5.8	3.9	4.99	3.7	4.6	4.6	4.7
	Dissolved Oxygen, mg/l	7.54	7.2	6.1	7.23	6.8	7.35	7.26	7.3	6.5	6.8	6.8	6.9
	Electrical Conductivity, µmhos/ cm	28.45	60	68	33.45	46.45	109	34	67.6	46	54	44	219
	Fecal coliform CFU/100ml	120	120	300	90	140	230	100	230	130	280	90	140
	Nitrates mg/l	0.09	0.09	0.28	0.01	0.28	0.34	0.22	1.08	0.94	0.76	1.2	0.25
	pH	7.2	7	6.9	7.1	7	7.3	8.1	6.4	6.2	6.4	8	6.9
	Phosphates, mg/l	0.88	0.32	0.06	0.79	0.88	0.45	0.86	1.76	0.48	0.46	0.89	0.79
	Sulphates, mg/l	0.33	0.67	0.78	0.34	0.55	1.21	0.56	0.66	0.32	1.04	1.7	0.78
	Temperature, °C	29.4	29	29.5	32.7	33.7	31.7	32.4	30.2	28.8	28.7	30.5	28.4
	Total Coliform CFU/100ml	500	450	1630	440	780	510	470	730	690	1000	300	420
	Total Dissolved Solids, mg/l	45	38	43.78	38	67	134.9	143.2	106.56	91.635	90.7	95	120
	Total hardness as CaCO3, mg/l	48	38.89	46.89	26.65	38.4	32	37.54	53.24	47.93	32	112	94
	Turbidity NTU	1.1	1.05	2.23	4.03	0.4	4.14	0.74	0.22	0.4	2.78	2.08	4.06
	Velocity, m/s	0.002	0.003	0.006	0.006	0.011	0.102	0.057	0.041	0.086	0.068	0.068	0.03
	Cross sectional area, m2	789	659	713	952	1047	1640	1685	1971	728	881	614	564
Calculated	DO saturation, %	98.8	93.8	80.1	100	95.9	100	100	96.9	84.3	88	90.8	88.8
	FC-TC ratio	0.24	0.27	0.18	0.2	0.18	0.45	0.21	0.32	0.19	0.28	0.3	0.33
	Flow rate, m3/s	1.634	1.72	4.3	5.246	11.094	167.872	96.148	80.152	62.522	59.684	41.71	16.684
	Saturation DO, mg/l	7.63	7.68	7.62	7.21	7.09	7.34	7.25	7.53	7.71	7.73	7.49	7.77
	BOD-COD ratio	0.65	0.93	0.87	0.98	0.2	0.45	0.64	0.84	0.72	0.61	0.61	0.4

Table 4.36: Qualitative and quantitative characteristics of surface water at Vynthala site during 2018

	Parameters	Jan-18	Feb-18	Mar-18	Apr-18	May-18	Sep-18	Oct-18
Experimental	BOD, mg/l	4.1	2.3	2.56	3.23	3.02	3.7	1.56
	Chlorides, mg/l	12.45	24	125.6	15.45	36	178.6	120.2
	COD, mg/l	5.3	3.9	5.45	5.44	4.35	6.33	2.88
	Dissolved Oxygen, mg/l	7.44	7.3	5.8	6.9	7.21	6.4	6.6
	Electrical Conductivity, µmhos/cm	46	102.43	68	76.5	203	300.66	212.2
	Fecal coliform CFU/100ml	340	40	480	80	400	2150	1250
	Nitrates mg/l	1.37	0.08	3.22	0.35	0.98	3.67	1.54
	pH	6.1	6.4	6.3	7.2	7	6.6	6.9
	Phosphates, mg/l	0.65	2.7	3.18	0.02	1.3	1.79	0.83
	Sulphates, mg/l	0.894	2	2.43	0.078	0.86	4.68	1.58
	Temperature, °C	31	31.8	32.5	31.4	32.8	28.8	30
	Total Coliform CFU/100ml	1590	600	940	400	1850	3500	2100
	Total Dissolved Solids, mg/l	116.9	127.88	218	67.5	89.56	310.5	218
	Total hardness as CaCO3, mg/l	142.6	78.99	100.7	76	59	218.6	127.8
	Turbidity NTU	0.3	1.05	7.93	1.05	1.9	4.7	3.7
	Velocity, m/s	0.002	0.003	0.006	0.005	0.013	0.101	0.053
	Cross sectional area, m2	739	560	591	1009	848	672	972
Calculated	DO saturation, %	100	99.7	80.1	93.6	100	77.8	79.5
	FC-TC ratio	0.21	0.07	0.51	0.2	0.22	0.61	0.6
	Flow rate, m3/s	1.72	1.72	3.44	5.16	11.18	68.026	51.256
	Saturation DO, mg/l	7.42	7.32	7.24	7.37	7.2	7.71	7.55
	BOD-COD ratio	0.77	0.59	0.47	0.59	0.69	0.58	0.54

Table 4.37: Qualitative and quantitative characteristics of surface water at Pulikkakadavu Site during 2013

	Parameters	Nov-13	Dec-13
Experimental	BOD, mg/l	2.4	2.2
	Chlorides, mg/l	48	12
	COD, mg/l	4.5	3.2
	Dissolved Oxygen, mg/l	7.2	7.1
	Electrical Conductivity, µmhos/cm	68	45
	Fecal coliform CFU/100ml	210	130
	Nitrates mg/l	0.64	0.38
	pH	7	7.1
	Phosphates, mg/l	1.7	0
	Sulphates, mg/l	6.89	0
	Temperature, °C	27.6	29
	Total Coliform CFU/100ml	320	410
	Total Dissolved Solids, mg/l	55	34
	Total hardness as CaCO3, mg/l	32	12
	Turbidity NTU	0.5	0.3
	Velocity, m/s	0.058	0.025
	Cross sectional area, m2	760	478
Calculated	DO saturation, %	91.4	92.4
	FC-TC ratio	0.66	0.32
	Flow rate, m3/s	43.9	12
	Saturation DO, mg/l	7.88	7.68
	BOD-COD ratio	0.53	0.69

Table 4.38: Qualitative and quantitative characteristics of surface water at Pulikkakadavu Site during 2014

	Parameters	Jan-14	Feb-14	Mar-14	Apr-14	May-14	Jun-14	Jul-14	Aug-14	Sep-14	Oct-14	Nov-14	Dec-14
Experimental	BOD, mg/l	0.8	1.3	3.2	3.99	3.6	3.9	3	0.8	1.4	2.4	3.2	4.2
	Chlorides, mg/l	30	16	18	26	59	46	12	38	84	34	12	26
	COD, mg/l	5.7	3.2	4.6	6.4	6.2	5	3.2	3.2	4	3.2	4.9	5.2
	Dissolved Oxygen, mg/l	7.1	7.6	6.8	5.7	6.9	6.5	6.3	7.1	5.8	6.9	7.6	7.3
	Electrical Conductivity, μmhos/cm	72	48	81	98	50	78	48	92	284	70	43	98
	Fecal coliform CFU/100ml	270	150	160	180	190	210	120	210	140	150	200	250
	Nitrates mg/l	0.28	0.09	0.39	0.27	0.6	0.15	0.35	0.01	0.4	0.003	0.06	0.14
	pH	6.3	8.6	7.1	7.1	7.4	6.8	5.9	7.4	7.2	7.2	7.1	7.5
	Phosphates, mg/l	0	2.8	1.2	0	0.4	0.4	1.28	0	0.2	0.7	1.3	2.7
	Sulphates, mg/l	0	0.1	0.9	2.6	0.8	2.2	5	0.1	26	1.2	0	0
	Temperature, °C	28.2	27.7	28.9	29.5	33	30.2	30	26.9	28.2	28.4	27.6	28
	Total Coliform CFU/100ml	840	580	510	880	310	590	780	290	990	810	520	1270
	Total Dissolved Solids, mg/l	60	35	53	47	167	180	33	52	106	50	40	48
	Total hardness as CaCO3, mg/l	40	52	20	30	54	90	105	48	78	25	28	40
	Turbidity NTU	0.32	1	1.88	2.9	1.43	1.92	1.05	0.4	0.22	0.9	2.03	1.43
	Velocity, m/s	0.021	0.039	0.024	0.02	0.083	0.105	0.18	0.112	0.132	0.087	0.053	0.021
	Cross sectional area, m2	443	302	246	202	230	1300	1395	1316	1005	1240	864	514
Calculated	DO saturation, %	91.1	96.7	88.3	74.8	96.1	86.3	83.4	89	74.5	88.8	96.4	93.4
	FC-TC ratio	0.32	0.26	0.31	0.2	0.61	0.36	0.15	0.72	0.14	0.19	0.38	0.2
	Flow rate, m3/s	9.2	11.9	6	4	19	136.3	251	146.9	132.6	107.9	46.2	10.9
	Saturation DO, mg/l	7.79	7.86	7.7	7.62	7.18	7.53	7.55	7.98	7.79	7.77	7.88	7.82
	BOD-COD ratio	0.14	0.41	0.7	0.62	0.58	0.78	0.94	0.25	0.35	0.75	0.65	0.81

Table 4.39: Qualitative and quantitative characteristics of surface water at Pulikkakadavu Site during 2015

	Parameters	Jan-15	Feb-15	Mar-15	Apr-15	May-15	Jun-15	Jul-15	Aug-15	Sep-15	Oct-15	Nov-15	Dec-15
Experimental	BOD, mg/l	2.6	3.9	3.5	4.8	2.7	2.8	3.35	1.54	2.9	4.6	3.9	2.6
	Chlorides, mg/l	29	34	21.16	31.22	28.78	16.4	3.44	22.39	7.8	12.66	19.45	20.33
	COD, mg/l	4.5	4.8	3.9	5.6	5.2	5.8	3.8	5.9	4.1	6.6	4.2	3.9
	Dissolved Oxygen, mg/l	5.6	7.5	5.3	7.1	6.44	6.4	7.45	6.1	6.3	7.5	6.5	6.2
	Electrical Conductivity, µmhos/ cm	62	108.33	70	77.6	65	48	56.7	56	28	43.34	70	55
	Fecal coliform CFU/100ml	230	360	230	360	340	120	120	70	120	120	70	60
	Nitrates mg/l	1.22	0.78	1.37	0.08	1.21	0.87	1.31	0.34	0.22	1.08	0.94	0.76
	pH	7.8	6.5	7.2	6.9	7.3	7.2	6.9	6.9	7.6	6.9	7.2	7.6
	Phosphates, mg/l	0.58	1.54	0.26	0.12	0.67	0.45	0.55	0.08	0.078	0.67	0.41	0.32
	Sulphates, mg/l	0.04	0.32	0.54	1.34	2.06	1.42	1.05	1.02	0.456	0.532	0.288	0.921
	Temperature, °C	29	28	29.2	31.3	32.1	29.8	30.2	27.7	27.6	29.3	27.8	28.5
	Total Coliform CFU/100ml	900	750	480	1210	1100	410	980	190	810	320	950	130
	Total Dissolved Solids, mg/l	65	68.8	70.44	80.5	87.45	93.7	90.32	70.45	88	81.5	79.5	83.4
	Total hardness, mg/l	36	48.5	25.6	34.6	40.2	89	78.88	46	30.44	28.67	38.3	20
	Turbidity NTU	1.05	2.43	0.5	5.3	1.44	1.5	0.4	0.43	0.77	1.78	0.4	0.33
	Velocity, m/s	0.019	0.037	0.023	0.023	0.075	0.142	0.248	0.079	0.042	0.058	0.057	0.059
	Cross sectional area, m2	457	321	264	215	256	1704	1545	1808	1649	946	912	507
Calculated	DO saturation, %	72.9	95.9	69.2	96.1	88.3	84.4	98.9	77.6	79.9	98.2	82.8	80
	FC-TC ratio	0.26	0.48	0.48	0.3	0.31	0.29	0.12	0.37	0.15	0.38	0.07	0.46
	Flow rate, m3/s	8.8	12	6	5	19.1	242	382.6	143.7	68.8	54.8	51.7	29.9
	Saturation DO, mg/l	7.68	7.82	7.66	7.39	7.29	7.58	7.53	7.86	7.88	7.64	7.85	7.75
	BOD-COD ratio	0.58	0.81	0.9	0.86	0.52	0.48	0.88	0.26	0.71	0.7	0.93	0.67

Table 4.40: Qualitative and quantitative characteristics of surface water at Pulikkakadavu Site during 2016

	Parameters	Jan-16	Feb-16	Mar-16	Apr-16	May-16	Jun-16	Jul-16	Aug-16	Sep-16	Oct-16	Nov-16	Dec-16
Experimental	BOD, mg/l	1.6	2.33	2.2	0.45	1.5	2.8	3.35	2.6	2.9	4.1	2.6	2.7
	Chlorides, mg/l	29	34	21.16	31.22	28.78	16.4	3.44	22.39	7.8	12.66	19.45	20.33
	COD, mg/l	4.5	4.8	3.9	5.6	2.7	5.6	6.7	5.9	4.98	6.6	4.2	3.9
	Dissolved Oxygen, mg/l	6.9	7.3	6.7	6.2	6.33	6.12	6.72	6.9	6.3	6.9	6.67	6.2
	Electrical Conductivity, µmhos/cm	62	108.33	70	77.6	65	48	56.7	56	28	43.34	70	55
	Fecal coliform CFU/100ml	120	150	280	120	300	130	140	70	120	220	270	140
	Nitrates mg/l	1.37	1.95	1.21	0.87	1.31	0.34	2.33	1.08	0.94	1.67	1.67	0.55
	pH	7.8	6.5	7.2	6.9	7.3	6.6	6.9	6.9	7.6	6.9	7.2	7.6
	Phosphates, mg/l	0.58	0.43	0.26	0.12	0.67	0.45	0.55	0.08	0.078	0.67	0.41	0.32
	Sulphates, mg/l	0.04	0.32	0.54	1.34	2.06	1.42	1.05	1.02	0.456	0.532	0.288	0.921
	Temperature, °C	29.2	27.5	29.1	32.2	32.5	31.5	30	29.6	29	29.4	29.5	29.2
	Total Coliform CFU/100ml	390	560	780	520	1470	430	450	470	780	600	590	1310
	Total Dissolved Solids, mg/l	65	68.8	70.44	80.5	87.45	93.7	90.32	70.45	88	81.5	79.5	83.4
	Total hardness, mg/l	36	48.5	25.6	34.6	40.2	89	78.88	20	30.44	28.67	38.3	43
	Turbidity NTU	0.67	0.4	1.2	1.05	2.43	0.9	2.03	1.43	1.05	2.43	0.8	1.8
	Velocity, m/s	0.03	0.006	0.005	0.009	0.005	0.177	0.119	0.059	0.077	0.017	0.013	0.017
	Cross sectional area, m2	567	889	875	582	1517	1775	1661	1454	1031	1300	1271	543
Calculated	DO saturation, %	90.1	92.5	87.4	85.3	87.4	83.2	89	90.8	82	90.4	87.5	80.9
	FC-TC ratio	0.31	0.27	0.36	0.23	0.2	0.3	0.31	0.15	0.15	0.37	0.46	0.11
	Flow rate, m3/s	17.1	5.2	4.1	5.1	8	314.4	198.3	85.8	79.3	22.3	16.2	9.1
	Saturation DO, mg/l	7.66	7.89	7.67	7.27	7.24	7.36	7.55	7.6	7.68	7.63	7.62	7.66
	BOD-COD ratio	0.36	0.49	0.56	0.08	0.56	0.5	0.5	0.44	0.58	0.62	0.62	0.69

Table 4.41: Qualitative and quantitative characteristics of surface water at Pulikkakadavu Site during 2017

	Parameters	Jan-17	Feb-17	Mar-17	Apr-17	May-17	Jun-17	Jul-17	Aug-17	Sep-17	Oct-17	Nov-17	Dec-17
Experimental	BOD, mg/l	4.5	3.8	3.9	5.6	2.7	2.8	5.83	5.32	1.67	3.8	3.2	3.06
	Chlorides, mg/l	29	34	21.16	31.22	28.78	16.4	3.44	22.39	7.8	20.77	19.45	20.33
	COD, mg/l	5.6	4.8	6.1	6.1	6	4.2	7.34	5.9	2.9	6.6	4.2	3.9
	Dissolved Oxygen, mg/l	6.4	6.9	7	6.2	7	7.1	5.8	6.1	6.6	6.8	6.9	6.2
	Electrical Conductivity, µmhos/cm	62	108.33	70	77.6	65	48	56.7	56	28	43.34	70	55
	Fecal coliform CFU/100ml	300	320	310	450	400	270	230	150	330	290	450	400
	Nitrates mg/l	1.7	0.1	0.96	0.06	1.76	0.04	0.04	0.26	0.14	0.12	0.67	0.16
	pH	7.8	6.5	7.2	6.9	7.3	7.2	6.9	6.9	7.6	6.9	7.2	7.6
	Phosphates, mg/l	0.58	0.43	0.26	0.12	0.67	0.45	0.55	0.08	0.078	0.089	0.41	0.32
	Sulphates, mg/l	0.04	0.32	0.54	1.34	2.06	1.42	1.05	1.02	0.456	0.532	0.288	0.921
	Temperature, °C	29.4	29	29.5	32.7	33.6	31.7	32.4	30	28.8	28.7	30.5	28
	Total Coliform CFU/100ml	1240	670	1500	1470	1450	690	500	800	430	1260	450	470
	Total Dissolved Solids, mg/l	65	68.8	70.44	80.5	87.45	93.7	90.32	70.45	88	80.5	79.5	83.4
	Total hardness, mg/l	36	48.5	25.6	34.6	40.2	118.4	134.7	20	30.44	98.66	38.3	20
	Turbidity NTU	2.9	1.43	0.4	1.44	1.5	0.4	0.43	0.77	1.78	0.4	0.33	0.67
	Velocity, m/s	0.005	0.01	0.019	0.026	0.055	0.276	0.083	0.076	0.056	0.051	0.031	0.015
	Cross sectional area, m2	437	192	270	230	253	787	1381	1267	1343	1338	1568	1392
Calculated	DO saturation, %	83.9	89.8	91.9	86	98.5	96.7	80	80.8	85.6	88	92.1	79.3
	FC-TC ratio	0.24	0.48	0.21	0.31	0.28	0.39	0.46	0.19	0.77	0.23	1	0.85
	Flow rate, m3/s	2.1	2	5	6	14	217.2	114.4	96.5	74.8	68.2	48.4	20.3
	Saturation DO, mg/l	7.63	7.68	7.62	7.21	7.11	7.34	7.25	7.55	7.71	7.73	7.49	7.82
	BOD-COD ratio	0.8	0.79	0.64	0.92	0.45	0.67	0.79	0.9	0.58	0.58	0.76	0.78

Table 4.42: Qualitative and quantitative characteristics of surface water at Pulikkakadavu Site during 2018

	Parameters	Jan-18	Feb-18	Mar-18	Apr-18	May-18	Sep-18	Oct-18
Experimental	BOD, mg/l	2.8	5.7	7.6	5.6	2.7	4.9	4
	Chlorides, mg/l	29	34	49.5	31.22	28.78	158	104
	COD, mg/l	4.5	6.3	12.2	5.8	3.08	7	4.7
	Dissolved Oxygen, mg/l	7.1	6.42	5.2	6.4	6.5	6.1	6.7
	Electrical Conductivity, μmhos/cm	62	108.33	333.7	77.6	65	298.6	241
	Fecal coliform CFU/100ml	370	120	340	180	130	2000	1300
	Nitrates mg/l	1.7	2.32	5.18	0.06	1.76	3.08	1.42
	pH	7.8	6.5	6	6.9	6.5	6.5	6.7
	Phosphates, mg/l	0.58	1.6	2.89	0.77	0.56	2.06	0.92
	Sulphates, mg/l	1.2	2.33	2.13	1.34	2.06	5.2	1.8
	Temperature, °C	31	31.7	32.4	31.4	32.7	28.7	30.5
	Total Coliform CFU/100ml	1780	610	1800	590	400	3640	2300
	Total Dissolved Solids, mg/l	65	78	300	103.2	93	260	178.9
	Total hardness, mg/l	89.5	48.5	273	34.6	75.45	196.8	123.7
	Turbidity NTU	0.8	1.8	10.65	1.43	3.2	4.6	2.1
	Velocity, m/s	0.005	0.01	0.016	0.028	0.042	0.071	0.047
	Cross sectional area, m2	402	200	257	214	180	1128	1231
Calculated	DO saturation, %	95.7	87.5	71.7	86.8	90.2	76.3	81.4
	FC-TC ratio	0.21	0.2	0.19	0.31	0.33	0.55	0.57
	Flow rate, m3/s	2	2	4.1	5.9	7.5	80.2	57.7
	Saturation DO, mg/l	7.42	7.34	7.25	7.37	7.21	7.73	7.49
	BOD-COD ratio	0.62	0.9	0.62	0.97	0.88	0.7	0.85

Table 4.43: Qualitative and quantitative characteristics of surface water at Palapuzhakadavu Site during 2013

	Parameters	Nov-13	Dec-13
Experimental	BOD, mg/l	2.35	2.45
	Chlorides, mg/l	29	11
	COD, mg/l	3.4	4.8
	Dissolved Oxygen, mg/l	6.4	6.4
	Electrical Conductivity, µmhos/cm	81.5	41.5
	Fecal coliform CFU/100ml	390	310
	Nitrates mg/l	0.435	0.27
	pH	7.05	7.55
	Phosphates, mg/l	0.53	0
	Sulphates, mg/l	5.64	0.02
	Temperature, °C	27.6	29
	Total Coliform CFU/100ml	680	740
	Total Dissolved Solids, mg/l	60.5	30.5
	Total hardness as CaCO3, mg/l	36	19
	Turbidity NTU	0.4	0.5
	Velocity, m/s	0.042	0.02
	Cross sectional area, m2	1009	635
Calculated	DO saturation, %	81.2	83.3
	FC-TC ratio	0.57	0.42
	Flow rate, m3/s	42.2	12.2
	Saturation DO, mg/l	7.88	7.68
	BOD-COD ratio	0.69	0.51

Table 4.44: Qualitative and quantitative characteristics of surface water at Palapuzhakadavu Site during 2014

	Parameters	Jan-14	Feb-14	Mar-14	Apr-14	May-14	Jun-14	Jul-14	Aug-14	Sep-14	Oct-14	Nov-14	Dec-14
Experimental	BOD, mg/l	2.25	3.05	1.2	2.45	2.05	3.2	3.2	3.2	1.05	1.15	1.65	1.65
	Chlorides, mg/l	21	12	16	12	43.5	107	40.5	40.5	38	29	33	33
	COD, mg/l	4.8	4.8	3.2	4.8	4.8	4.8	3.6	3.9	3.2	4.8	3.2	3.2
	Dissolved Oxygen, mg/l	7.7	7.5	7.6	7.5	7.2	6.8	7.05	7.13	6.9	7.1	7.3	7.1
	Electrical Conductivity, μmhos/cm	74	55.5	23.5	60	53	191.5	113.5	113.5	97.5	101	87	83
	Fecal coliform CFU/100ml	290	350	210	230	250	200	160	230	230	130	260	220
	Nitrates mg/l	0.38	0.105	0.27	0.305	0.685	0.1	0.1	0.1	0.03	0.14	0.065	0.065
	pH	6.4	6.65	6.95	7.25	7.6	7.1	7.35	7.35	7.4	6.95	7.9	7.75
	Phosphates, mg/l	0	1.75	0.7	0	0.15	1.1	0.48	0.5	0	0.09	0.1	0
	Sulphates, mg/l	0.025	0	0	0	0.55	6	1.6	0.175	0	12.5	2	3.77
	Temperature, °C	28.2	27.7	28.9	29.5	33	30.2	30	26.9	28.2	28.4	27.6	28
	Total Coliform CFU/100ml	980	1100	280	380	560	920	260	380	690	490	570	820
	Total Dissolved Solids, mg/l	45	34	39	40	110.5	140	72.5	72.5	72.5	80.5	157	38
	Total hardness as CaCO3, mg/l	29	20	18	29	41.5	77	41	41	38	33.5	35	35
	Turbidity NTU	0.35	0.67	0.3	1.92	1.05	3.67	1.74	1.5	0.81	0.51	1.32	1.05
	Velocity, m/s	0.038	0.046	0.022	0.02	0.029	0.179	0.198	0.129	0.125	0.089	0.042	0.014
	Cross sectional area, m2	209	263	272	206	623	798	1327	1200	1092	1240	1030	722
Calculated	DO saturation, %	98.8	95.4	98.7	98.4	100	90.3	93.4	89.3	88.6	91.4	92.6	90.8
	FC-TC ratio	0.3	0.32	0.75	0.61	0.45	0.22	0.62	0.61	0.33	0.27	0.46	0.27
	Flow rate, m3/s	7.9	12	6.1	4.1	18	143.1	263.4	154.6	137	110.3	43.7	10.2
	Saturation DO, mg/l	7.79	7.86	7.7	7.62	7.18	7.53	7.55	7.98	7.79	7.77	7.88	7.82
	BOD-COD ratio	0.47	0.64	0.38	0.51	0.43	0.67	0.89	0.82	0.33	0.24	0.52	0.52

Table 4.45: Qualitative and quantitative characteristics of surface water at Palapuzhakadavu Site during 2015

	Parameters	Jan-15	Feb-15	Mar-15	Apr-15	May-15	Jun-15	Jul-15	Aug-15	Sep-15	Oct-15	Nov-15	Dec-15
Experimental	BOD, mg/l	4.35	1.65	3.7	3.2	1.8	6.3	3.2	1.3	3.2	3.2	2.8	2.15
	Chlorides, mg/l	26.5	33	46	44	52	32	16	13	30	30	12	17
	COD, mg/l	4.35	3.2	4.6	4.9	3.2	6.7	6.3	3.2	3.72	4.5	4.6	3.3
	Dissolved Oxygen, mg/l	7.45	6.9	6.85	6.9	6.5	6.7	6.8	6.9	7.1	7.73	7.6	5.6
	Electrical Conductivity, µmhos/cm	82	87	107.8	95	90	121	56	34	72	70	90	84
	Fecal coliform CFU/100ml	250	260	250	260	320	290	230	150	140	330	150	100
	Nitrates mg/l	0.28	0.065	0.065	0.21	0.15	0.45	0.2	0.39	0.28	0.28	0.68	0.54
	pH	7.95	7.9	6.9	7	7	6.5	7.3	7	7.1	6.8	7.3	7.05
	Phosphates, mg/l	2.35	2.35	2.55	2.56	3.4	2.08	2.89	1.77	2.33	1.43	1.2	1.15
	Sulphates, mg/l	3.78	4.98	3.66	3.67	9	4.56	3.98	2.56	5.4	3.23	0.4	2.8
	Temperature, oC	29	28	29.2	31.3	32.1	29.8	30.2	27.7	27.6	29.3	27.8	28.5
	Total Coliform CFU/100ml	960	650	340	1450	1000	1100	940	240	650	750	820	960
	Total Dissolved Solids, mg/l	58	50	50	132	116	231	73	38	38	42	24	47
	Total hardness as CaCO3, mg/l	11	35	35	37	34	68	14	12	40	40	20	19
	Turbidity NTU	2.05	0.66	3.05	0.4	0.32	6.5	1.43	1.03	1.89	0.36	1.5	2.06
	Velocity, m/s	0.043	0.042	0.023	0.023	0.028	0.168	0.419	0.067	0.041	0.055	0.061	0.057
	Cross sectional area, m2	209	289	264	215	692	1491	902	1908	1649	946	912	507
Calculated	DO saturation, %	97	88.2	89.4	93.4	89.2	88.4	90.3	87.8	90.1	100	96.8	72.3
	FC-TC ratio	0.26	0.4	0.74	0.18	0.32	0.26	0.24	0.63	0.22	0.44	0.18	0.1
	Flow rate, m3/s	9	12.1	6	5	19.1	249.9	377.7	127.2	68	52.2	55.4	29.1
	Saturation DO, mg/l	7.68	7.82	7.66	7.39	7.29	7.58	7.53	7.86	7.88	7.64	7.85	7.75
	BOD-COD ratio	1	0.52	0.8	0.65	0.56	0.94	0.51	0.41	0.86	0.71	0.61	0.65

Table 4.46: Qualitative and quantitative characteristics of surface water at Palapuzhakadavu Site during 2016

	Parameters	Jan-16	Feb-16	Mar-16	Apr-16	May-16	Jun-16	Jul-16	Aug-16	Sep-16	Oct-16	Nov-16	Dec-16
Experimental	BOD, mg/l	2.5	2.1	2.3	2.55	0.8	2.9	3.3	2.2	4	6.4	6.4	3.6
	Chlorides, mg/l	73.5	27.5	62.5	31	46	52	16	3.44	24	14.33	31.55	36
	COD, mg/l	3.2	3.35	4.2	3.3	2.8	3.22	4.2	5.9	4.6	6.8	7.9	5.88
	Dissolved Oxygen, mg/l	7.06	7.9	7.7	7.39	6.8	6.9	7.5	7.2	6.2	7	7.1	7.3
	Electrical Conductivity, μmhos/cm	142	66	102	88.5	99	36	48	48	48	126	111.6	60.6
	Fecal coliform CFU/100ml	120	300	320	270	420	100	270	150	140	140	290	230
	Nitrates mg/l	0.03	0.255	0.24	0.1	0.135	0.45	0.76	0.09	0.36	0.02	1.06	1.53
	pH	6.9	7.2	6.9	7.1	6.75	7.16	7.5	7.6	7.2	7.3	7.3	7.3
	Phosphates, mg/l	0.3	5.4	2.8	2.34	2.12	2.33	0.6	0.18	0.12	0.78	0.12	0.12
	Sulphates, mg/l	2.88	4.6	1.315	3.54	3.5	0.78	1.54	0.78	0.67	0.67	1.33	0.98
	Temperature, oC	29.2	27.5	29.1	32.2	32.5	31.5	30	29.6	29	29.4	29.5	29.2
	Total Coliform CFU/100ml	580	1600	900	760	1600	620	780	510	530	320	780	890
	Total Dissolved Solids, mg/l	153.5	79	110.5	48	76.5	34	55	43	69	46	75	77
	Total hardness, mg/l	47	24	55	30	42.5	7.2	58	49	41.33	42.45	50.44	48.3
	Turbidity NTU	3.04	1.43	1.05	2.05	0.66	1.5	1.32	1.05	2.05	0.66	3.18	5.9
	Velocity, m/s	0.024	0.008	0.004	0.009	0.019	0.168	0.125	0.061	0.065	0.018	0.016	0.015
	BOD-COD ratio	0.78	0.63	0.55	0.77	0.29	0.9	0.79	0.37	0.87	0.94	0.81	0.61
Calculated	Cross sectional area, m2	662	630	875	582	420	1775	1661	1454	1140	1281	940	612
	DO saturation, %	92.2	100	100	100	93.9	93.8	99.3	94.7	80.7	91.7	93.2	95.3
	FC-TC ratio	0.21	0.19	0.36	0.36	0.26	0.16	0.35	0.29	0.26	0.44	0.37	0.26
	Flow rate, m3/s	16	5	3.8	5.2	8	298.8	207.8	88.3	74.1	22.5	14.7	8.9
	Saturation DO, mg/l	7.66	7.89	7.67	7.27	7.24	7.36	7.55	7.6	7.68	7.63	7.62	7.66

Table 4.47: Qualitative and quantitative characteristics of surface water at Palapuzhakadavu Site during 2017

	Parameters	Jan-17	Feb-17	Mar-17	Apr-17	May-17	Jun-17	Jul-17	Aug-17	Sep-17	Oct-17	Nov-17	Dec-17
Experimental	BOD, mg/l	2.8	1.6	1.88	4.9	4.5	3.45	3.2	3.3	2.2	4.6	6.2	3.23
	Chlorides, mg/l	42.22	0	45.8	16.66	79	4.33	1.06	16	3.44	24	14.33	21
	COD, mg/l	8.9	9.6	5.4	5.7	5.8	3.56	6.19	4.67	3.98	6.1	6.8	4.7
	Dissolved Oxygen, mg/l	6.7	6.6	7	6.9	6.6	6.9	7.49	7.2	7.3	6.2	7	6.9
	Electrical Conductivity, μmhos/cm	60.6	212	132	139.78	78	48	7.1	48	48	48	126	219
	Fecal coliform CFU/100ml	520	400	400	460	410	330	130	140	230	380	460	410
	Nitrates mg/l	0.38	0.78	1.43	2.56	0.45	0.76	0.45	0.76	0.09	0.36	0.02	0.25
	pH	7.3	7.7	7.7	7.5	7.4	7.3	7.5	7.2	7.3	7.2	6.9	6.9
	Phosphates, mg/l	0.78	0.55	1.22	0.65	0.42	0.44	1.67	0.6	0.18	0.12	0.78	0.79
	Sulphates, mg/l	1.78	0.77	0.56	1.33	0.654	0.345	0.12	1.54	0.78	0.67	0.67	0.78
	Temperature, °C	29.4	29	29.5	32.7	33.7	31.7	32.4	30.2	28.8	28.7	30.5	28.4
	Total Coliform CFU/100ml	1390	1470	1790	1400	1900	480	480	440	780	1300	780	510
	Total Dissolved Solids, mg/l	68.7	60.44	73.3	121.5	62.45	59.45	13.3	55	43	69	46	60.3
	Total hardness as CaCO3, mg/l	65.7	49.67	123.5	93.33	49.5	78.54	79.56	63	49	41.33	42.45	79.3
	Turbidity NTU	1.05	1.05	1.5	3.14	1.8	1.43	1.03	1.89	0.36	1.5	2.06	3.04
	Velocity, m/s	0.004	0.001	0.004	0.005	0.011	0.131	0.064	0.086	0.056	0.053	0.069	0.034
	Cross sectional area, m2	576	1920	1254	1209	1330	1604	1824	1121	1346	1338	723	547
Calculated	DO saturation, %	87.8	85.9	91.9	95.7	93.1	94	100	95.6	94.7	80.2	93.5	88.8
	FC-TC ratio	0.37	0.27	0.22	0.33	0.22	0.69	0.27	0.32	0.29	0.29	0.59	0.8
	Flow rate, m3/s	2.1	2	5.1	6	14.1	210.2	116.9	95.9	75.6	70.4	49.9	18.8
	Saturation DO, mg/l	7.63	7.68	7.62	7.21	7.09	7.34	7.25	7.53	7.71	7.73	7.49	7.77
	BOD-COD ratio	0.31	0.17	0.35	0.86	0.78	0.97	0.52	0.71	0.55	0.75	0.91	0.69

Table 4.48: Qualitative and quantitative characteristics of surface water at Palapuzhakadavu Site during 2018

	Parameters	Jan-18	Feb-18	Mar-18	Apr-18	May-18	Sep-18	Oct-18
Experimental	BOD, mg/l	5.3	3.9	8.3	5.2	4.1	4.5	3.89
	Chlorides, mg/l	12.45	24	90.8	57.67	23.45	160	117
	COD, mg/l	5.6	6.3	9.4	7.9	4.4	7.3	4.5
	Dissolved Oxygen, mg/l	6.5	6.7	5.6	6.85	7.3	6.3	6.8
	Electrical Conductivity, µmhos/cm	46	102.43	287	105.65	96.09	360.5	254
	Fecal coliform CFU/100ml	400	210	530	140	350	2100	1100
	Nitrates mg/l	1.37	1.89	7.89	0.87	1.31	3.66	1.26
	pH	6.5	6.4	6.2	6.8	6.7	6.5	6.9
	Phosphates, mg/l	0.65	0.59	2.84	1.43	1.72	1.95	0.93
	Sulphates, mg/l	0.894	2	2.43	2.18	1.43	5.4	1.3
	Temperature, °C	31	31.8	32.5	31.4	32.7	29	30.5
	Total Coliform CFU/100ml	1530	1400	2900	390	1100	3800	2400
	Total Dissolved Solids, mg/l	78.67	87.45	360	102.2	95.67	348	245
	Total hardness, mg/l	40.88	67.56	183.55	172	76.55	193	122
	Turbidity NTU	3.18	5.9	13.8	7.9	3.07	5.9	3.6
	Velocity, m/s	0.003	0.002	0.003	0.006	0.015	0.103	0.044
	Cross sectional area, m2	599	1113	1304	1016	950	760	1325
Calculated	DO saturation, %	87.6	91.5	77.3	92.9	100	75.5	80.1
	FC-TC ratio	0.26	0.15	0.18	0.36	0.32	0.55	0.46
	Flow rate, m3/s	1.8	2	3.9	6	14.1	78.3	58.9
	Saturation DO, mg/l	7.42	7.32	7.24	7.37	7.21	7.68	7.49
	BOD-COD ratio	0.95	0.62	0.88	0.66	0.93	0.62	0.86

4.2 Analysis of Water Quality Trend of Chalakudy River

The trend of water quality parameters was analyzed spatially, temporally and seasonally along the study area based on the analytical results mentioned above. The results of trend analysis in terms of spatial, temporal and seasonal variations using various graphical representations such as box plots, ANOVA and posthoc ANOVA statistical analysis of each water quality parameter using Minitab 17 are consolidated as follows:-

4.2.1 Spatial, temporal and seasonal variations of biochemical oxygen demand (BOD)

The BOD in the river water from Vazhachal to Vynthala sites was observed between the range of 0.22 mg/l to 8.3 mg/l with an average ± SD 2.77 mg/l ± 1.36. Maximum BOD 8.3 mg/l, 7.6mg/l, 6.5 mg/l, and 6.1 mg/l were observed during the period of study at Palapuzhakadavu, Pulikkakadavu, Chalakudy and Vettilappara sites respectively. At Palapuzhakadavu and Pulikkakadavu sites were observed maximum value of BOD during March 2018. At Chalakudy site the maximum BOD 6.5 mg/l was observed during January 2016. All these high values were obtained rarely during the period of study. Most of the values BOD values were less than 2.5mg/l. So these high values were noticed as outliers in box plots. The very high values of BOD were obtained after the flood in August 2018. The box plot representation of spatial, temporal and seasonal variations of mean BOD are shown in Fig.4.1, Fig.4.2, and Fig.4.3 respectively. Along the study area, an unpredictable trend of BOD was observed.

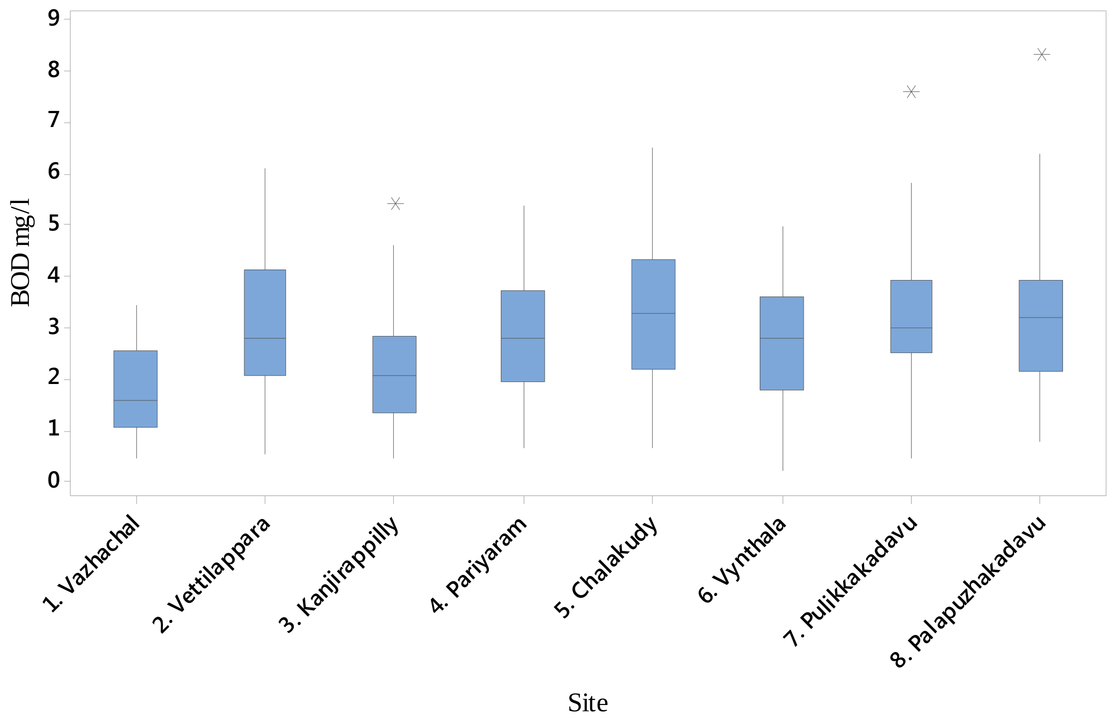

Fig. 4.1: Spatial variations of BOD

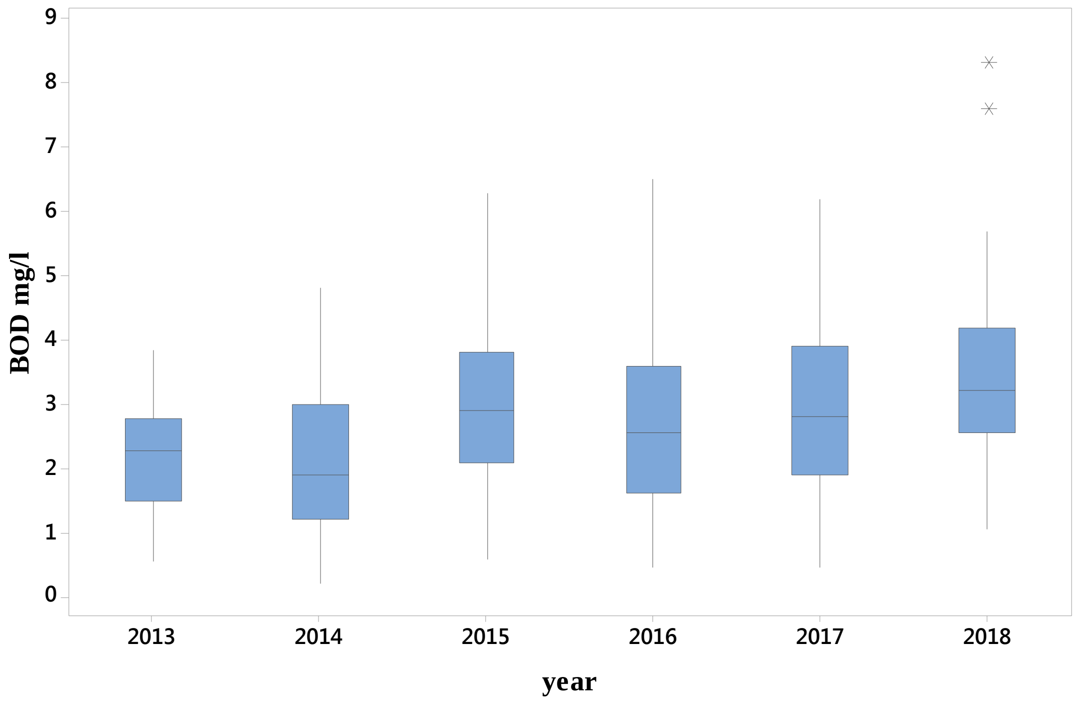

Fig. 4.2: Temporal variations of BOD

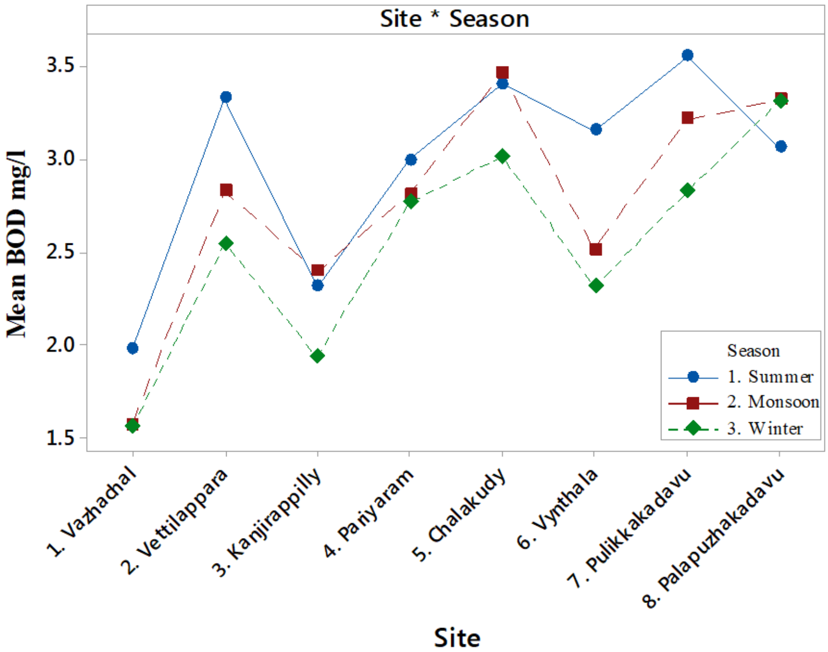

Fig. 4.3: Seasonal variations of BOD

4.2.1.1 ANOVA results of BOD

Two-way analysis of variance (ANOVA) was carried out to evaluate the variation of water quality and analyze statistically with respect site and season. Variations with respect to mean BOD were also identified. The plot shown in Fig.4.3 gives an idea about the seasonal variations in the mean values of BOD along the area of study. The results of ANOVA and Post hoc ANOVA analysis (Tukey) performed are shown in Table 4.49 & Table.4.50. From these results, it was identified that BOD of river water is statistically significant with site and seasons (season $P<0.05$, Site $P=0$).

Table 4.49: ANOVA results of BOD, mg/l

Source	***DF***	***Seq SS***	***Adj SS***	***Adj MS***	***F***	***P***
Season	2	13.4	13.4	6.7	4.16	0.016
Site	7	123.7	119.7	17.1	10.58	0
Season*Site	14	11.7	11.7	0.8	0.52	0.924
Error	432	698.2	698.2	1.6		
Total	455	847.1				

Table 4.50: Grouping Information Using Tukey Method at 95 % Confidence for BOD, mg/l

Season	***N***	***Mean***	***Grouping***		
Summer	160	3	A		
Monsoon	176	2.8	A	B	
Winter	120	2.5		B	
Site	***N***	***Mean***	***Grouping***		
Chalakudy	57	3.3	A		
Palapuzhakadavu	57	3.2	A		
Pulikkakadavu	57	3.2	A		
Vettilappara	57	2.9	A	B	
Pariyaram	57	2.9	A	B	
Vynthala	57	2.7	A	B	
Kanjirappilly	57	2.2		B	C
Vazhachal	57	1.7			C

The influence of parameters such as season and site are anlaysed using ANOVA. $P \leq 0.05$ means the parameter is found influencing, the specific sites or seasons causing this influence is found by post-hoc ANOVA analysis (Tukey method). Tukey method automatically group sites or seasons in to groups (A, B, and C) indicating the specific site or season different from others. During summer and monsoon seasons significant variations in BOD level in water was found in Chalakudy, Pulikkakadavu and Palapuzhakadavu sites. As per surface water quality standard (IS 2296, 1992), the BOD of drinking water is should be <2mg/l, for recreation <3 mg/l, for fish <6 mg/l and <10 mg/l for irrigation When BOD level is high, dissolved oxygen (DO) level decreases because of the bacteria consuming the oxygen in the water (Sawyer et al., 2003). Survival of fish and other aquatic organisms in the water are very difficult at low DO level.

4.2.2 Spatial, temporal and seasonal variations of pH

pH of water along the area of study varied from 4.2 to 8.6 with an average value of 7.07±0.435. Maximum pH value observed during the period of study (8.6) at Pulikkakadavu site during summer 2014. This may be due to the acceptance of treated industrial effluent from nearby industry. Seasonal variations in pH values during the period of study were contributed by factors like removal of CO_2 by photosynthesis through bicarbonate degradation, dilution of contaminants with fresh water, reduction in salinity and temperature, and degradation of organic matter (Rajasegar., 2003).

The lowest pH value observed was 4.2 at Kanjirappilly site during winter 2016. The reason for lowest pH could be related with temperature, organic matter decomposition etc (Nhapi.et.al.,2011). During summer, most of the sites were found to be alkaline due to comparatively high pH value. It was very useful for freshwater organisms and for tropical fish species. Minimum pH values 5.9 and 6 were observed at Pulikkakadavu site during monsoon 2014 and summer 2018. Pulikkakadavu, Palapuzhakadavu, Vettilappara, Vazhachal, and Vynthala sites were found to have lower values of pH than standard values such as 5.9, 6.2, 6.2, 6.4, and 6.1 respectively. The box plot representations of spatial, temporal and seasonal variations of pH are shown in Fig.4.4, Fig. 4.5, and Fig.4.6. Seasonal variations in mean pH are shown in the Fig.4.6. Maximum average pH 7.3 and 7.4 were observed during winter, at the sites Pariyaram and Pulikkakadavu, during the period of study. At Pariyaram and Pulikkakadavu, sites, the variations of pH may be due to the effect of treated effluent discharge from the nearby industry. During monsoon and winter, the mean pH was found around seven. Vazhachal and Vettilappara sites showed comparatively low mean pH value than other sites. All these high and low values compared with yearly average value are shown as outliers in the box plot representation.

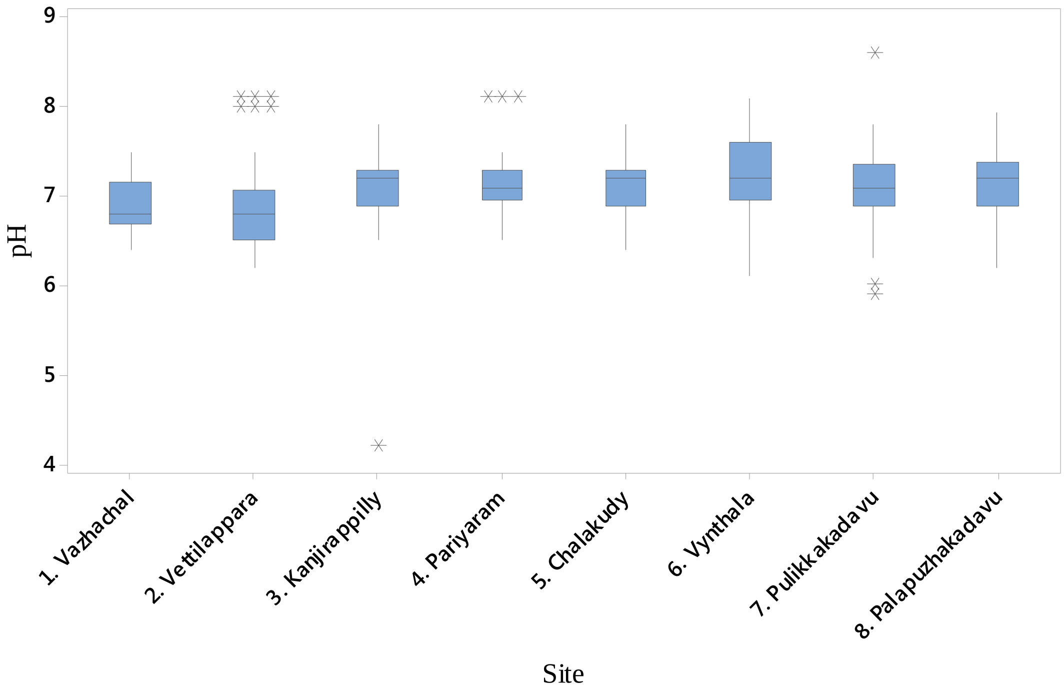

Fig. 4.4: Spatial variations of pH

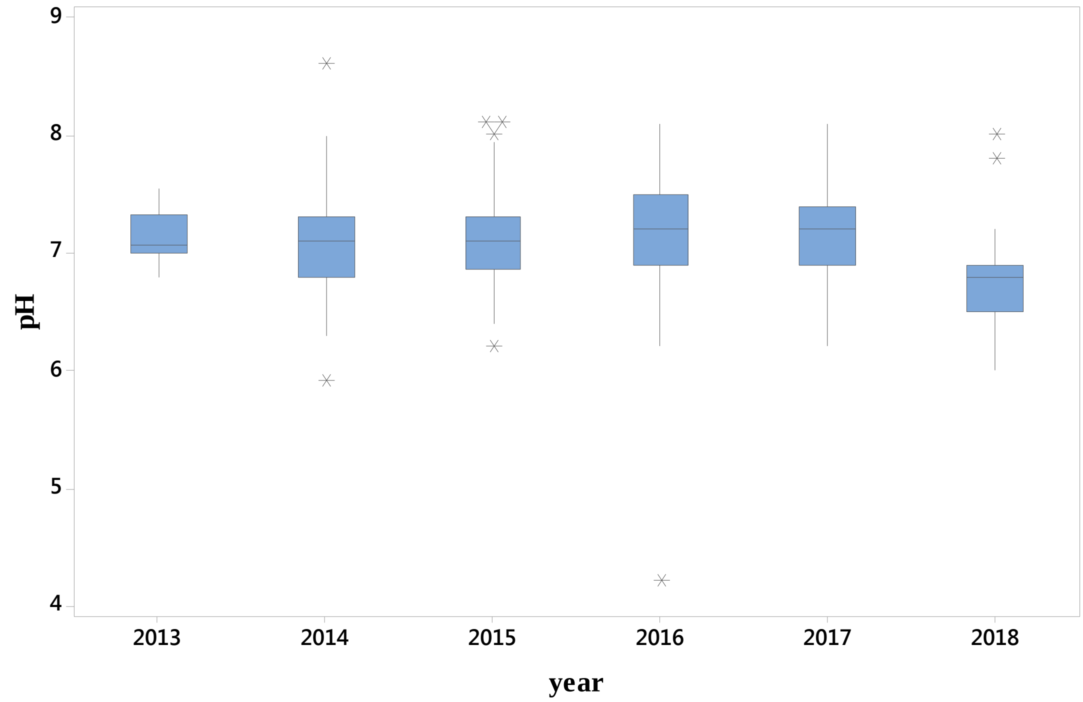

Fig. 4.5: Temporal variations of pH

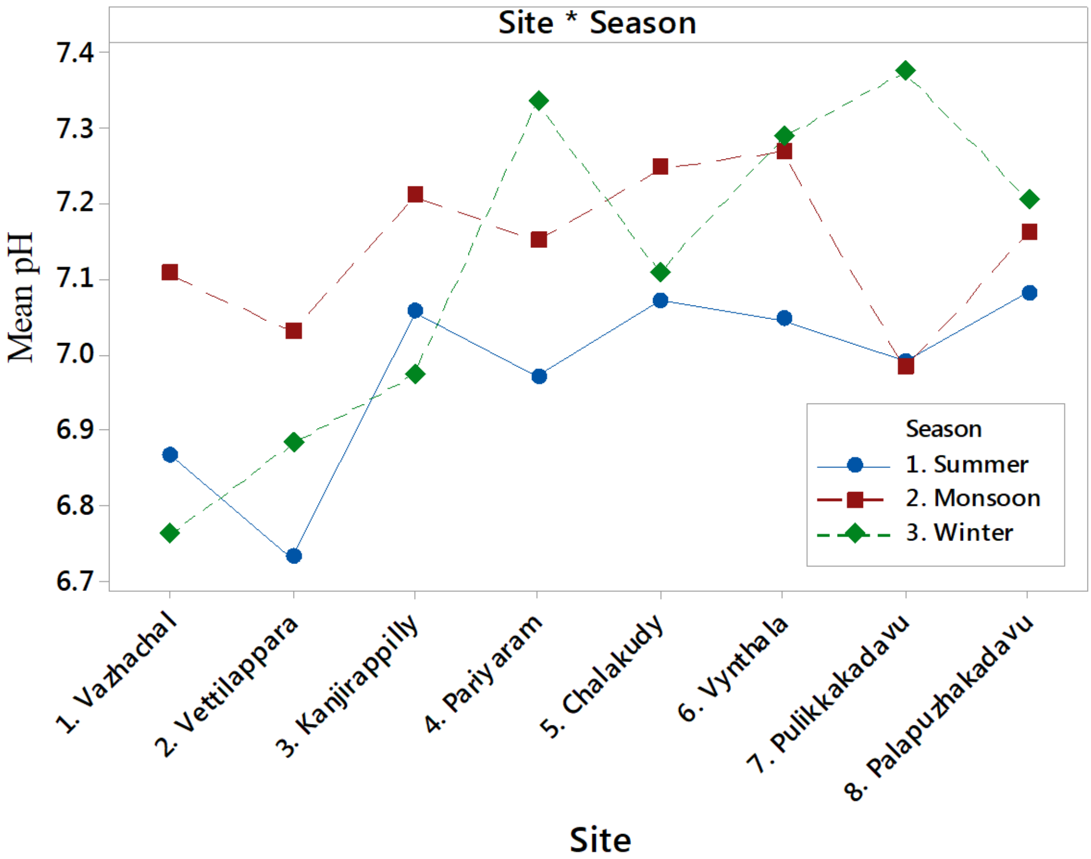

Fig. 4.6: Seasonal variations of pH

4.2.2.1 ANOVA results of pH

To evaluate the pH variations statistically, two-way analysis of variance (ANOVA) was carried out. By analyzing the results of Tukey method, the grouping information of variations in the mean pH values with respect to site and season were identified.

Table 4.51: ANOVA results of pH

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Season	2	2.59	2.59	1.3	7.49	0.001
Site	7	4.87	5.44	0.78	4.49	0
Season*Site	14	4.07	4.07	0.29	1.68	0.057
Error	432	74.75	74.75	0.17		
Total	455	86.28				

Table 4.51 and Table 4.52 are the ANOVA results of pH along the period of study. As per these results, P value of the season and sites, of pH were 0.001, and 0 respectively. This indicates that sites and seasons were statistically significant (season $P<0.001$, Site $P=0$) with pH ($P\leq0.05$). Sites, seasons and interaction effects on pH are statistically significant.

During summer seasons, significant variations on pH were found than in winter and in monsoon. During the period of study Vynthala, Pariyaram and Vettilappara sites were found to show significant changes in pH than other sites. The variation of pH at Vynthala site may be due to the salinity (Chlorides) and temperature effects on the site. The referred work (Chouhan. 2010) has specified that pH range 6.7 to 8.4 is very essential for the growth of aquatic biota. For most of the samples along the area of study, pH values met this standard (6.5-8.5) assigned by WHO and IS (IS.10500: 2012).

Table 4.52: Grouping Information Using Tukey Method at 95 % Confidence for pH

Season	**N**	**Mean**	**Grouping**		
Monsoon	176	7.1	A		
Winter	120	7.1	A		
Summer	160	6.9		B	
Site	**N**	**Mean**	**Grouping**		
Vynthala	57	7.2	A		
Pariyaram	57	7.2	A		
Palapuzhakadavu	57	7.1	A	B	
Chalakudy	57	7.1	A	B	
Pulikkakadavu	57	7.1	A	B	C
Kanjirappilly	57	7.1	A	B	C
Vazhachal	57	6.9		B	C
Vettilappara	57	6.9			C

4.2.3 Spatial, temporal and seasonal variations of Chlorides

Presence of Chlorides in the surface water of river along the area of study varies from 0.4 to 178.6 mg/l with an average 29.026 mg/l ± 23.95. Maximum Chloride value observed during the period of study is 178.6 mg/l at Vynthala site during September 2018. The washout water entry from the nearest water treatment plant containing bleaching powder might be the reason for this high value of chlorides at that particular period. Sea water intrusion has been found to contain chlorides. According to Bureau of Indian standards (BIS 10500, 2012), the maximum Chloride value permissible in drinking water is 250 mg/l. The lowest value for Chloride was observed 0.4 at Palapuzhakadavu site in February 2017.

The spatial and temporal variations of chlorides are shown Fig.4.7 and Fig.4.8. All the outliers in the box plot diagrams are much higher than the average values obtained during the period of study. But all these outliers are values within the permissible limits. Most of the surface water samples analysed during September 2018 (after flood) also were found to show outliers for all the parameters. During September 2018 (after flood), the level of contamination in the surface water was very high. It was due to the sudden decrease in the water discharge in the river.

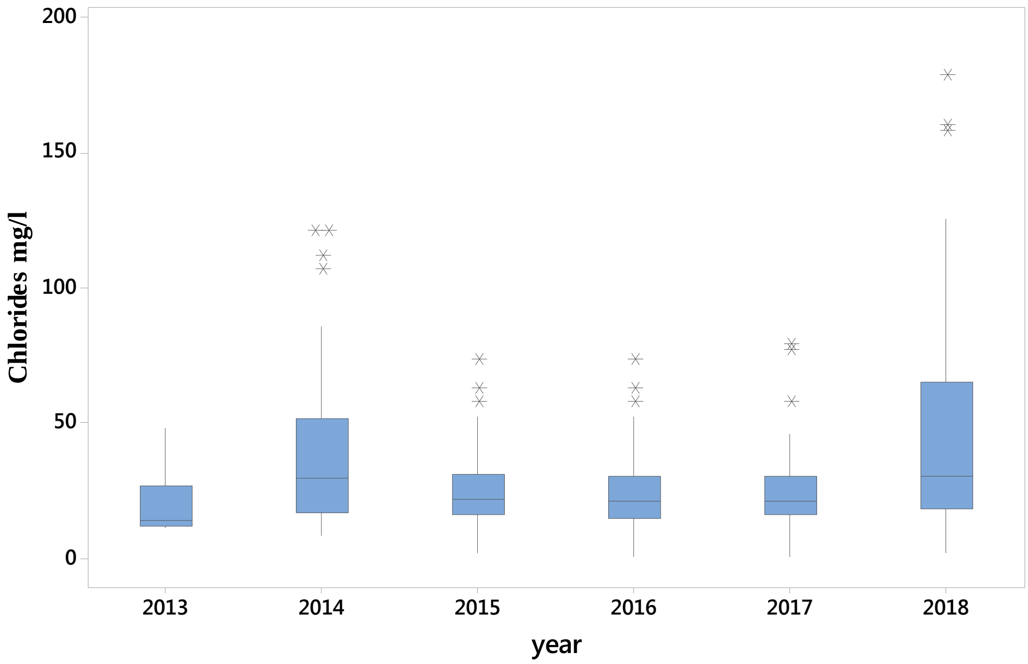

Fig. 4.7: Temporal variations of Chlorides

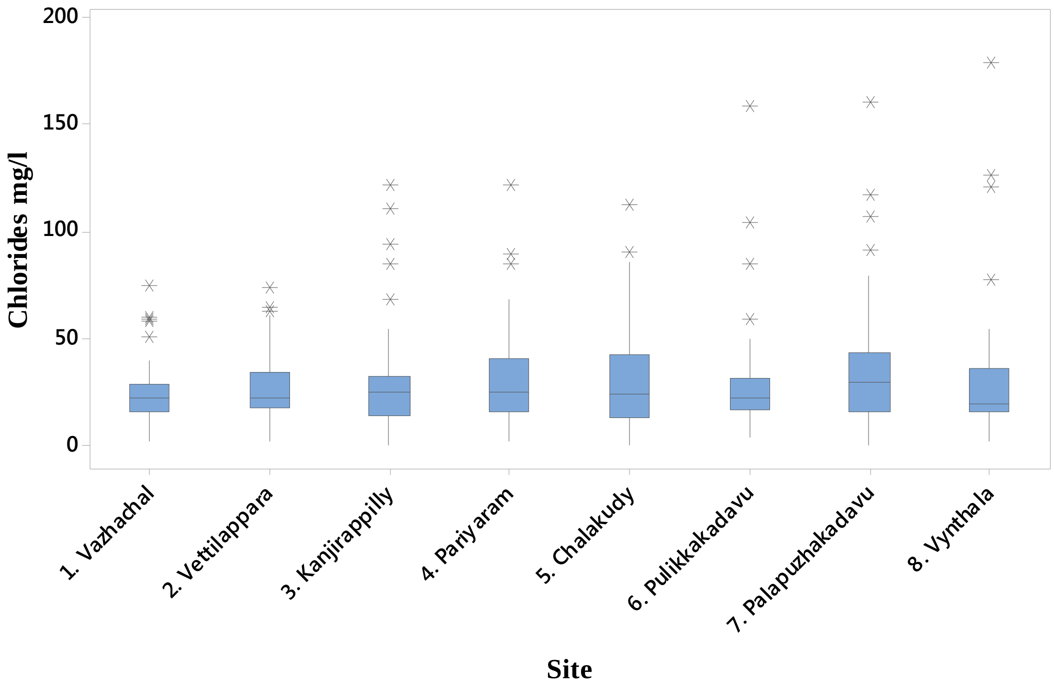

Fig. 4.8: Spatial variations of Chlorides

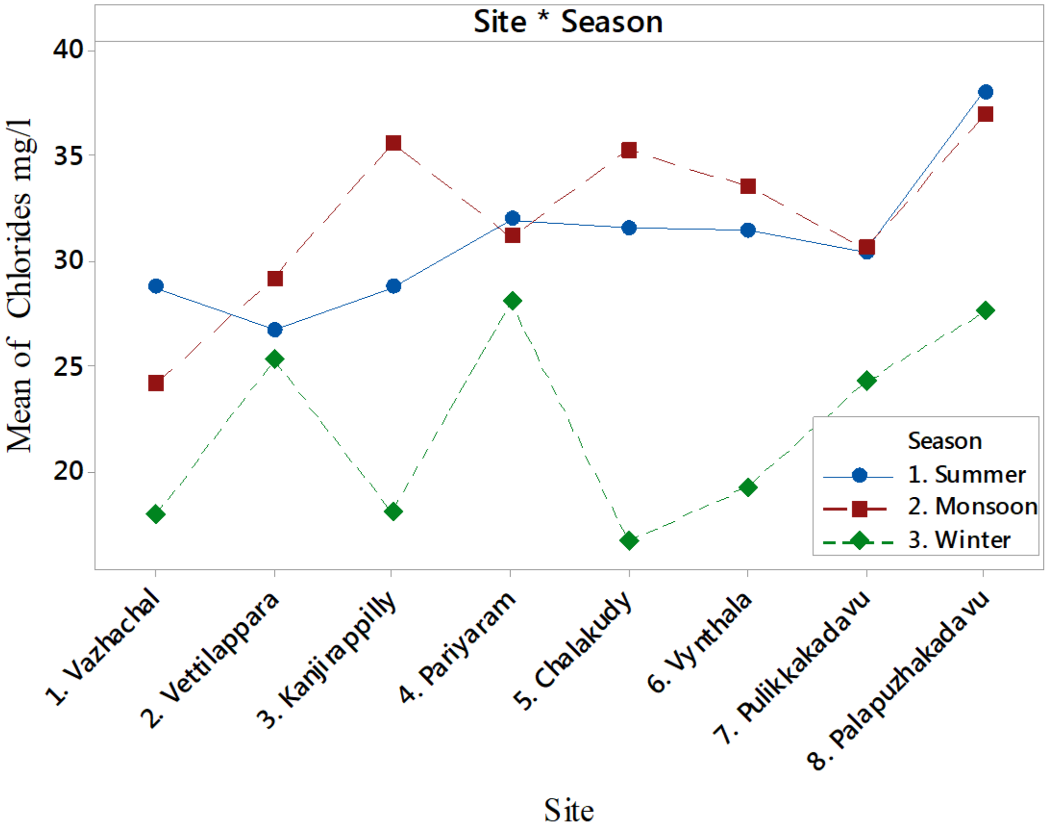

Fig. 4.9 Seasonal variations Chlorides

4.2.3.1 ANOVA results of Chlorides

Variations of Chlorides with respect to site and season were statistically analysed using two-way ANOVA. Along the period of study, variations of chlorides with respect to the season are statistically significant ($P < 0.05$) and the site is statistically not significant ($P = 0.525$). According to the post hoc analysis Tukey method, comparatively high mean values of chlorides were obtained during monsoon and summer seasons than in the winter season.

The ANOVA and post hoc ANOVA results are shown in Fig.4.9, Table 4.53 and Table 4.54. These results indicate that variations in the concentration of chloride during the period of study mainly depend on season. Weathering of rock salts also may be a strong reason for the variations in the chloride salts (Chottapathy.et.al., 2005). Comparatively high values of Chlorides were found in the Pariyaram site and towards the downstream. At Pariyaram, this may be due to the treated or untreated effluent discharge from the laundry situated near Kappathodu, which joins with the river at Pariyaram. However, all the values of chlorides were within the permissible limit of drinking water quality standard.

Table 4.53: ANOVA results of Chlorides, mg/l

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Season	2	7890	7890	3945	6.91	0.001
Site	7	3618	3503	501	0.88	0.525
Season*Site	14	2916	2916	208	0.36	0.984
Error	432	246607	246607	571		
Total	455	261030				

Table 4.54: Grouping Information Using Tukey Method at 95 % Confidence for Chlorides, mg/l

Season	N	Mean	Grouping	
Monsoon	176	32	A	
Summer	160	30.9	A	
Winter	120	22.1		B
Site	**N**	**Mean**	**Grouping**	
Palapuzhakadavu	57	34.1	A	
Pariyaram	57	30.4	A	
Pulikkakadavu	57	28.4	A	
Vynthala	57	28	A	
Chalakudy	57	27.8	A	
Kanjirappilly	57	27.4	A	
Vettilappara	57	27	A	
Vazhachal	57	23.6	A	

4.2.4 Spatial, temporal and seasonal variations of COD

COD of river water along the study area varies from 0.76 mg/l to 12.2 mg/l with an average 4.483 mg/l ± 1.56. Maximum COD value 12.2mg/l was observed during the study period at Pulikkakadavu site during March 2018. The lowest COD value 0.76 mg/l was observed at Vazhachal site during January 2014. The box plot representations of temporal and special variations of COD are shown in Fig.4.10 Fig. 4.11 and Fig.4.12. the plots represents the significance variations in COD.

At some sites, the COD of the water samples were high especially at Pariyaram, Pulikkakadavu, Chalakudy and Palapuzhakadavu sites. During the year 2015, 2016, 2017, and 2018, some outlier values (>8) of COD were obtained; it might be due to the treated or untreated industrial effluent discharge at Pariyaram and Pulikkakadavu sites. These elevated values of COD in these sites might be due to the human anthropogenic activities such as sewage discharge, urban land use, and farm waste discharge as the part of cattle and poultry activities. All these high values compared with yearly average value are shown as outliers in the box plot representation. Most of the results showed very low values of COD at Vazhachal site along the period of study.

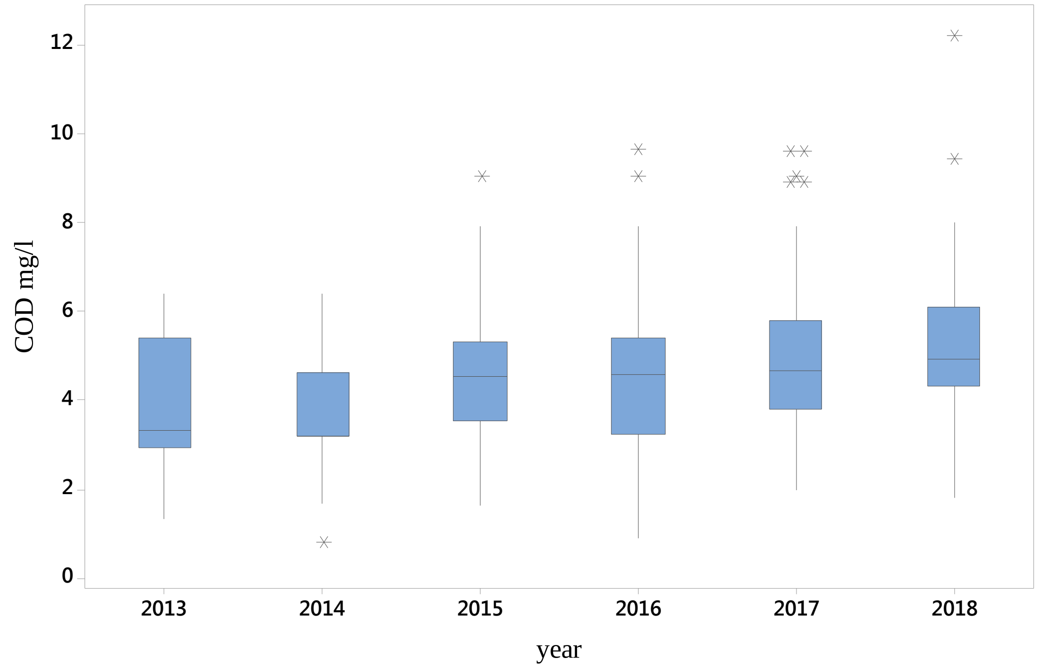

Fig.4.10: Temporal variations of COD

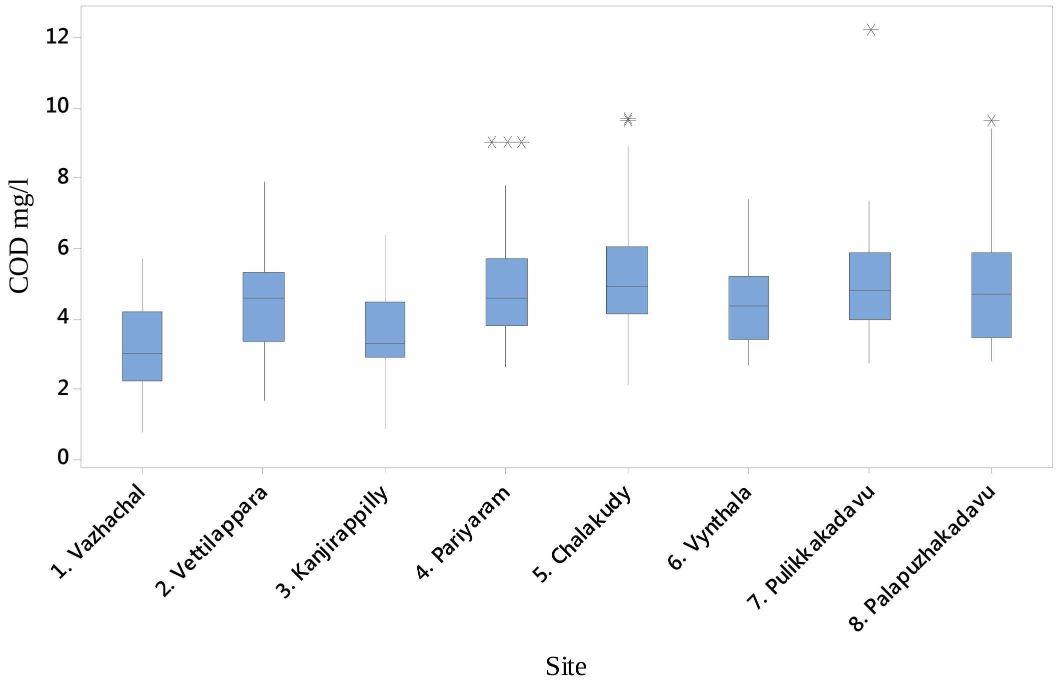

Fig.4.11: Spatial variations of COD

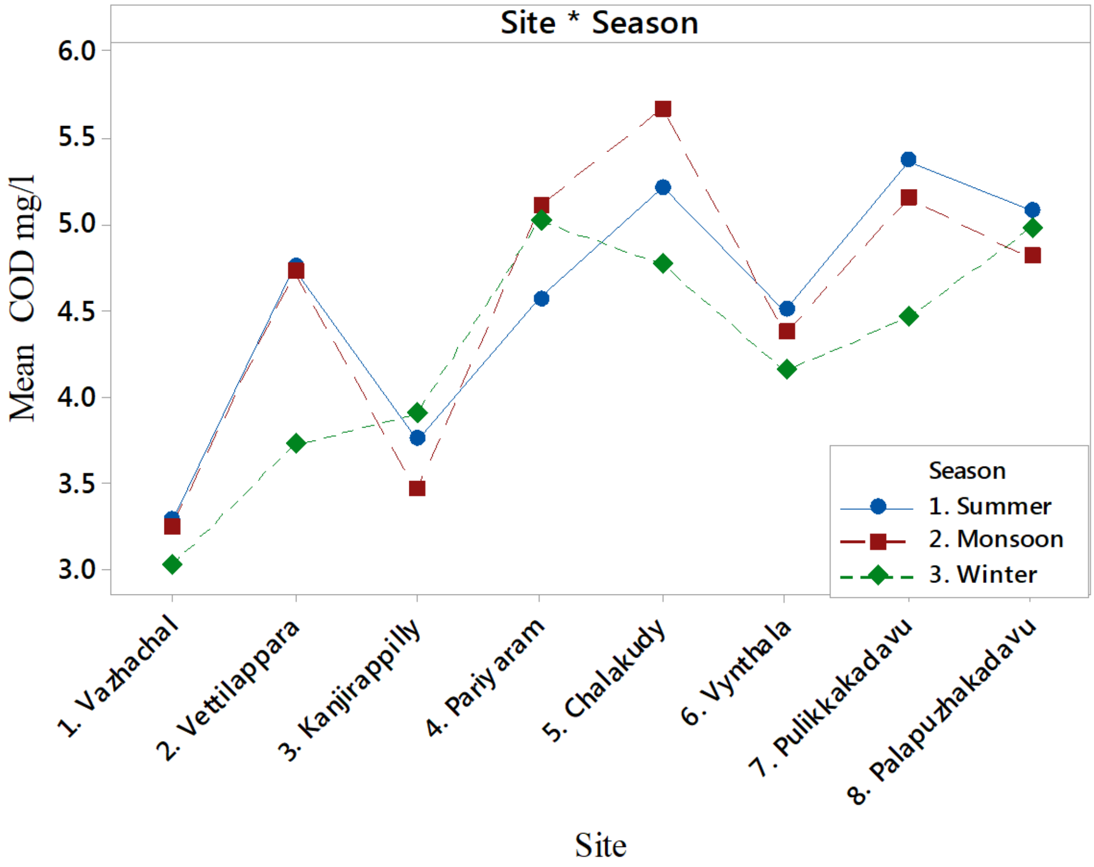

Fig.4.12: Seasonal variations of COD

4.2.4.1 ANOVA results of COD

Table 4.55: ANOVA analysis result of COD, mg/l

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Season	2	8.7	8.7	4.3	2.16	0.117
Site	7	206.8	194.7	27.8	13.87	0
Season*Site	14	25.4	25.4	1.8	0.9	0.554
Error	432	866.6	866.6	2		
Total	455	1107.5				

Table 4.56: Grouping Information Using Tukey Method at 95 % Confidence for COD, mg/l

Season	N	Mean	Grouping			
Monsoon	176	4.6	A			
Summer	160	4.6	A			
Winter	120	4.3	A			
Site	**N**	**Mean**	**Grouping**			
Chalakudy	57	5.2	A			
Pulikkakadavu	57	5	A	B		
Palapuzhakadavu	57	5	A	B		
Pariyaram	57	4.9	A	B		
Vettilappara	57	4.4		B	C	
Vynthala	57	4.3		B	C	
Kanjirappilly	57	3.7			C	D
Vazhachal	57	3.2				D

Variations in the mean value of COD were shown in Fig.4.12. The analysis results by two-way ANOVA and grouping information by Tukey method are shown in Table.4.55 and Table.4.56. From these results, it is clear that along the period of the study site is an only significant factor (P=0) in the COD variations observed in the river. At Pariyaram, Chalakudy, Pulikkakadavu, and Palapuzhakadavu sites were found to have high mean values of COD. However, as per the posthoc ANOVA results, Chalakudy site was found to have higher COD values than the other sampling sites.

4.2.5 Spatial, temporal and seasonal variations of DO

DO of river water along the study area ranges from 5.2 mg/l to 8mg/l with an average ± SD 6.89 mg/l ± 0.58. Maximum DO values observed during the study period is 8mg/l at Pariyaram site during August 2014. The lowest DO values of were 5.2 mg/l observed at Pulikkakadavu, Chalakudy, and Vynthala sites during March 2018. Temperature is highly correlated with DO. During summer, river water flow is very low to the extent of no water in certain places. High temperature may results in low solubility of oxygen. This also affects adversely on the health of the river. Maximum mean values of DO were found at Pariyaram, Vynthala and at Vazhachal sites during monsoon.

Box plot representations of spatial and temporal variations of DO are shown in Fig.4.13 and Fig. 4.14. The seasonal changes are represented by the mean value plot

Fig.4.15. DO is commonly reduced in the water because of the decomposition of organic matter, effect of high water temperature, respiration of aquatics, oxygen consumable wastes, and inorganic reluctant such as hydrogen sulphide , ammonia, nitrates etc (Barman et al, 2000).

According to the environmental quality standard, prescribed values of DO for drinking purpose is 6 mg/, 4 to 5 mg/l for desirable for recreation. DO levels below 4 mg/l will not support fish; levels of 5 to 6 mg/l are usually required for most of the fish cultivation. DO content is one of the most important factor of river health. Lack of DO directly affects the ecosystem of a river due to bioaccumulation and biomagnifications (Kannel et al., 2007). Oxygen is the most important gas for most aquatic organisms; free oxygen (O_2) or DO is needed for the respiration of aquatic organisms. The minimum value of DO levels 5.2 mg/l indicates the river can consider as healthy as long as with minimum DO. This might be a reason for the survival of special fishes in this river. All the comparatively low values of DO are shown as outliers in the box plot representation. Minimum values of DO were observed compared with the yearly average value during the year 2014.

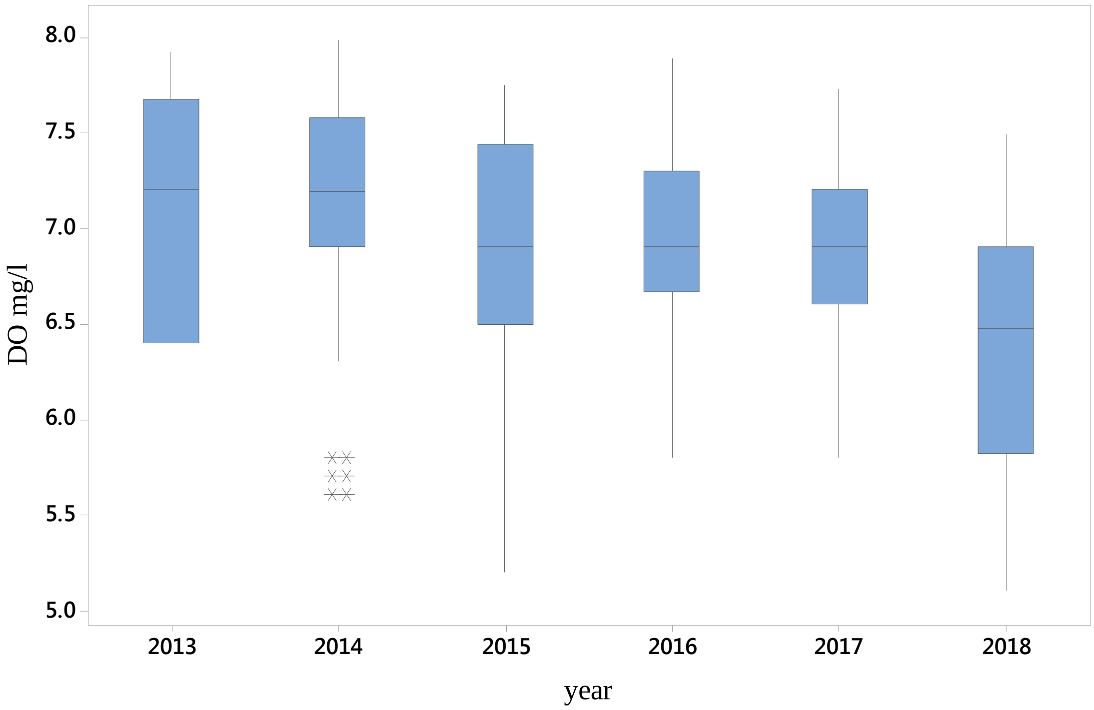

Fig.4.13: Temporal variations of DO

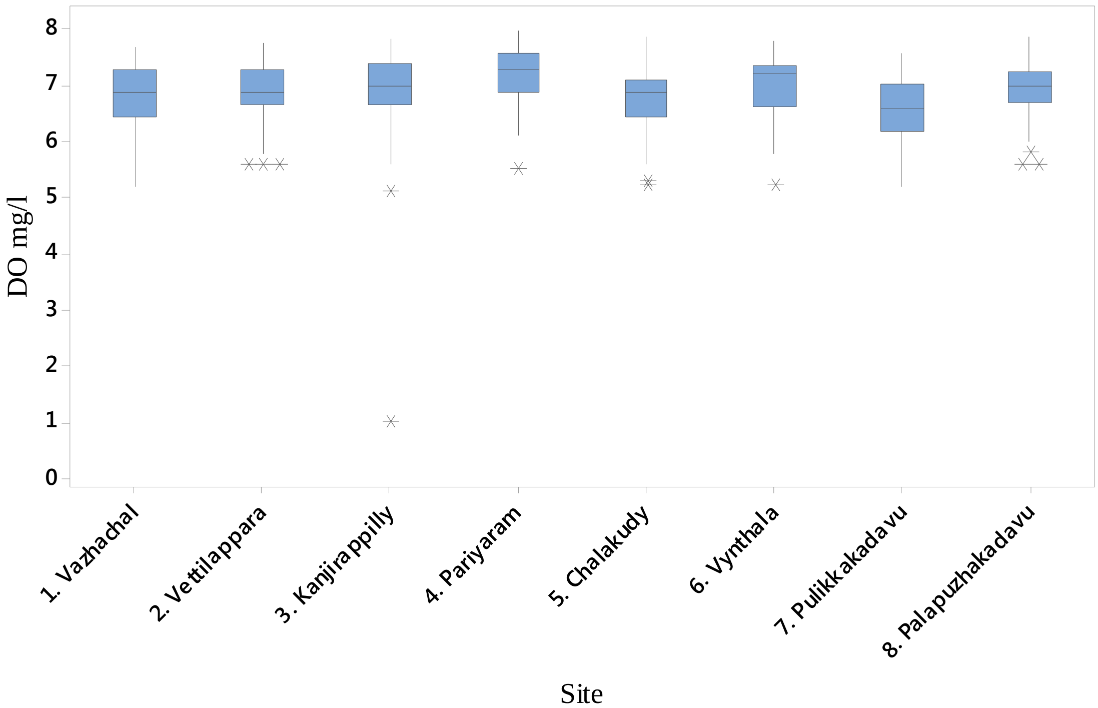

Fig.4.14. Spatial variations of DO

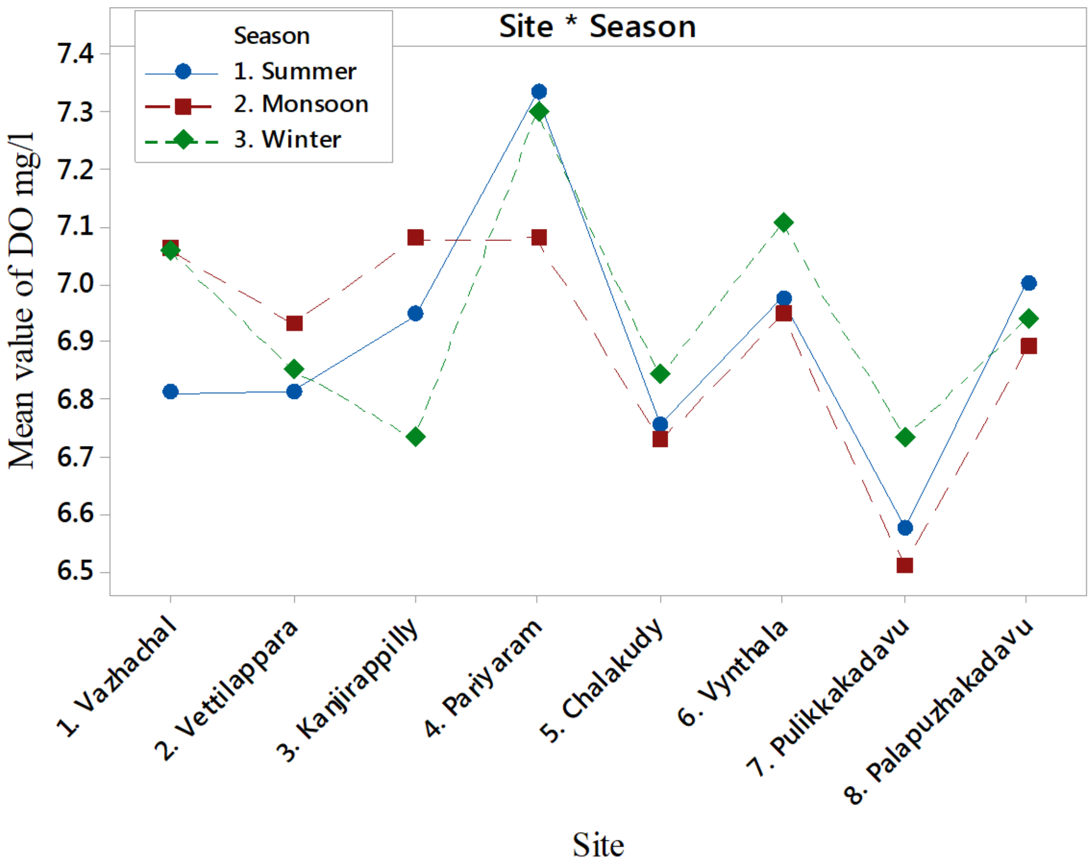

Fig. 4.15: Seasonal variations of DO.

4.2.5.1 ANOVA results of DO

Table 4.57: ANOVA results of DO, mg/l

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Season	2	0.42	0.42	0.21	0.53	0.59
Site	7	13.37	13.15	1.88	4.69	0
Season*Site	14	3.92	3.92	0.28	0.7	0.775
Error	432	172.94	172.94	0.4		
Total	455	190.66				

Table 4.58: Grouping Information Using Tukey Method at 95 % Confidence for DO, mg/l

Season	N	Mean	Grouping		
Winter	120	6.9	A		
Monsoon	176	6.9	A		
Summer	160	6.9	A		
Site	**N**	**Mean**	**Grouping**		
Pariyaram	57	7.2	A		
Vynthala	57	7	A	B	
Palapuzhakadavu	57	6.9	A	B	C
Vettilappara	57	6.9		B	C
Vazhachal	57	6.8		B	C
Kanjirappilly	57	6.8		B	C
Chalakudy	57	6.8		B	C
Pulikkakadavu	57	6.6			C

As per the ANOVA results listed in Table 4.57 and Table 4.58 , it is clear that in the case of DO level, site is significant (P=0) with the variations of DO. Pariyaram site showed comparatively high values of mean DO. Pulikkakadavu site was found to have low mean values of DO.

4.2.6 Spatial, temporal and seasonal variations of Electrical Conductivity

During the period of study, EC value ranges from 6 µmhos/cm to 390 µmhos/cm with an average ± SD, 82.12 µmhos/cm ± 56µmhos/cm. Maximum EC value observed is 390 µmhos/cm at Chalakudy site during September 2018. The lowest EC values observed 6µmhos/cm at Chalakudy during January 2016.

Fig.4.16, Fig.4.17, and Fig.4.18 are the box plot representations of spatial, temporal and seasonal variations of EC. A very high EC value indicates high presence of ionized inorganic substances in the water (Gupta.et.al. 2013). All these high values compared with yearly average value are shown as outliers in the box plot representation.

At Palapuzhakadavu , Pariyaram and Chalakudy sites were found to have high values of EC. This may be due to increased concentration of dissolved solids due to relatively low flow of water, increased evaporation during summer and the inflow of sewage discharge from the urban area. Because of the nearby areas of these sites are thickly populated. However, all the values obtained during this study period are within the recommended standard (IS 2012).

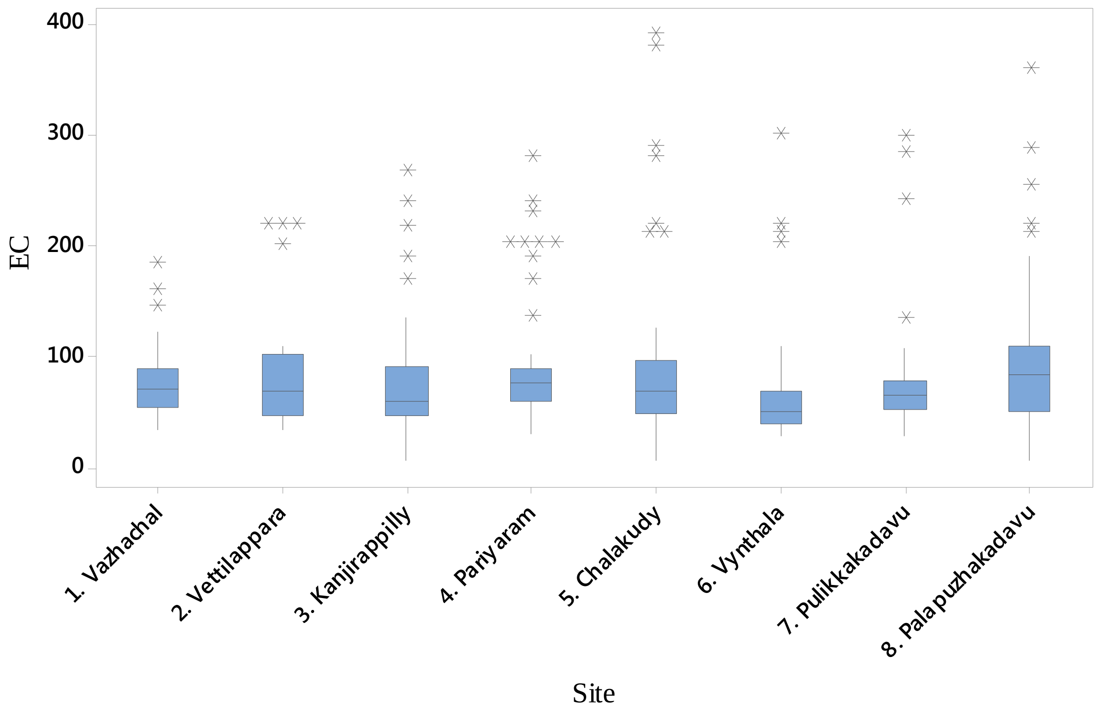

Fig. 4.16: Spatial variations of EC μmhos/cm

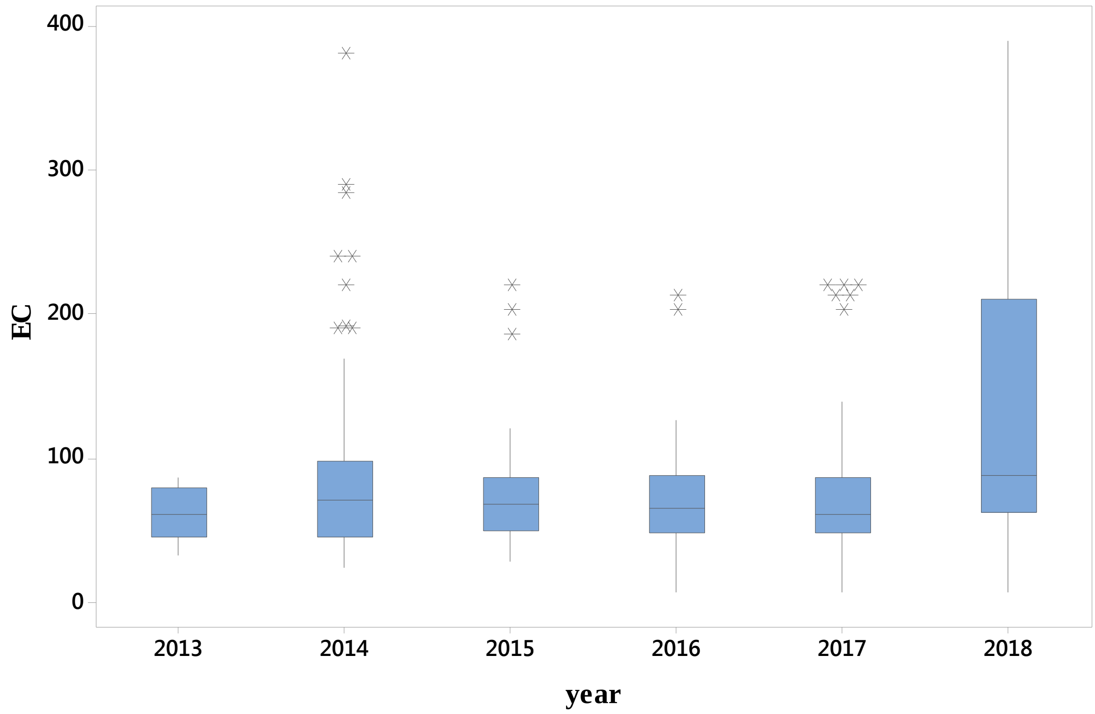

Fig. 4.17: Temporal variations of EC µmhos/cm

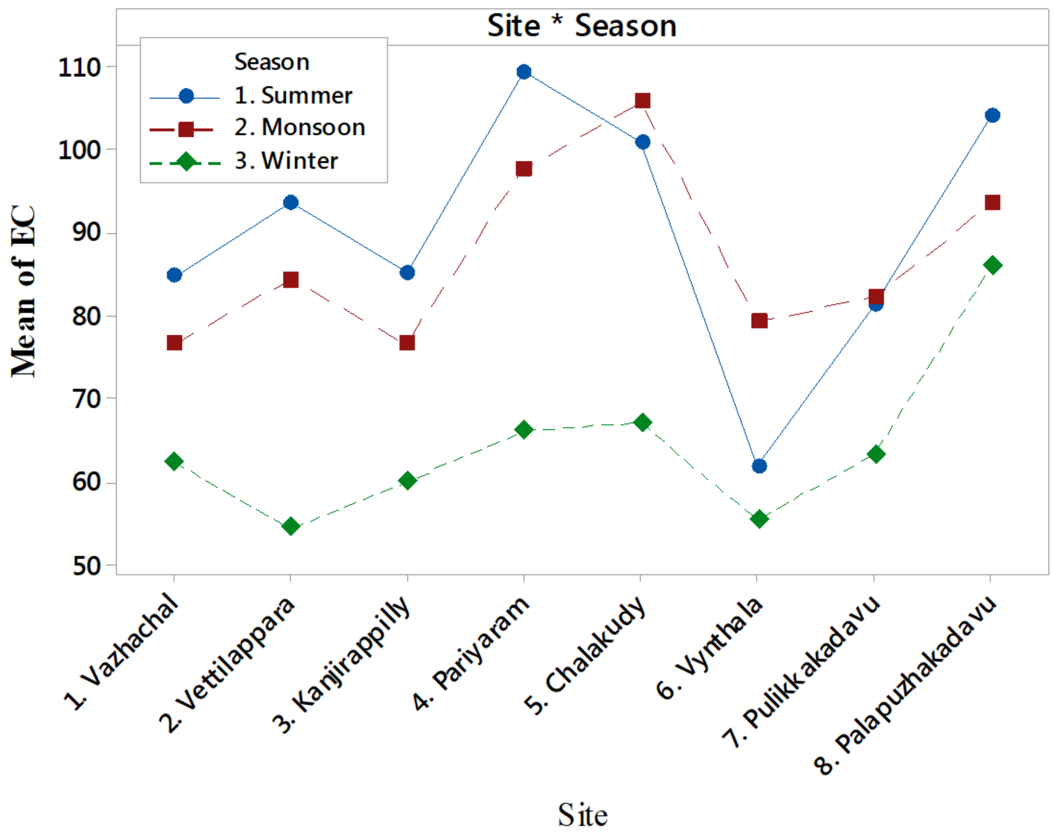

Fig. 4.18: Seasonal variations of EC µmhos/cm

In the EC values, along the period of study, large seasonal variation was observed. All these are comparatively high values and are shown as outliers in the box plot representation. Maximum values of EC were observed during the year 2014 and 2018 (after flood).

4.2.6.1 ANOVA results of EC

Table 4.59: ANOVA analysis result of for EC, µmhos/cm

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Season	2	52503	52503	26251	8.63	0
Site	7	45361	42337	6048	1.99	0.055
Season*Site	14	15467	15467	1105	0.36	0.984
Error	432	1313563	1313563	3041		
Total	455	1426893				

During summer, high value of electrical conductivity was found in all sites. As per the ANOVA results shown in Table 4.59 and Table 4.60, EC decreased significantly during winter. Statistically significant variations were observed in EC between sites (P=0.05) and seasons (P=0) along the period of study. The dilution after getting monsoon may cause a low value of EC. Except some values, all the other EC values during the period of study were within the permissible limit (300µmhos/cm) of drinking water standards.

Table 4.60: Grouping Information Using Tukey Method at 95 % Confidence for EC, µmhos/cm

Season	N	Mean	Grouping	
Summer	160	90.1	A	
Monsoon	176	87	A	
Winter	120	64.3		B
Site	**N**	**Mean**	**Grouping**	
Palapuzhakadavu	57	94.5	A	
Chalakudy	57	91.3	A	
Pariyaram	57	91.1	A	
Vettilappara	57	77.4	A	
Pulikkakadavu	57	75.6	A	
Vazhachal	57	74.5	A	
Kanjirappilly	57	73.9	A	
Vynthala	57	65.5	A	

4.2.7 Spatial, temporal and seasonal variations of Fecal coliform

Variations in FC CFU/100ml in the river water along the study area ranges from 20 to 2150 CFU/100ml with an average ± SD, 250.3 CFU/100ml ± 327.8. Maximum FC value observed during the period of study was 2150 CFU/100ml at Chalakudy site during September 2018. The main reason for the increase in FC value in 2018 might be due to the impact of flood in the river, in August 2018.

The highest value of FC was observed 600 CFU/100ml before the flood. The lowest FC value was observed 20 CFU/100ml at Vazhachal site during February 2014. The low values of FC observed during winter, might be due to cold climatic conditions, which was not been supportive for bacterial duplication largely (Meitei et al, 2004). Box plot representation of spatial, temporal and seasonal variations of FC is shown in Fig .4.19, Fig.4.20 and Fig.4.21. FC in Chalakudy site and Palapuzhakadavu site were found to shown an increasing trend in all the three seasons. All these high values compared with yearly average value are shown as outliers in the box plot representation.

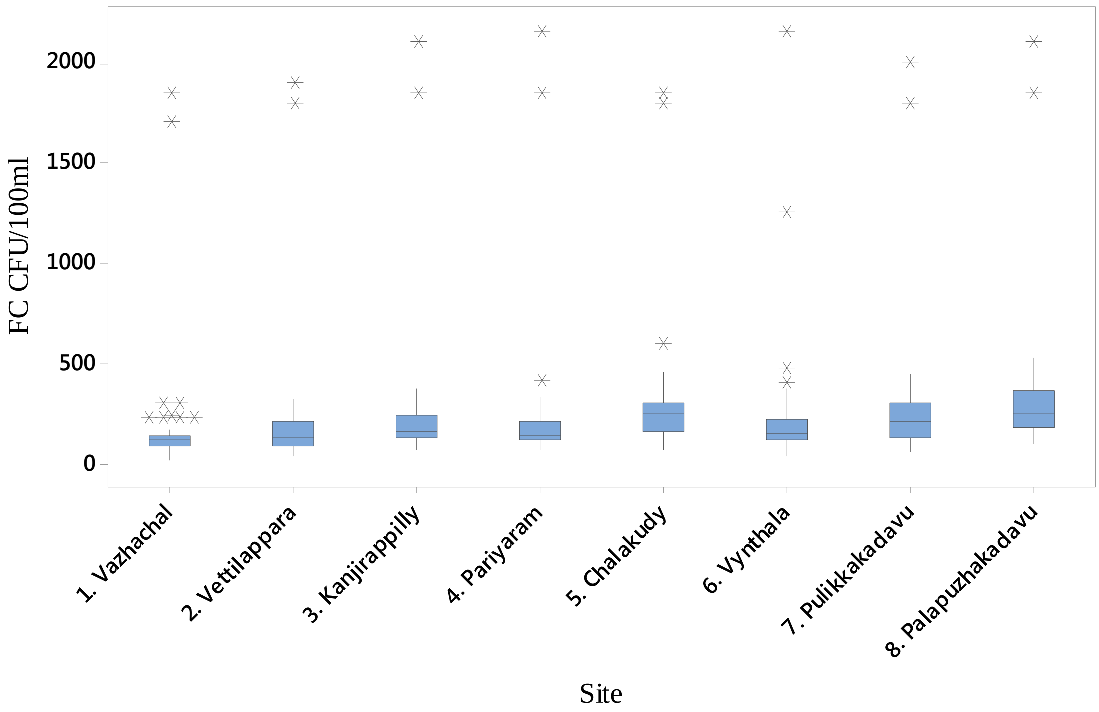

Fig. 4.19: Spatial variations of FC CFU/100ml

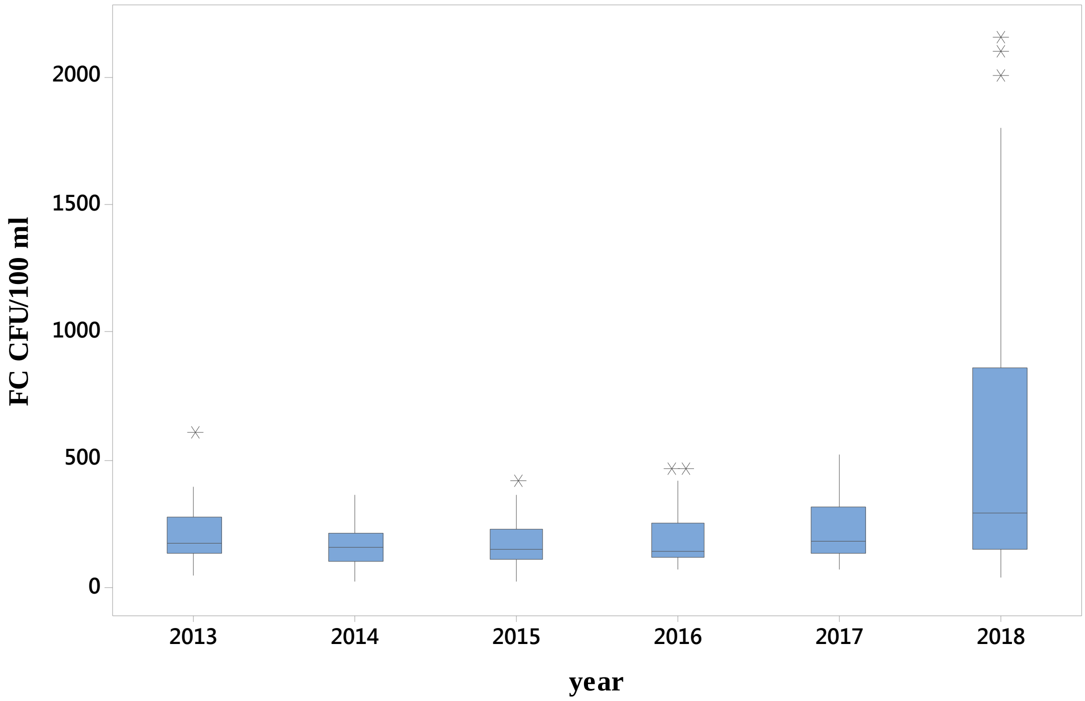

Fig. 4.20: Temporal variations of FC CFU/100ml

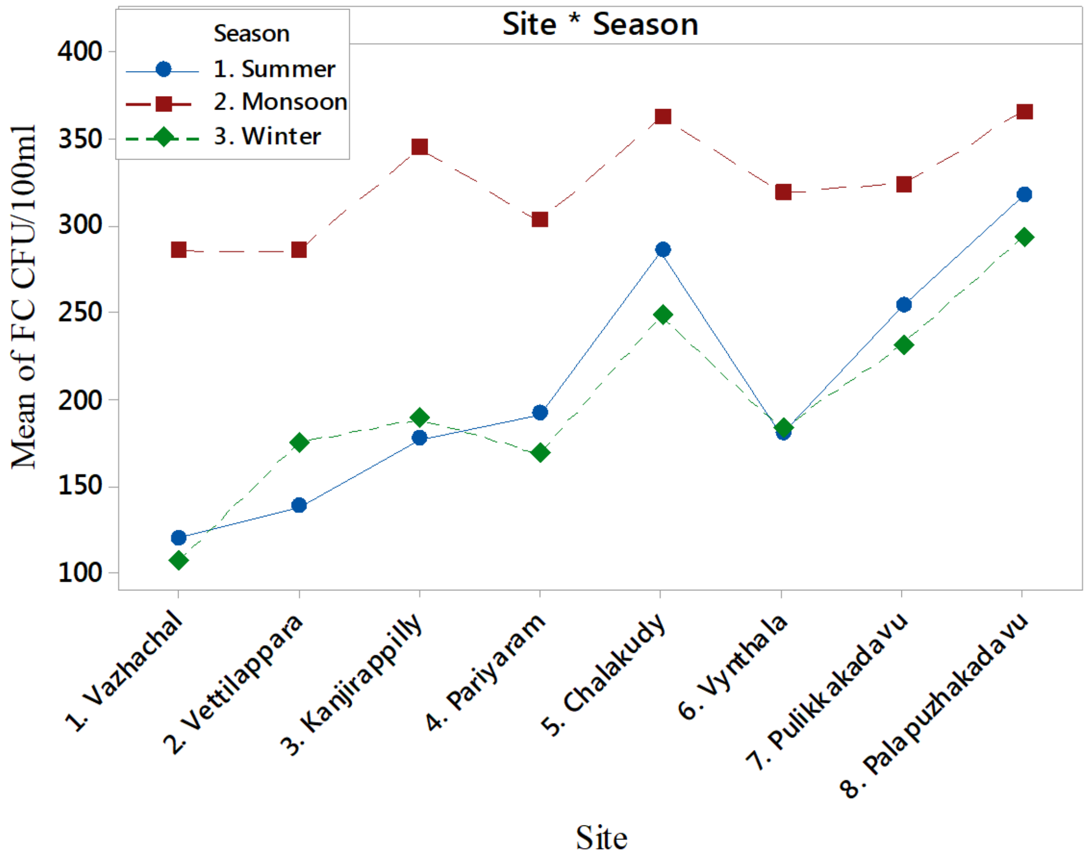

Fig.4.21: Seasonal variations of FC CFU/100ml

4.2.7.1 ANOVA results of FC

Table 4.61: ANOVA results of FC, CFU/100ml

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Season	2	1556753	1556753	778376	7.28	0.001
Site	7	1010465	1029947	147135	1.38	0.213
Season*Site	14	185052	185052	13218	0.12	1
Error	432	46164103	46164103	106861		
Total	455	48916372				

From the ANOVA results shown in Table 4.61 and grouping information from Tukey method Table 4.62, it is clear that season is statistically significant (P=0.001) with the variations in FC. During the period of the study, all the sites downstream from Kanjirappilly showed high FC values than upstream sites. It is clear that the load of bacterial contamination is high at the downstream of this river than upstream sites.

Table 4.62: Grouping Information Using Tukey Method at 95 % Confidence for FC, CFU/100ml

Season	N	Mean	Grouping	
Monsoon	176	323.9	A	
Summer	160	207.7		B
Winter	120	199.3		B
Site	**N**	**Mean**	**Grouping**	
Palapuzhakadavu	57	325.4	A	
Chalakudy	57	298.8	A	
Pulikkakadavu	57	269.6	A	
Kanjirappilly	57	236.9	A	
Vynthala	57	227.6	A	
Pariyaram	57	221	A	
Vettilappara	57	199.2	A	
Vazhachal	57	170.5	A	

Among these sites, Chalakudy and Palapuzhakadavu were found to have high values of FC. It might be due to the discharge of domestic wastes containing fecal matters to the river body and open defecation along the sides of the riverbank through seasonal runoff. At all the sites during the period of study, high FC values were observed in the river water.

4.2.8 Spatial, temporal and seasonal variations of Nitrates

Nitrates values in the Chalakudy river water along the period of study ranged from 0.03 mg/l to 7.89 mg/l with the mean value of 0.66 ± 0.434 mg/l. The maximum obtained value of nitrates along the study period was within the permissible limit as per the drinking water standards (45 mg/l). The sources of nitrates contributing to the natural water bodies are anthropogenic activities, uses of fertilizer, landfill by domestic wastes and discharge of sewage wastes (Singh., 2001). The box plot representations of temporal, spatial and seasonal variations of nitrates are shown in Fig.4.22, Fig.4.23 and Fig 4.24 respectively. It is evident from the box plots that the sites downstream from Pulikkakadavu were found to have the maximum value of nitrates after the flood in Aug 2018. All these high values compared with yearly average value are shown as outliers in the box plot representation. During all other season, all the values were found to be within the standards.

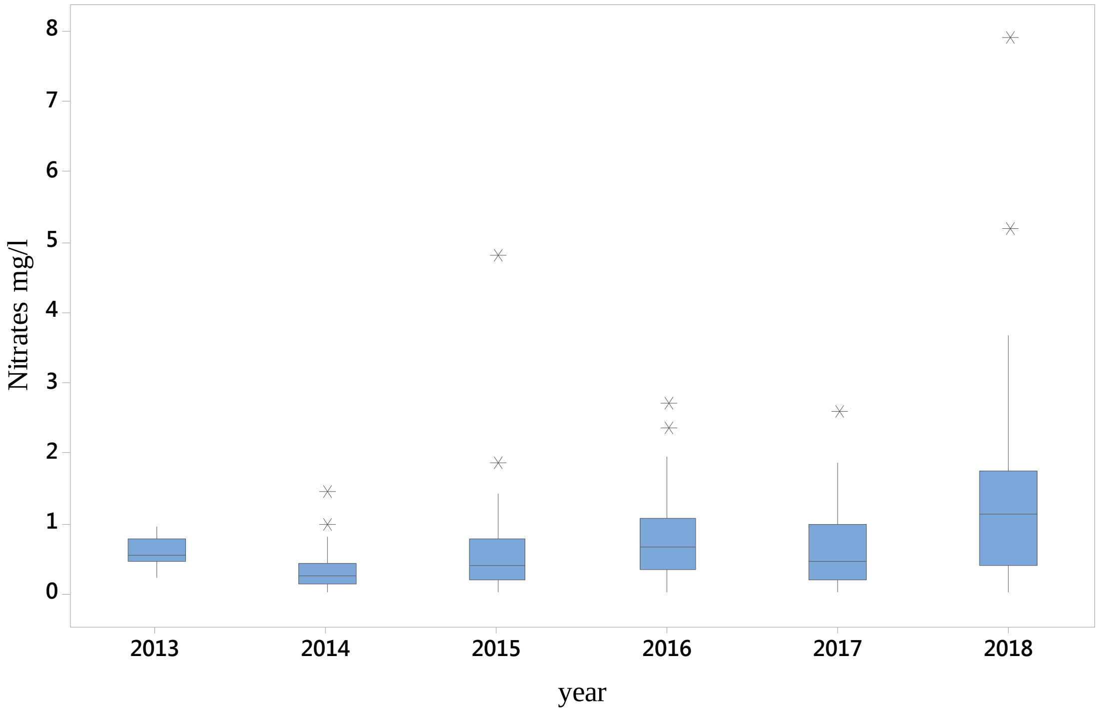

Fig. 4.22: Temporal variations of Nitrates

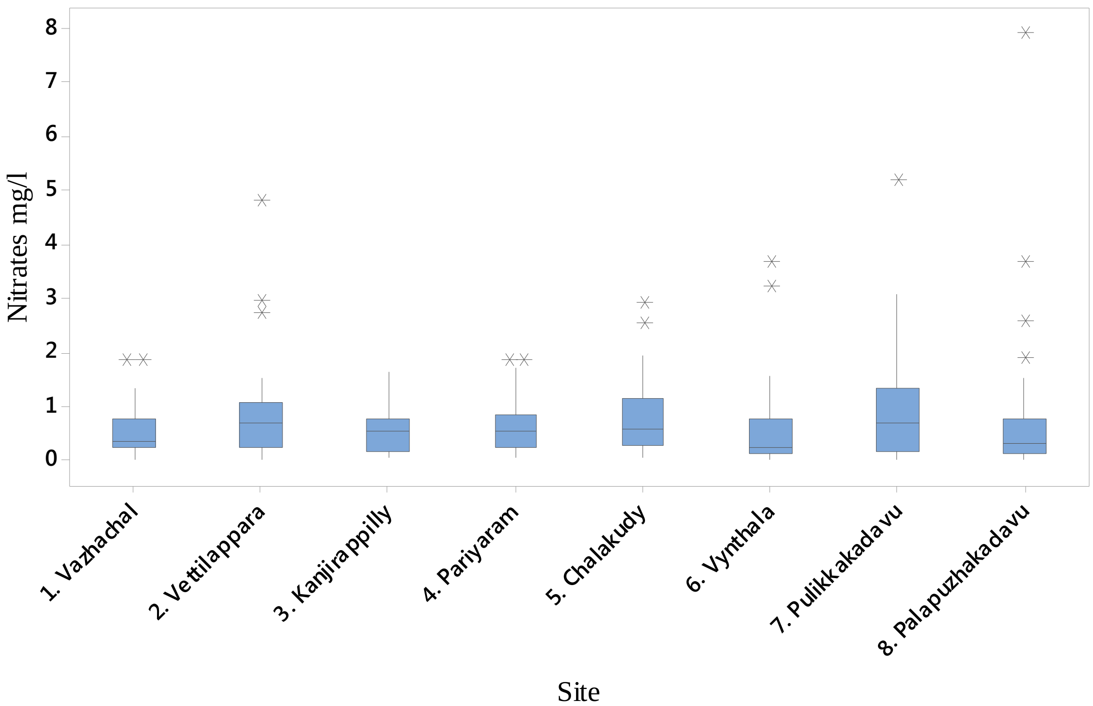

Fig.4.23: Spatial variations of Nitrates

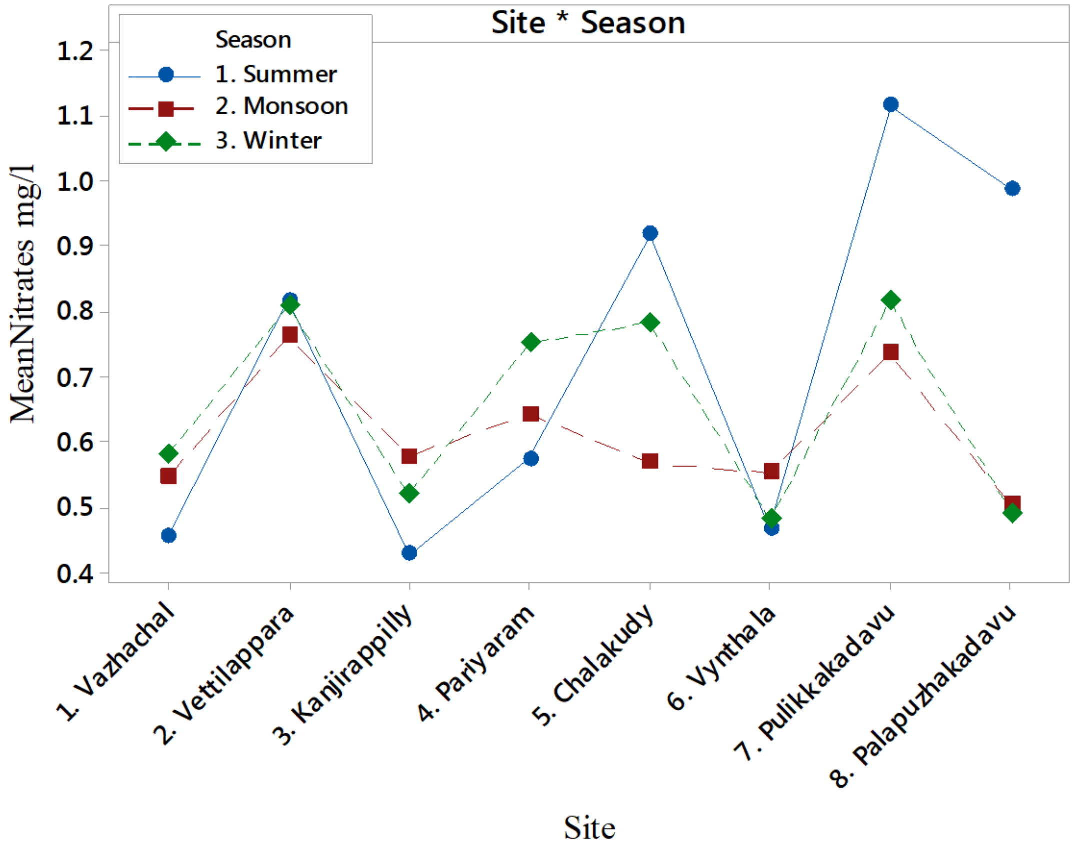

Fig.4.24: Seasonal variations of Nitrates

4.2.8.1 ANOVA results of nitrates

The ANOVA analysis results and Tukey analysis results were shown in Table.4.63 and Table 4.64. As per the ANOVA results, the site is significant with the variations of nitrates level in the river water and grouping information obtained by the Tukey method, it was observed that all the season at Pulikakadavu site showed comparatively high values of nitrates. That surely due to the discharge of effluent from the DCP plant in to the river.

Table 4.63: ANOVA analysis result of Nitrates

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Season	2	1.02	1.02	0.51	0.95	0.389
Site	7	8.26	8.15	1.16	2.17	0.036
Season*Site	14	5.84	5.84	0.42	0.77	0.697
Error	432	232.4	232.4	0.54		
Total	455	247.51				

Table 4.64: Grouping information at 95 % confidence for Nitrates mg/l, using the Tukey Method

Season	N	Mean	Grouping	
Summer	160	0.7	A	
Winter	120	0.7	A	
Monsoon	176	0.6	A	
Site	**N**	**Mean**	**Grouping**	
Pulikkakadavu	57	0.9	A	
Vettilappara	57	0.8		B
Chalakudy	57	0.8		B
Palapuzhakadavu	57	0.7		B
Pariyaram	57	0.7		B
Vazhachal	57	0.5		B
Kanjirappilly	57	0.5		B
Vynthala	57	0.5		B

4.2.9. Spatial, temporal and seasonal variations of phosphates

Phosphates variations in the water samples of Chalakudy river during the period of study ranged from 0 mg/l (absence) to 5.5mg/l with the mean value of 0.7 ± 0.81 mg/l. The maximum value of phosphates obtained along the period of study was during February 2014 at Vynthala site. The observed values were within the permissible limit as per the drinking water specifications (≤6 mg/l). Most of the samples, the presence of phosphates was not detected. The maximum mean value of phosphates obtained was 1.1 mg/l. As per Fig.4.25, Fig. 4.26, Fig.4.27. It was identified that Vettilappara, Vynthala, Chalakudy, and Palapuzhakadavu sites have presence of more phosphates than in the water samples collected from other sites. All these high values compared with yearly average values are shown as outliers in the box plot representation.

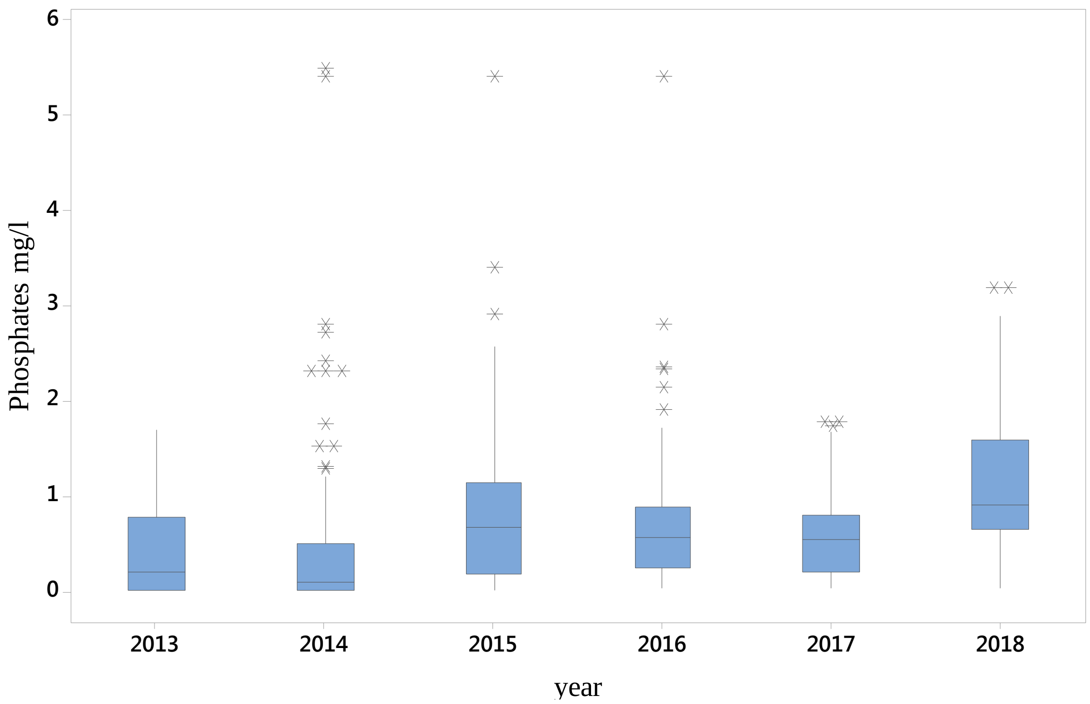

Fig.4.25: Temporal variations of Phosphates

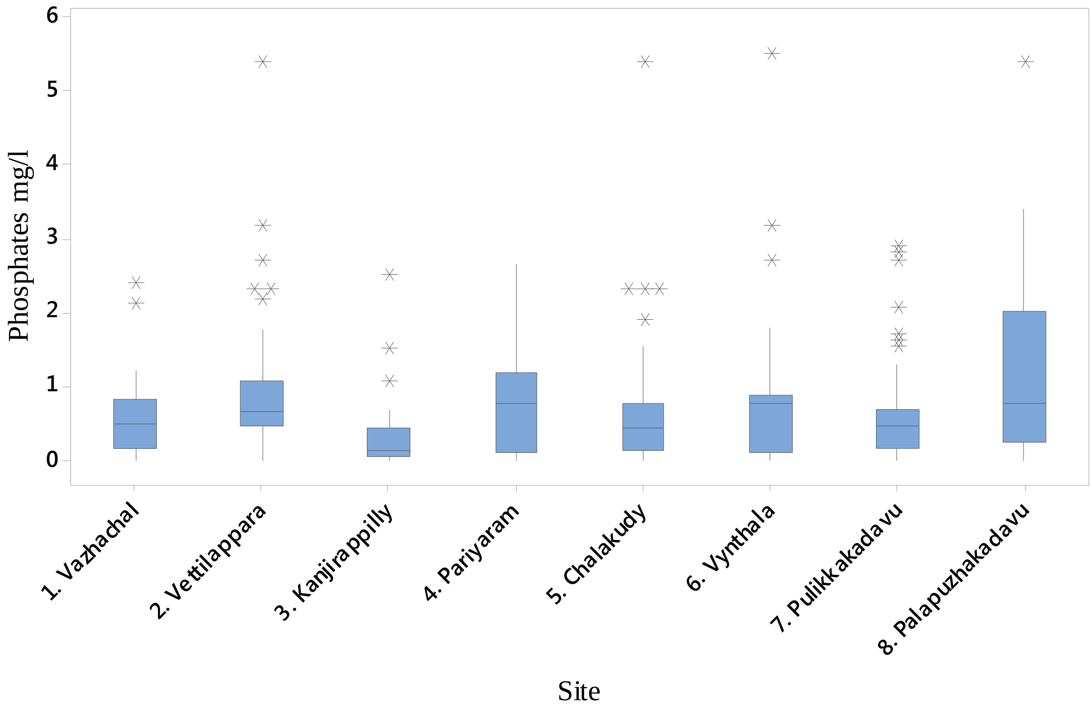

Fig.4.26: Spatial variations of Phosphates

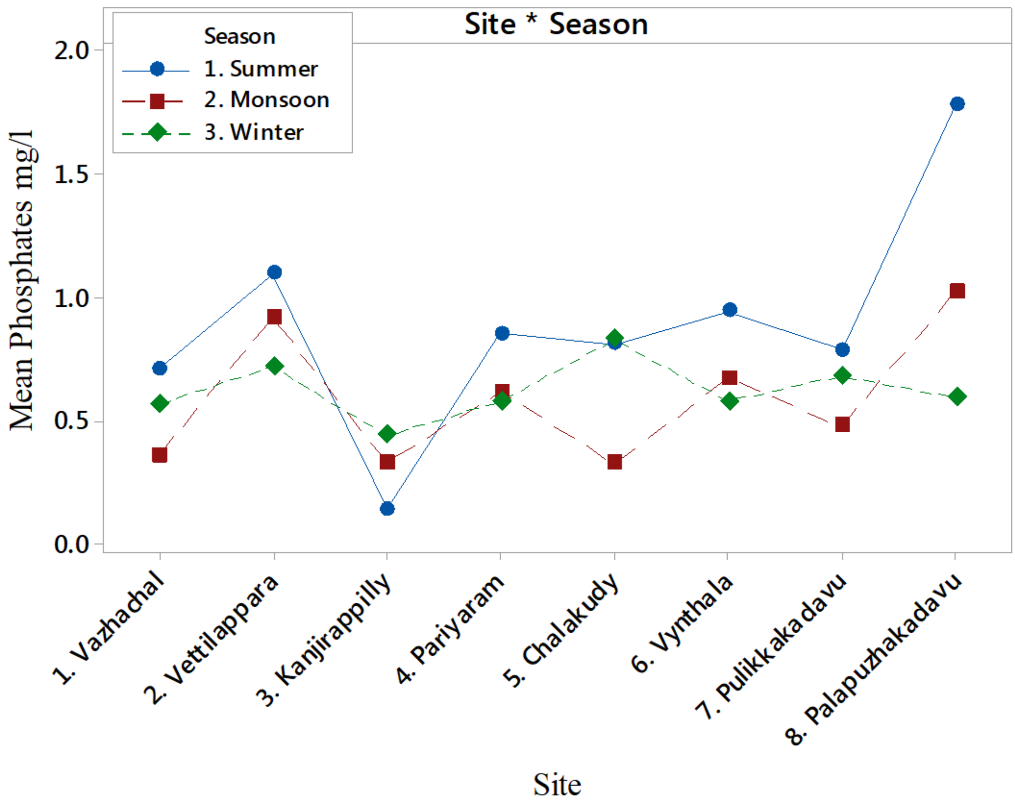

Fig.4.27: Seasonal variations of Phosphates

4.2.9.1 ANOVA results of phosphates

As per the ANOVA results shown in Table 4.65 and Table 4.66, both site and season (P=0, P=0.001) significantly depended on the variations of phosphates in the samples collected from the study area. The maximum mean value was observed at Palapuzhakadavu site during summer. The presence of phosphates at this site is mainly because of the agricultural and poultry activities in the area. Vettilappara and Vynthala sites were also found to show comparatively high mean value of phosphates. The reason for this may be the settling of salts due to the low quantity of water in the site during summer.

Table 4.65: ANOVA results of Phosphates

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Season	2	8.58	8.58	4.29	7.41	0.001
Site	7	27.56	23.3	3.33	5.76	0
Season*Site	14	14.1	14.1	1.01	1.74	0.045
Error	432	249.85	249.85	0.58		
Total	455	300.09				

Table 4.66: Grouping Information at 95 % Confidence for Phosphates mg/l,by Tukey Method

Season	N	Mean	Grouping		
Summer	160	0.9	A		
Winter	120	0.6		B	
Monsoon	176	0.6		B	
Site	**N**	**Mean**	**Grouping**		
Palapuzhakadavu	57	1.1	A		
Vettilappara	57	0.9	A	B	
Vynthala	57	0.7	A	B	C
Pariyaram	57	0.7		B	C
Chalakudy	57	0.7		B	C
Pulikkakadavu	57	0.6		B	C
Vazhachal	57	0.5		B	C
Kanjirappilly	57	0.3			C

4.2.10 Spatial, temporal and seasonal variations of sulphates

Sulphate variations in the surface water samples of Chalakudy river along the period of study ranged from 0 mg/l (absence) to 26 mg/l with the mean value and a standard deviation of 1.1 ± 1.79 mg/l. The maximum value of sulphates obtained along the period of study was at Pulikkakadavu site during September 2014. But the obtained value is within the permissible limit as per the drinking water standards (250 mg/l). The maximum mean value of sulphates obtained along the period of study was 2.2 mg/l at Palapuzhakadavu site. Spatial, temporal and seasonal variations of sulphates along the area of study are shown in Fig. 4.28, Fig. 4.29 and Fig.4.30 respectively. Comparatively low values were obtained during the year 2017.

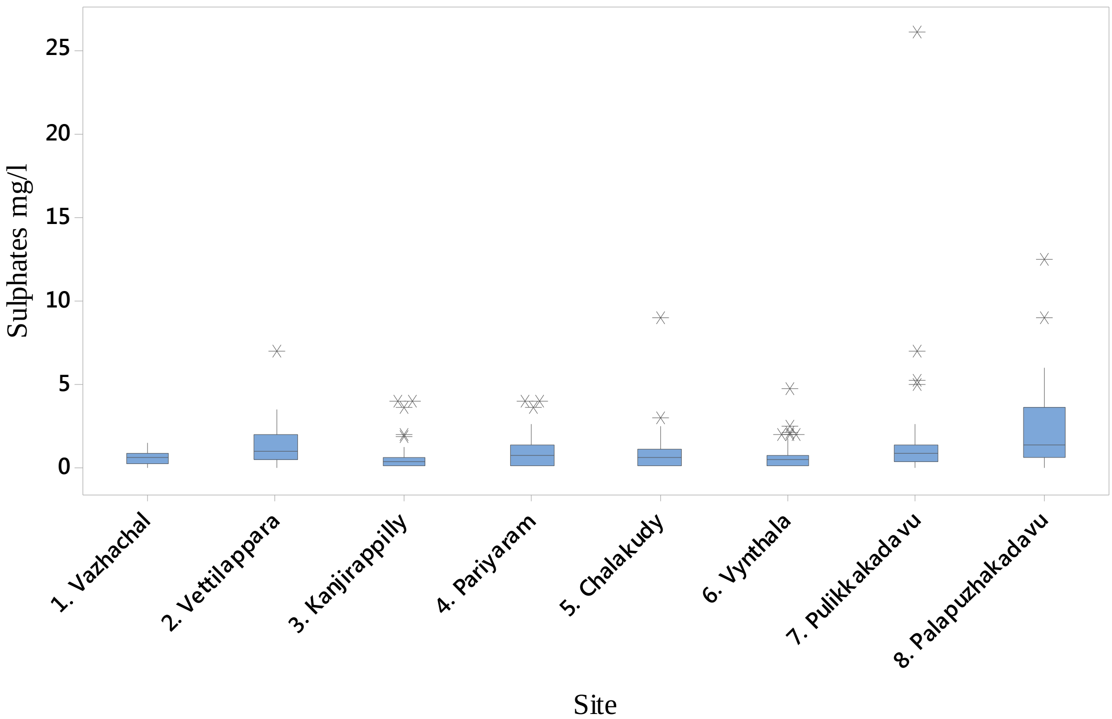

Fig.4.28: Spatial variations of Sulphates

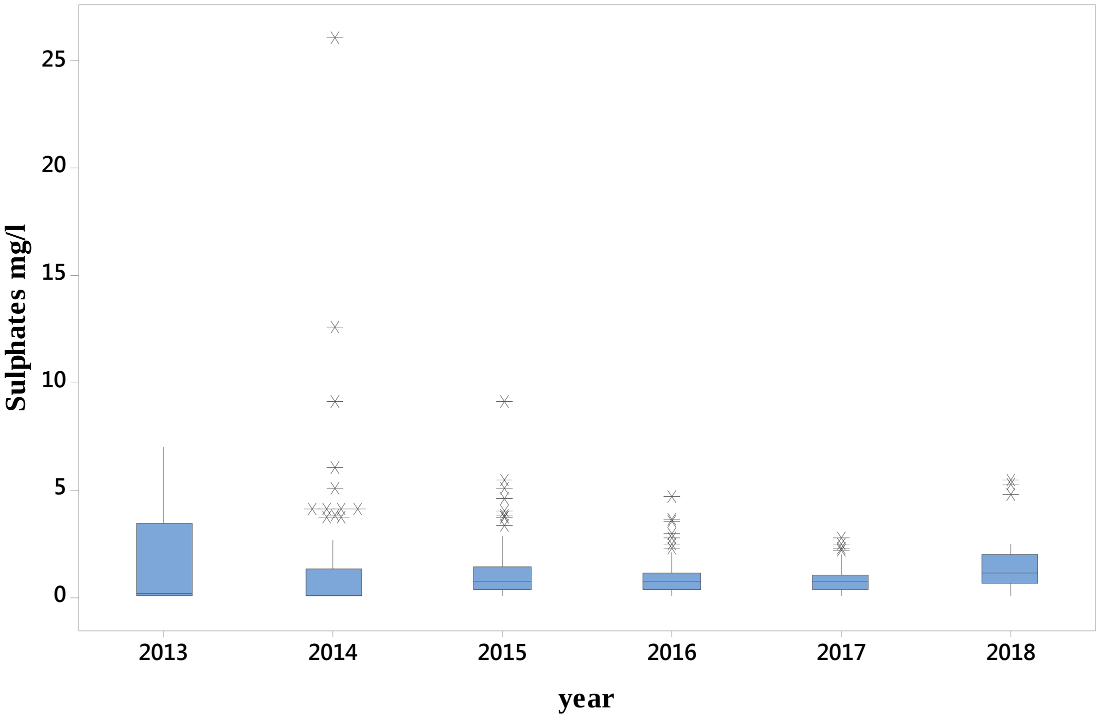

Fig. 4.29: Temporal variations of Sulphates

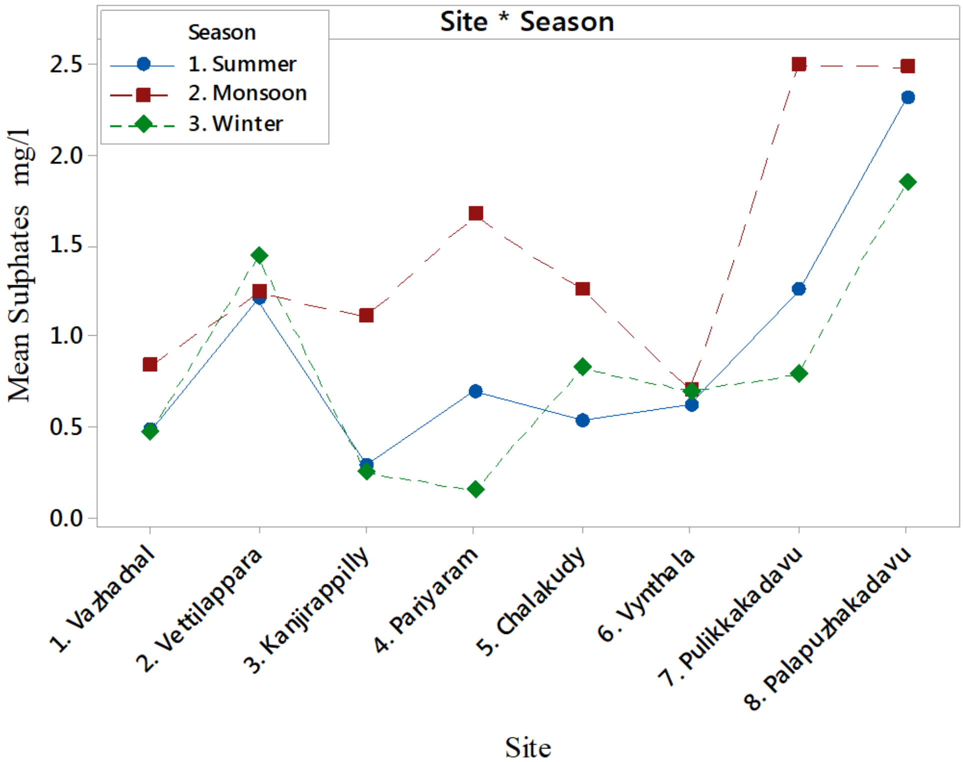

Fig. 4.30: Seasonal variations of Sulphates

4.2.10.1 ANOVA results of sulphates

Table 4.67: ANOVA results of Sulphates

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Season	2	39.9	39.9	20	6.88	0.001
Site	7	135.5	127.9	18.3	6.3	0
Season*Site	14	33.3	33.3	2.4	0.82	0.647
Error	432	1252.9	1252.9	2.9		
Total	455	1461.5				

ANOVA results were shown in Table.4.67 and Table. 4.68. From these tables, it was clear that variation in sulphates was positively significant with the site and season.

Table 4.68: Grouping Information at 95 % Confidence for Sulphates mg/l, using Tukey Method

Season	N	Mean	Grouping	
Monsoon	176	1.5	A	
Summer	160	0.9	B	
Winter	120	0.8		B
Site	**N**	**Mean**	**Grouping**	
Palapuzhakadavu	57	2.2	A	
Pulikkakadavu	57	1.8	A	
Vettilappara	57	1.3	A	B
Chalakudy	57	0.9		B
Pariyaram	57	0.8		B
Vynthala	57	0.7		B
Vazhachal	57	0.6		B
Kanjirappilly	57	0.5		B

Vettilappara, Pulikkakadavu, and Palapuzhakadavu sites were observed to have comparatively high presence of sulphates. This may be attributed to the treated effluent discharge from the nearby industry and agriculture discharges from nearby plantations. All the values obtained for all the samples throughout the study period with low SD were within the permissible limit (250 mg/l) of IS.

4.2.11 Spatial, temporal and seasonal variations of total coliform

The analytical result along the period of the study showed that the total coliform(TC) of the Chalakudy river varied from 120 CFU/100ml to 3800 CFU/ 100ml with the average values of 792 ± 520.6 CFU/ 100ml. The average values of total coliform exceed the limit of water quality standards. According to the IS and WHO standards coliform bacteria in drinking water should be absent because these are indicator organisms of bad and impure water quality water. Compared with the upstream sampling points, the presence of TC at Chalakudy site and towards downstream was high as per shown in Fig.4.31, Fig.4.32 and Fig 4.33. Especially Chalakudy and Palapuzhakadavu sites were found to have high values of TC from 2016 onwards. The outliers shown in the graphs are the comparatively high values compared with other values of TC during the period of study.

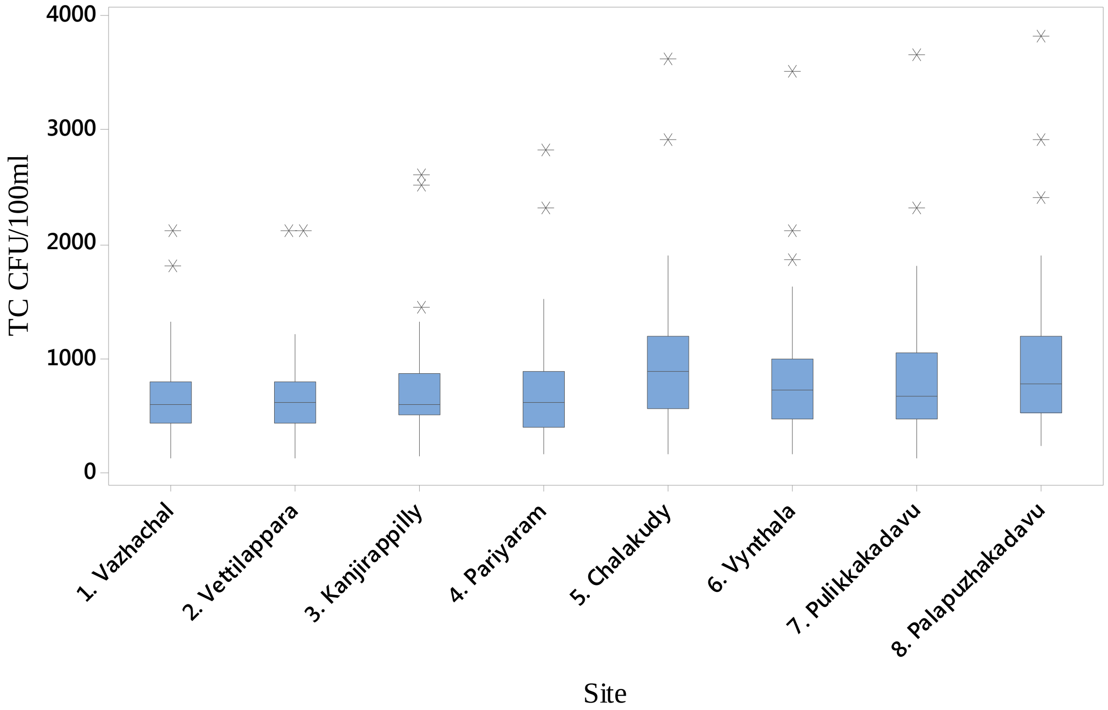

Fig. 4.31: Spatial variations of TC CFU/100ml

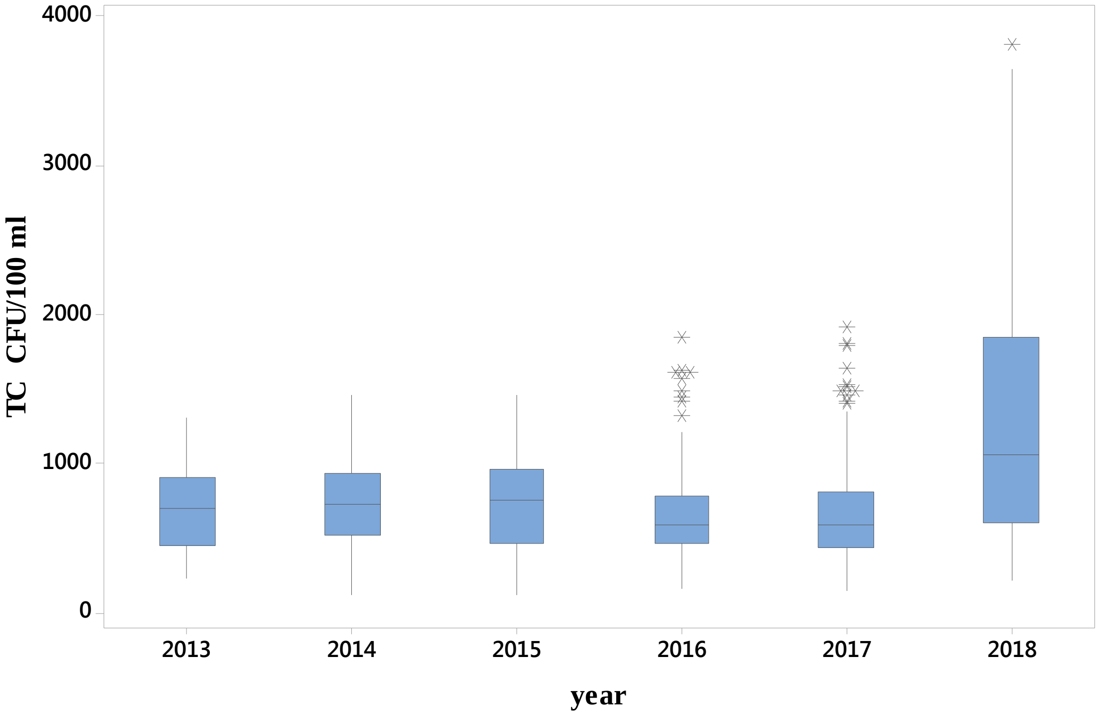

Fig. 4.32: Temporal variations of TC CFU/100ml

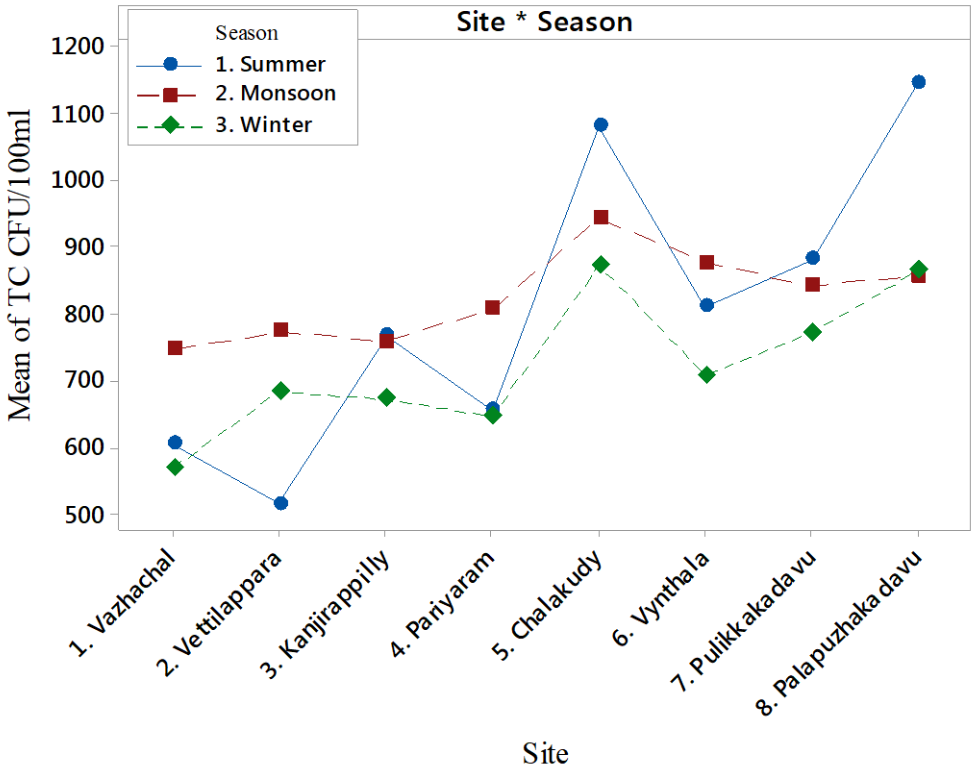

Fig. 4.33: Temporal variations of TC CFU/100ml

4.2.11.1 ANOVA results of TC

The results of ANOVA and posthoc ANOVA analysis are shown in Table 4.69 and Table 4.70 respectively. According to statistical results, only site is more significant with the TC. The information explored by the Tukey method, indicates that the high mean value of TC at Chalakudy and Palapuzhakadavu sites are due to the direct discharge of septic wastes in to the river. It was clear that water samples collected from all sites contain a high rate of bacterial contamination. High contamination in this site might be due to the human anthropogenic activities such as farm waste discharge as the part of cattle and poultry activities.

Table 4.69: Anova analysis result of TC, CFU/100ml

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Season	2	802409	802409	401204	1.52	0.219
Site	7	6335744	6191468	884495	3.36	0.002
Season*Site	14	2504909	2504909	178922	0.68	0.795
Error	432	113707282	113707282	263211		
Total	455	123350344				

Table 4.70: Grouping Information Using Tukey Method at 95 % Confidence for TC, CFU/100ml

Season	N	Mean	Grouping	
Monsoon	176	826	A	
Summer	160	808.5	A	
Winter	120	723.9	A	
Site	**N**	**Mean**	**Grouping**	
Chalakudy	57	966.6	A	
Palapuzhakadavu	57	957.3	A	
Pulikkakadavu	57	831.7	A	B
Vynthala	57	799.1	A	B
Kanjirappilly	57	732.8	A	B
Pariyaram	57	703.3	A	B
Vettilappara	57	657.5		B
Vazhachal	57	640.6		B

4.2.12 Spatial, temporal and seasonal variations of Temperature.

Temperature is a very important parameter for its effects on chemical and biological reactions taking place in water and aquatic organisms (Sreevastava and Patil., 2002). The maximum value of water temperature was 33.7°C during May 2017 in Palapuzhakadavu and Vynthala sites and minimum value of water temperature observed was 25.5°C during 2014 winter at Vazhachal sites. The mean± SD of water temperature of Chalakudy River observed during the study period is 29.2 ± 1.71°C. The spatial, temporal and seasonal variations of temperature are shown in figures Fig.4.34, Fig.4.35, and Fig. 4.36 respectively. In this study it has been observed that highest surface water temperature was observed from March to June and lowest was from July to February. All these high values compared with yearly average are shown as outliers in the box plot representation. Characteristics of waterways and growth of aquatic organisms in this river are directly affected by the temperature.

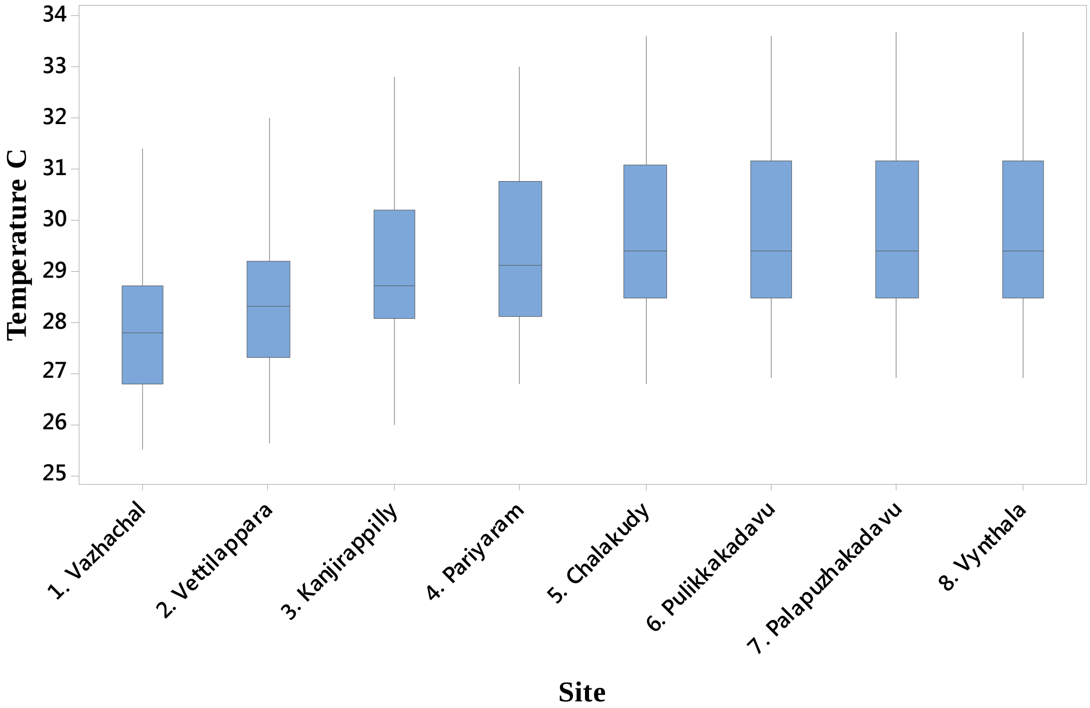

Fig. 4.34: Spatial variations of Temperature

Fig. 4.35: Temporal variations of Temperature

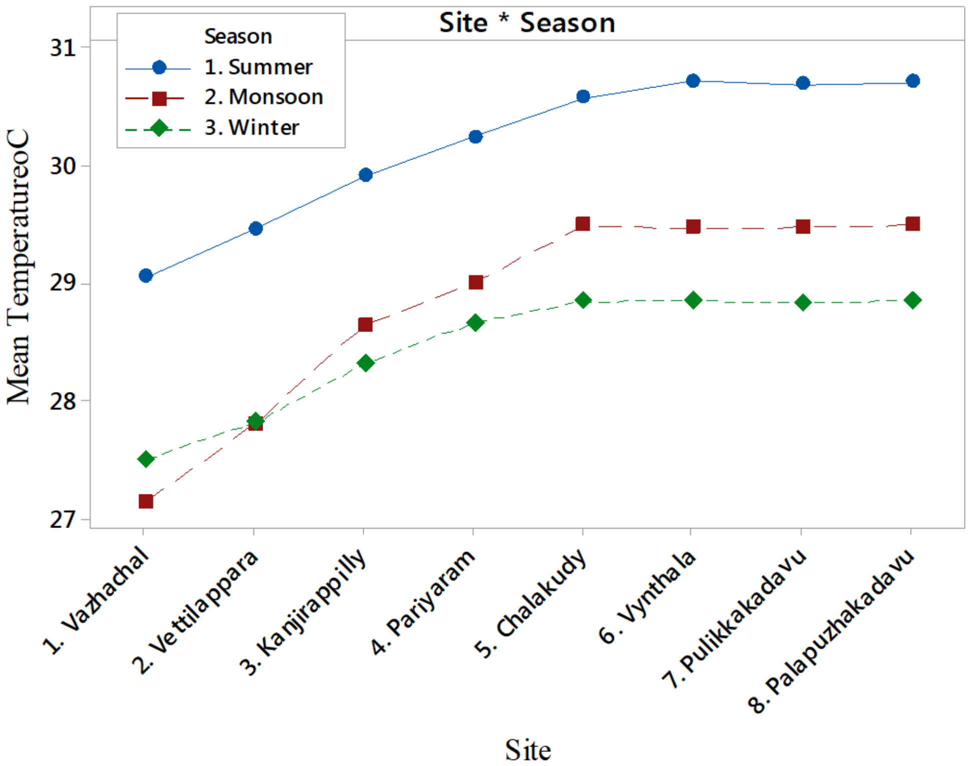

Fig. 4.36: Seasonal variations of Temperature

4.2.12.1 ANOVA results of Temperature

The ANOVA results and grouping information by posthoc ANOVA Tukey method are shown in Table 4.71 and Table 4.72. P values of the ANOVA results showed that temperature variation in the Chalakudy river during the period of study are statistically significant with the factors such as site (P=0) and season (P=0). During the period of study, the variations in temperature were observed to be positively significant with site and season, downward from Pariyaram site to Palapuzhakadavu site. During winter season water in the river at Vazhachal site was observed to be very clear at low temperature. Solubility of oxygen in water increases with decrease in temperature (Joshi *et al.*, 2001).

Table 4.71: ANOVA result of Temperature, ^{o}C

Source	*DF*	*Seq SS*	*Adj SS*	*Adj MS*	*F*	*P*
Season	2	242.7	242.7	121.3	58.95	0
Site	7	201.8	185	26.4	12.84	0
Season*Site	14	10.5	10.5	0.8	0.36	0.984
Error	432	889.2	889.2	2.1		
Total	455	1344.2				

Table 4.72: Grouping Information Using Tukey Method at 95 % Confidence for Temperature, ^{o}C

Season	**N**	**Mean**	**Grouping**		
Summer	160	30.2	A		
Monsoon	176	28.8		B	
Winter	120	28.5		B	
Site	**N**	**Mean**	**Grouping**		
Palapuzhakadavu	57	29.7	A		
Vynthala	57	29.7	A		
Pulikkakadavu	57	29.7	A		
Chalakudy	57	29.6	A		
Pariyaram	57	29.3	A		
Kanjirappilly	57	29	A	B	
Vettilappara	57	28.4		B	C
Vazhachal	57	27.9			C

4.2.13 Spatial, temporal and seasonal variations of TDS

TDS values of the Chalakudy river water varied from a minimum value of 13.3 mg/l to maximum value 360 mg/l with the mean value of 82.7 ± 51.6 mg/l, respectively. TDS mainly indicates the presence of various types of minerals like ammonia, nitrite, nitrate, phosphate, alkalis, some acids, sulphates, metallic ions, organic matters and other particles (Mishra and Saksena, 1991). The value indicates the presence of both colloidal and dissolved solids in water. A high concentration of TDS makes water denser.

The minimum value of TDS was observed during, July 2017 and the maximum value was recorded during March 2018 at Palapuzhakadavu site. This indicates the presence of high content of organic and inorganic solids as a result of surface runoff during monsoon. The spatial, temporal and seasonal variations of TDS are shown in Fig. 4.37, Fig.4.38, and Fig. 4.39. High values of dissolved solid content was observed in the river during March 2018 and after the flood in September 2018. All these high values are shown as outliers in the box plot representation.

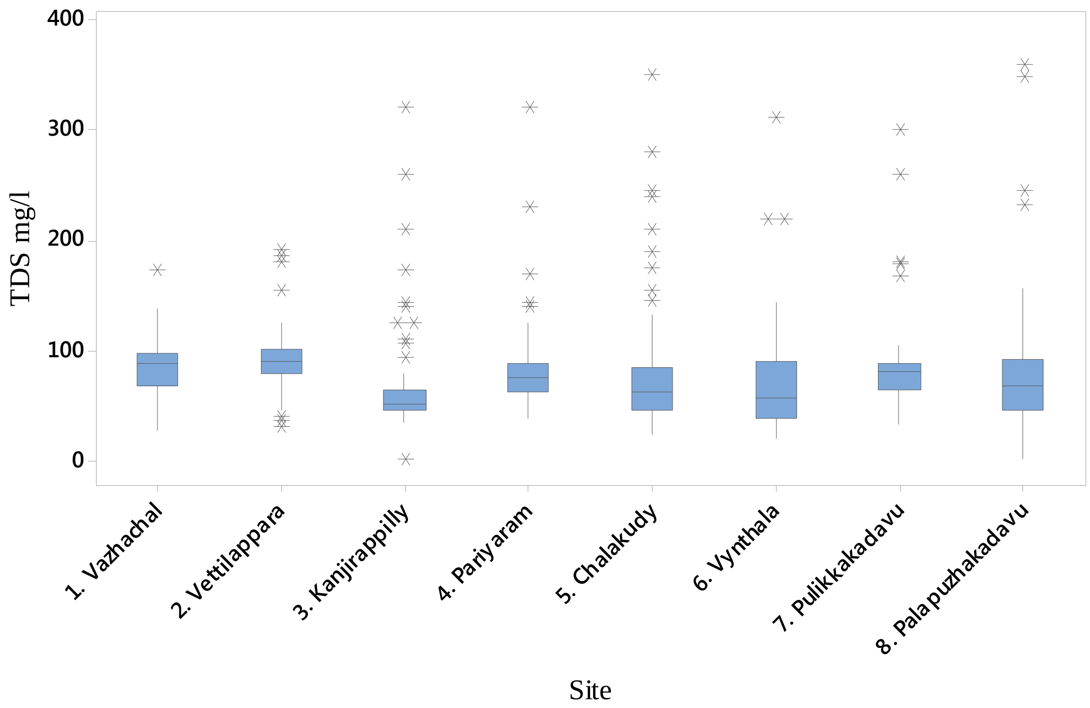

Fig. 4.37. Spatial variations of TDS

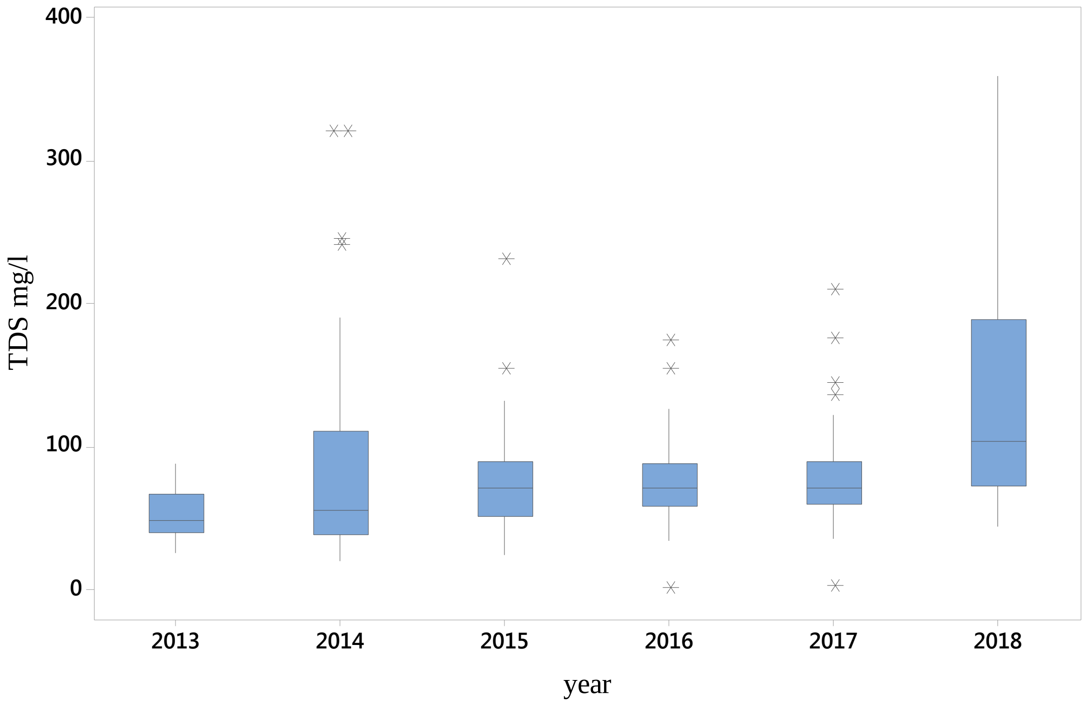

Fig. 4.38: Temporal variations of TDS

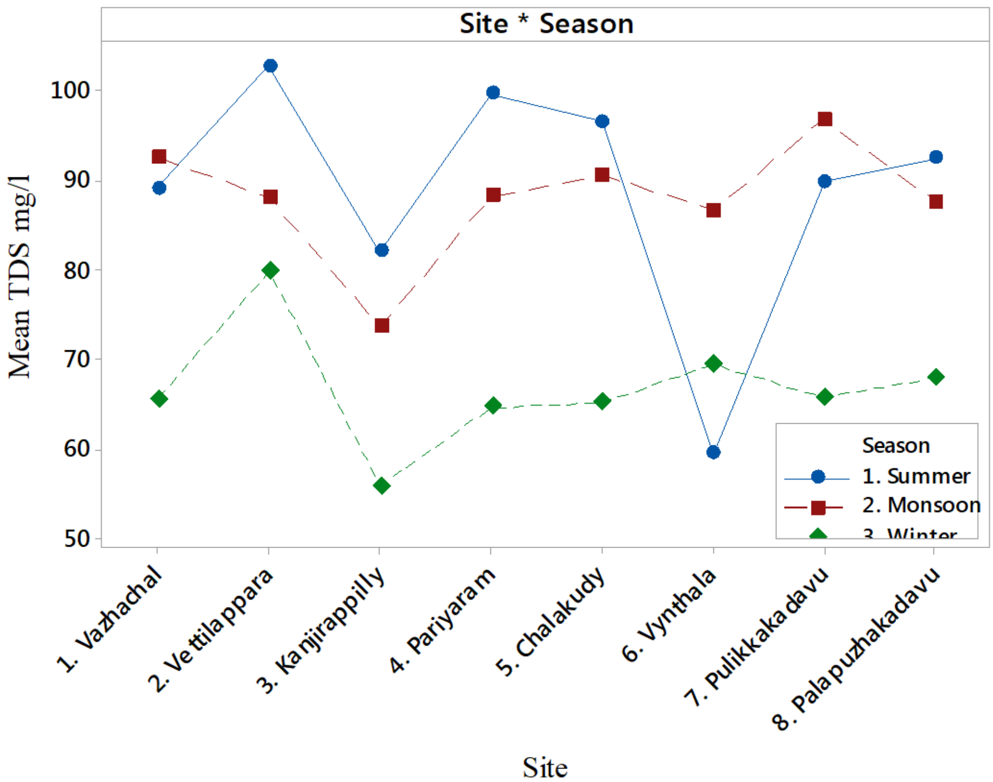

Fig.4.39: Seasonal variations of TDS

4.2.13.1 ANOVA results of TDS

The statistical analysis by ANOVA is shown in Table 4.73 and posthoc ANOVA result is shown in Table.4.74. TDS is statistically significant with the season (P=0). Site was not significant along the period of study.

Table 4.73: ANOVA results of TDS mg/l

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Season	2	41790	41790	20895	7.97	0
Site	7	18755	17446	2492	0.95	0.467
Season*Site	14	18815	18815	1344	0.51	0.926
Error	432	1132251	1132251	2621		
Total	455	1211611				

TDS variation in Chalakudy river during the period of study is mainly due to effect of seasonal impacts such as surface runoff from the plantations at Vettilappara site, treated effluent discharge from the nearby industries and riverside vegetation. TDS concentrations along this site were within the limit of Indian standard. The maximum allowable limit is 500 mg/l for drinking water.

Table 4.74: Grouping Information Using Tukey Method at 95 % Confidence for TDS, mg/l

Season	N	Mean	Grouping	
Summer	160	89	A	
Monsoon	176	88	A	
Winter	120	66.8		B
Site	**N**	**Mean**	**Grouping**	
Vettilappara	57	90.3	A	
Pulikkakadavu	57	84.2	A	
Pariyaram	57	84.1	A	
Chalakudy	57	84.1	A	
Palapuzhakadavu	57	82.7	A	
Vazhachal	57	82.4	A	
Vynthala	57	71.8	A	
Kanjirappilly	57	70.5	A	

4.2.14 Spatial, Temporal and seasonal variations of Turbidity

Chalakudy river has a range of turbidity (TUR) from 0.1 NTU to 13.8 NTU with the mean value of 1.6 ± 1.49 NTU. Some values obtained during monsoon and summer, exceeded the recommended Indian drinking water standard (5 NTU). Fig. 4.40, Fig.4.41 and Fig.4.42 were give an idea about the spatial, temporal and seasonal variations of turbidity. Very high turbidity value was obtained after the flood beyond the drinking water limit. Growth of phytoplankton may be caused the high turbidity of river water.

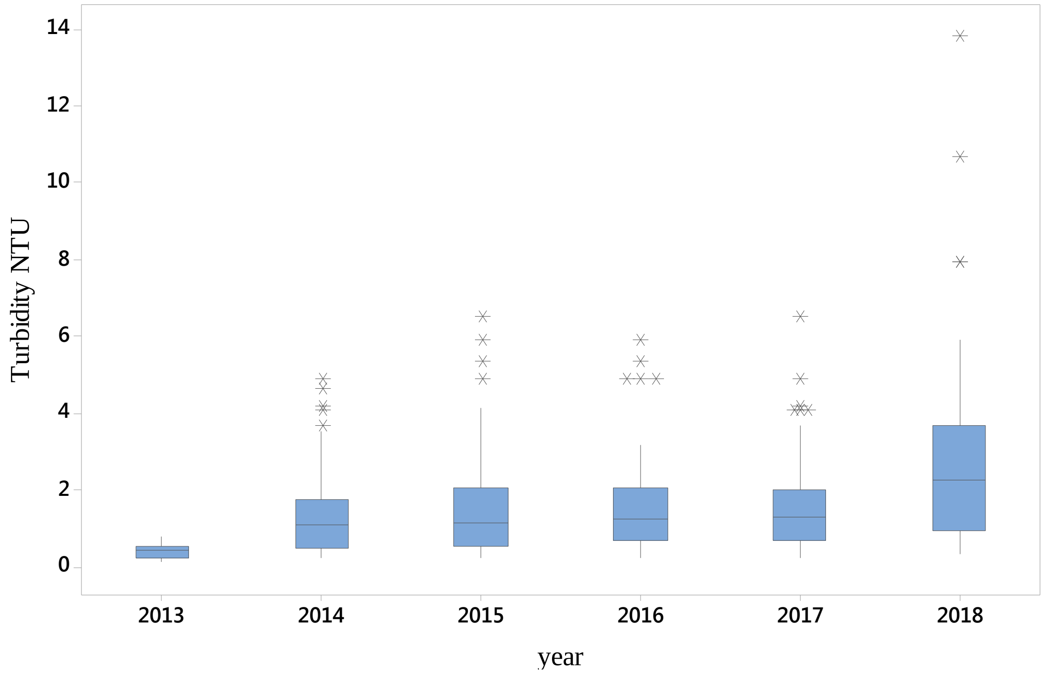

Fig.4.40: Temporal variations of Turbidity

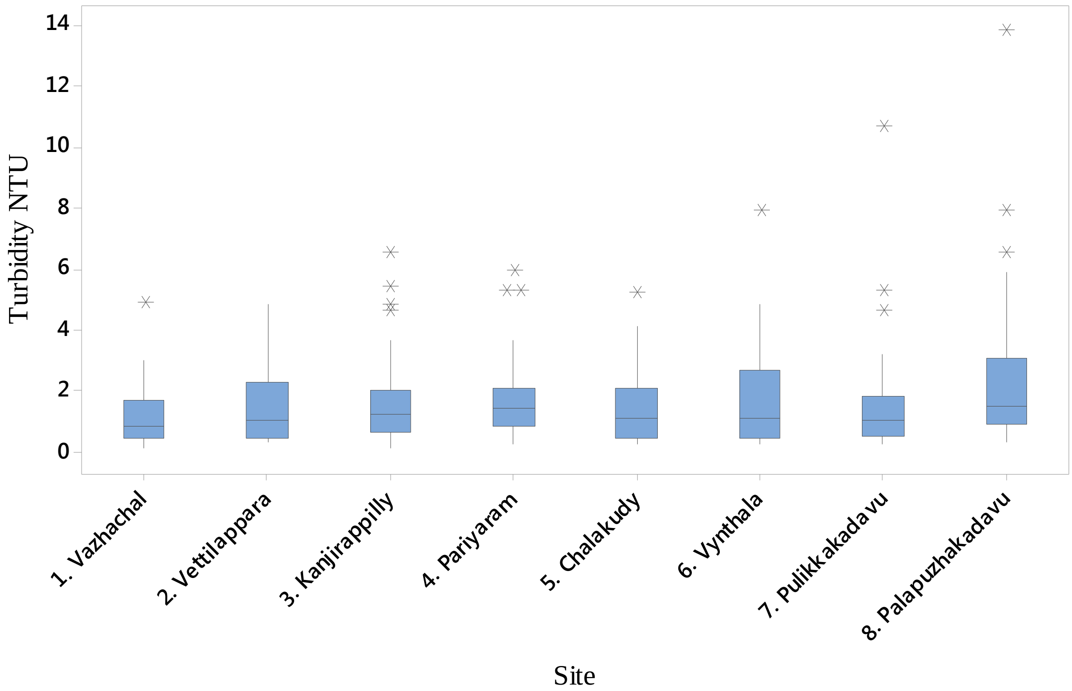

Fig.4.41: Spatial variations of Turbidity

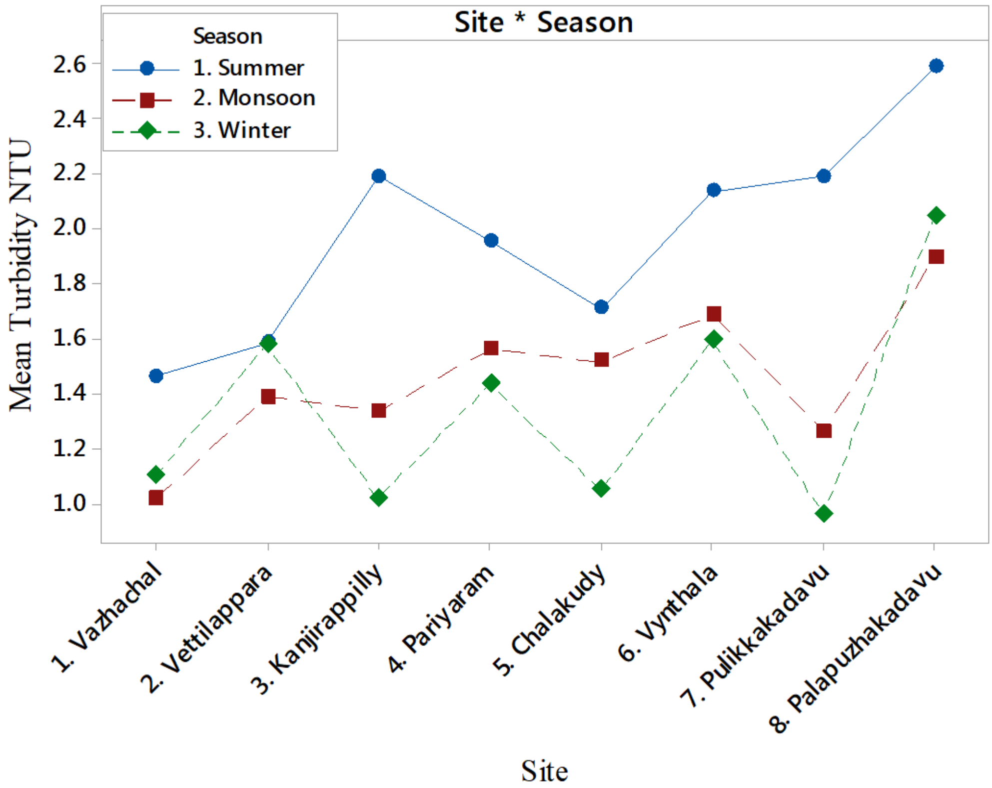

Fig.4.42: Seasonal variations of Turbidity

4.2.14.1 ANOVA results of Turbidity

The results of statistical analysis ANOVA and Tukey analysis are shown in Table 4.75 and Table 4.76. Variations in turbidity were significant with both the site and season. As per the grouping information obtained by the Tukey method, the maximum mean value of turbidity 2 NTU was observed during summer. The maximum turbidity of 13.8 NTU was obtained along the study area during March 2018 at Palapuzhakadavu site. It might be due to the high evaporation rate during summer and direct discharge in to the river.

Table 4.75: ANOVA analysis result of Turbidity NTU

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Season	2	33.9	33.9	16.9	7.77	0
Site	7	33.5	33.5	4.8	2.2	0.033
Season*Site	14	12.6	12.6	0.9	0.41	0.97
Error	432	941.3	941.3	2.2		
Total	455	1021.3				

Table 4.76: Grouping Information at 95 % Confidence for Turbidity NTU, using Tukey Method

Season	N	Mean	Grouping	
Summer	160	2	A	
Monsoon	176	1.5		B
Winter	120	1.3		B
Site	**N**	**Mean**	**Grouping**	
Palapuzhakadavu	57	2.2	A	
Vynthala	57	1.8	A	B
Pariyaram	57	1.6	A	B
Vettilappara	57	1.5	A	B
Kanjirappilly	57	1.5	A	B
Pulikkakadavu	57	1.5	A	B
Chalakudy	57	1.4	A	B
Vazhachal	57	1.2		B

As per ANOVA results, seasonal and spatial effects are positively significant with ($P \leq 0.05$) turbidity. Turbidity in water is mainly caused by suspended and colloidal matter such as clay, silts, finely divided organic and inorganic matter, plankton and other microscopic organisms. Higher turbidity in November 2015 was observed by high turbulence of river water due to monsoon precipitations. Human activity like removing vegetation as part of the cleaning of vegetation, construction, sand mining, and agriculture can also lead to increase in suspended solids level entering in to the water bodies during rain storms due to storm water runoff may be a cause of high turbidity. The highest value for turbidity was observed during monsoon, because of the high flow of monsoon precipitation from the river catchments. Along the period, September and October 2018 also showed high values for all sites. All these high values are shown as outliers in the box plot representation. Lower turbidity values obtained in winter season might be due to the calm nature of river water and low evaporation rate in winter.

4.2.15 Spatial, Temporal and seasonal variations of Total hardness

Variations in total hardness of water in Chalakudy river along the period of study ranged between 6.9 mg/l to maximum 218.6 mg/l with the mean value and standard deviation 62.68 ± 35.76 mg/l. Along the period of study, Kanjirappilly site during January 2018 showed maximum and at Vynthala site during September 2018 was showed minimum hardness. The temporal, spatial and seasonal variations of total hardness of water samples were shown in Fig.4.43, Fig.4.44 and Fig.4.45 respectively. The maximum mean values of total hardness obtained during monsoon in the Vazhachal, Pariyaram, and Pulikkakadavu sites. All the observed values are within the prescribed values of drinking water standards. According to some classification , water having hardness up to 75 mg/l considered as soft, 76-150mg/l is moderately hard and 151- 300 as very hard water. So the commonly the nature of this river water considered to be moderately hard water.

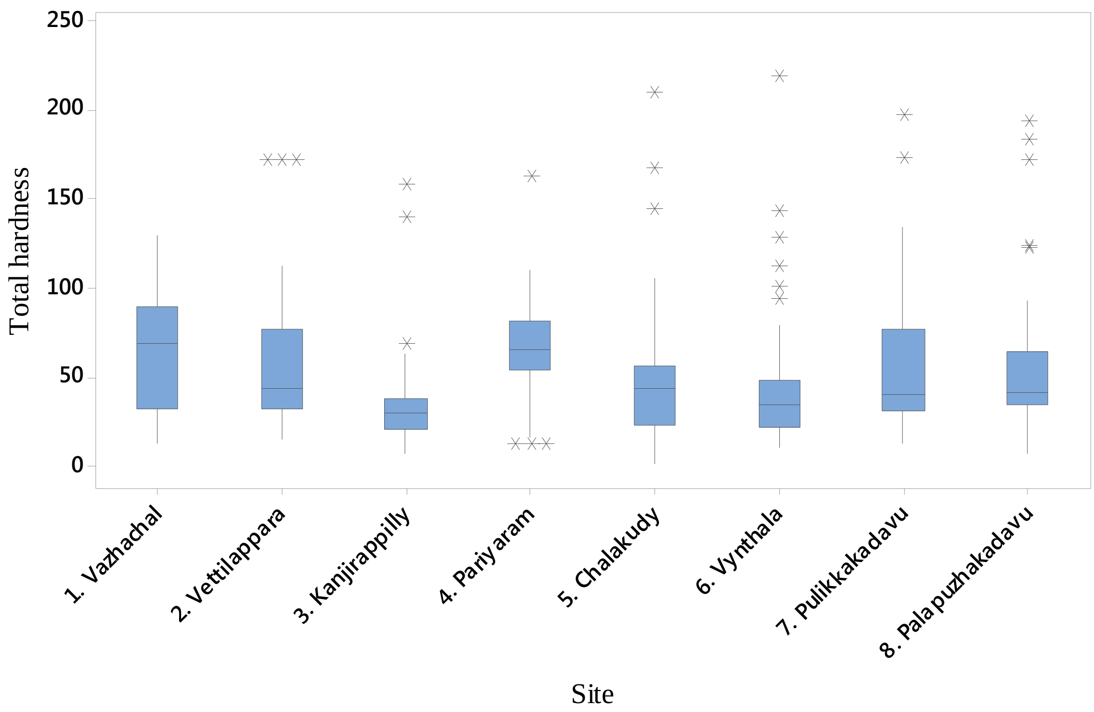

Fig.4.43: Spatial variations of Total Hardness

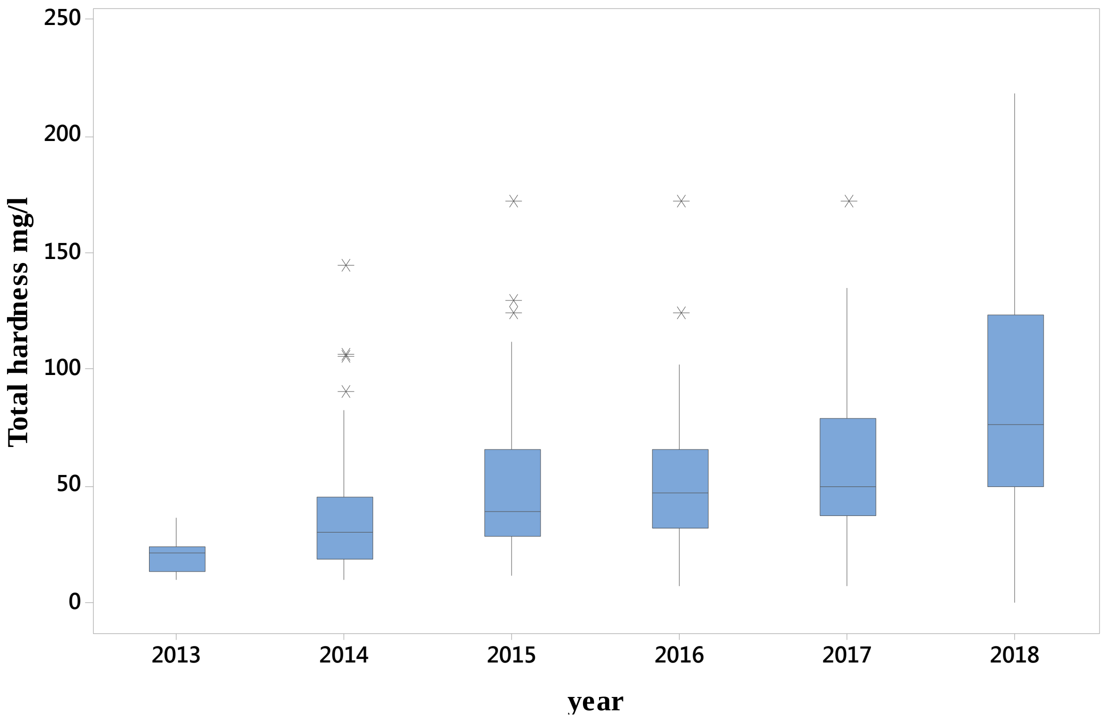

Fig.4.44: Temporal variations of Total Hardness

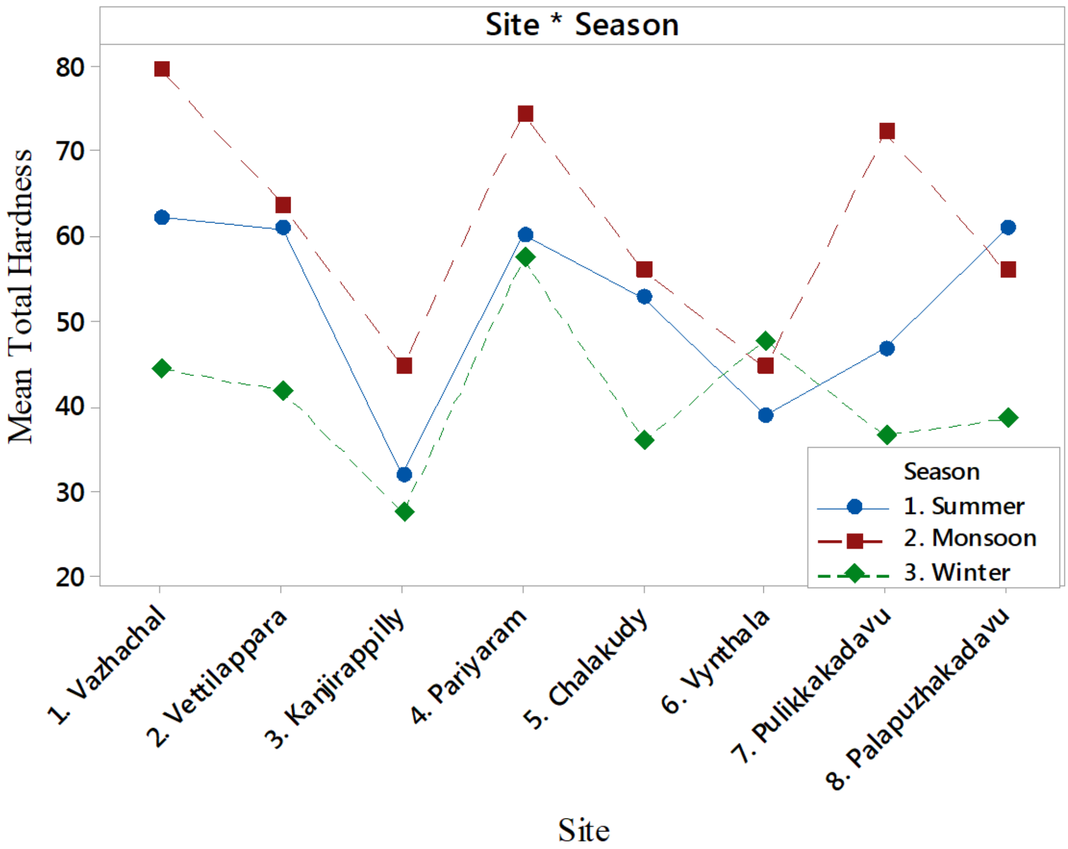

Fig.4.45: Seasonal variations of Total Hardness

4.2.15.1 ANOVA results of Total hardness

As per the statistical results shown in Tables 4.77 and 4.78, it was identified that both season and site were significant (P=0) with the parameter total hardness. The maximum mean value was observed at Pariyaram site during monsoon. All the sites have shown comparatively high values of TH (within the permissible limit) during monsoon season. Pariyaram site is a bathing ghat and laundry activity is high at this site. A laundry unit is situated nearby Kappathodu which joins with the river before Pariyaram site. The continuous use of soap and detergents can make water hard. Treated effluent discharge from industries situated near Pariyaram and Pulikakadavu sites may also be a reason for the comparatively high values of TH observed at these sites.

Table 4.77: ANOVA results of Total Hardness

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Season	2	29635	29635	14818	12.73	0
Site	7	40534	36594	5228	4.49	0
Season*Site	14	14621	14621	1044	0.9	0.562
Error	432	502794	502794	1164		
Total	455	587584				

Table 4.78: Grouping Information at 95 % Confidence for total hardness mg/l, using the Tukey Method.

Season	N	Mean	Grouping		
Monsoon	176	61.4	A		
Summer	160	50.9		B	
Winter	120	41.2			C
Site	**N**	**Mean**	**Grouping**		
Pariyaram	57	64	A		
Vazhachal	57	62	A	B	
Vettilappara	57	55.5	A	B	
Pulikkakadavu	57	51.8	A	B	C
Palapuzhakadavu	57	51.7	A	B	C
Chalakudy	57	45.7	A	B	C
Vynthala	57	43.7		B	C
Kanjirappilly	57	34.7			C

4.2.16 Spatial, temporal and seasonal variations of % DO saturation

% DO saturation (Benson and Krause equation 1984) is listed in the Table 4.1 to Table.4.48 at the beginning of this chapter. The box plot representations of these % DO values such as spatial distribution, temporal distribution of % DO are shown in Fig 4.46 and Fig 4.47 respectively. Hundred percentage of DO saturation was obtained in some water samples collected from Kanjirappilly, Pariyaram, Palapuzhakadavu and Vynthala sites during monsoon season. This indicates very less biological pollution during the period. % DO saturation ranged from 66.2% to 100% with an average of 90.068 ±7.639%. The minimum % DO saturation of 66.2% was observed at Vynthala site during summer 2015. During March 2018, very low % DO was observed at Pulikkakadavu and Palapuzhakadavu sites. During September and October 2018, the water level in the river was very less. The percentage DO of the river in all sites also decreased after flood. All these low values compared with yearly average percentage DO at each sites are shown as outliers in the box plot representation.

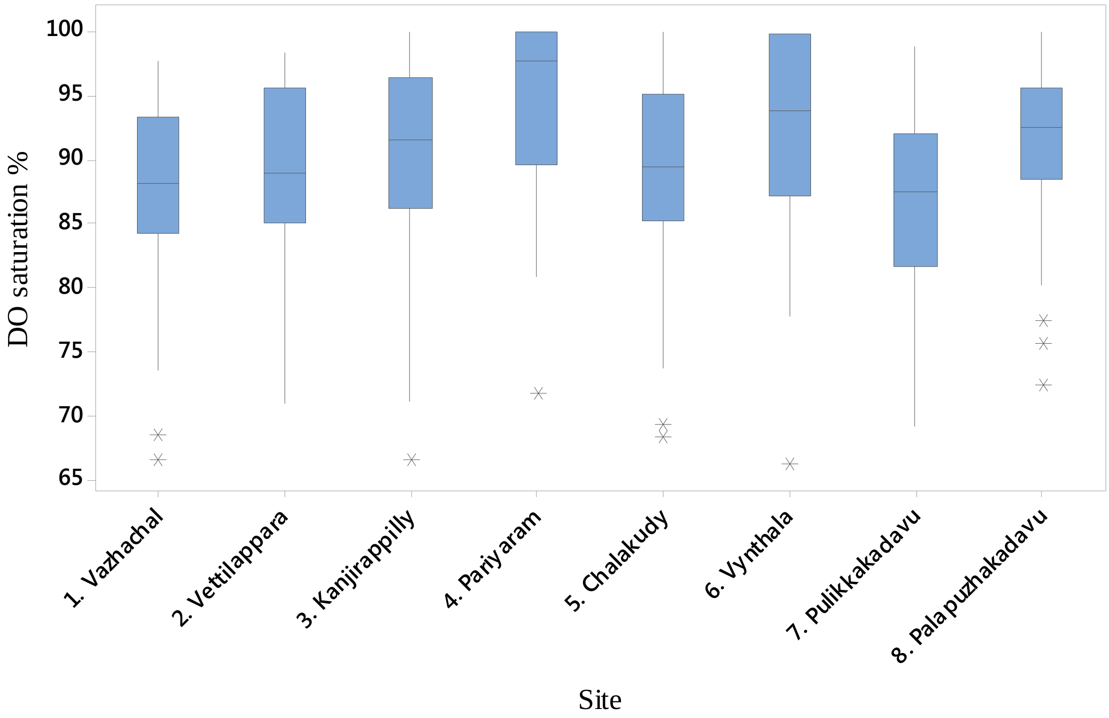

Fig. 4.46: Spatial variations of % DO Saturation

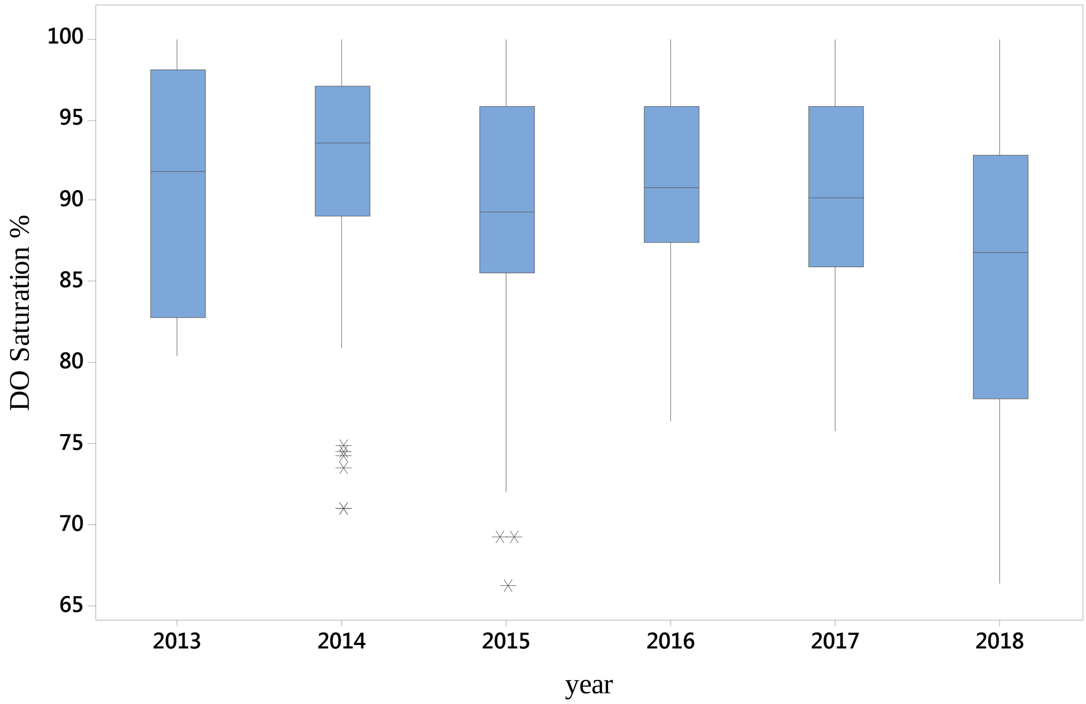

Fig.4.47: Temporal variations of % DO saturation

4.2.17 Spatial, temporal and seasonal variations of cross-section area (flow area)

Measured cross-section area (flow area) of the river sites during the period of study varied from 121m^2 to 1971 m^2 with an average of 786.8 m^2 ± 480.22 m^2. The high value of SD was showed a varying trend of the study area with respect to site and season. The variations in flow area are shown in Fig.4.48 and Fig.4.49. Chalakudy and Vynthala site during monsoon was observed the maximum mean cross-section area of flow.

During summer, with respect to the altitudinal variations and slope of the sites, upstream sites get dry fast. So in most of the sites discontinuity of flow was observed in summer. During monsoon, all the sites showed high flow area compared with other seasons. Maximum cross section of flow (flow area) was obtained during August 2018 due the flood occurred and in September 2018, a drastic reduction in flow area was observed immediately after the flood. However, the maximum mean area of flow obtained along the period of study (other than period of flood) was during monsoon 2017. As per the posthoc ANOVA results, all the sites showed an increasing trend during monsoon and decreasing trend during winter and summer.

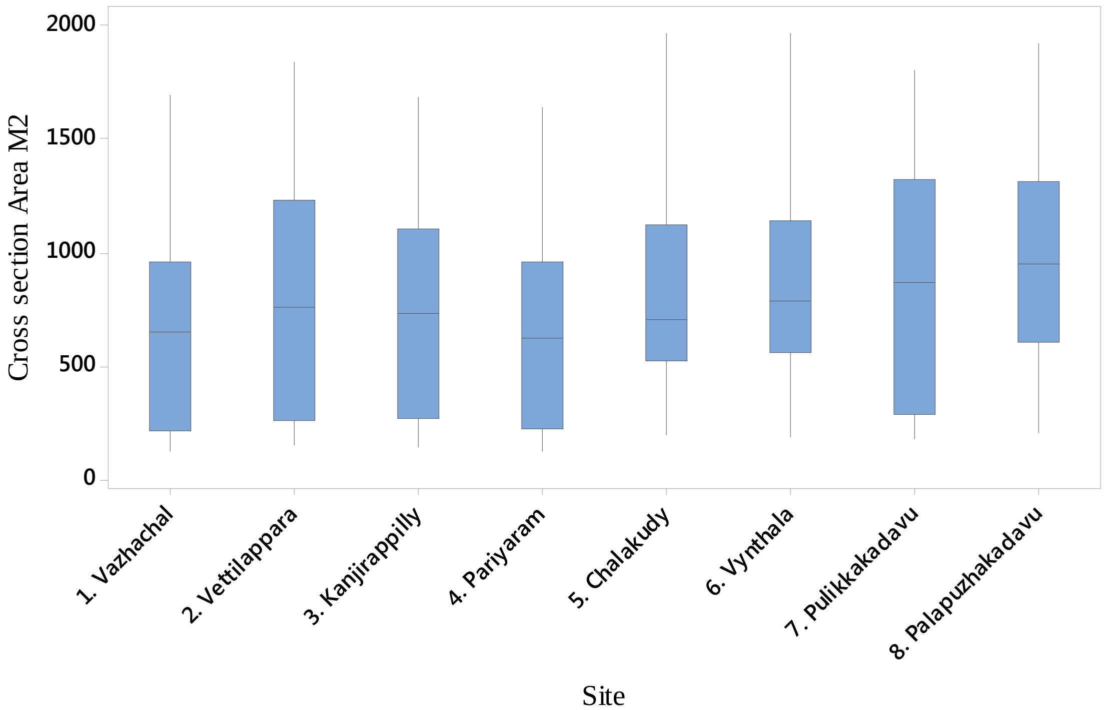

Fig.4.48: Spatial variations of mean cross section area m^2

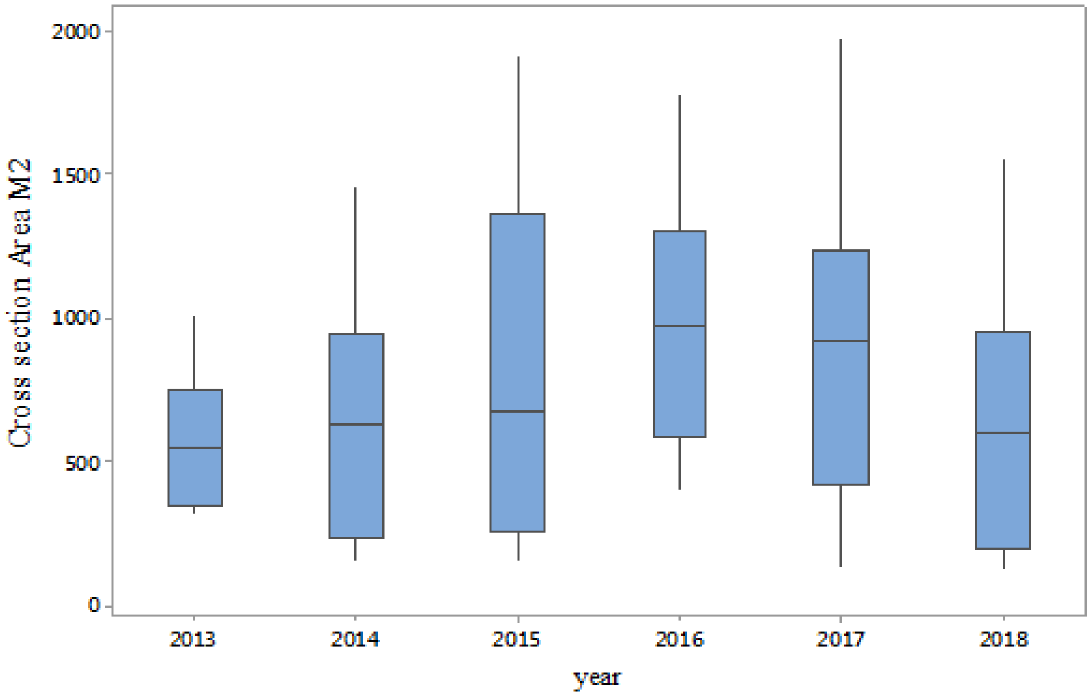

Fig. 4.49: Temporal variations of mean cross-section area in m^2

Table 4.79: ANOVA results of cross section area along the study area

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Season	2	1976166	1976166	988083	286.13	0
Site	7	33258	27643	3949	1.14	0.335
Season*Site	14	22270	22270	1591	0.46	0.953
Error	432	1491795	1491795	3453		
Total	455	3523489				

Table 4.80: Grouping Information at 95 % Confidence for cross-section area in m^2, using the Tukey method

Season	N	Mean	Grouping	
Monsoon	176	80.6	A	
Winter	120	24.5		B
Summer	160	9.4		B
Site	**N**	**Mean**	**Grouping**	
Vazhachal	57	74.1	A	
Kanjirappilly	57	69.4	A	
Vettilappara	57	68.1	A	
Pariyaram	57	60.1	A	
Chalakudy	57	58.7	A	
Palapuzhakadavu	57	56.5	A	
Pulikkakadavu	57	56.4	A	
Vynthala	57	48.4	A	

4.2.18 Spatial, temporal and seasonal variations of flow velocity

Measured flow velocity (v, in m/s) of study area along the period of study was varied from 0 to 0.419 m/s with an average ± SD of 0.074 m/s ± 0.07. The variations in flow velocity along the study area were showed in Fig.4.50, Fig.4.51 and Fig.4.52.Sampling was not able to carried out at the month of August 2018(at the time of flood). During the month of September 2018, the water level and flow velocity in this river had drastically decreased. So the maximum velocity could not be measured. Before flood, Pariyaram site and Palapuzhakadavu site were noticed highest flow velocity during monsoon.

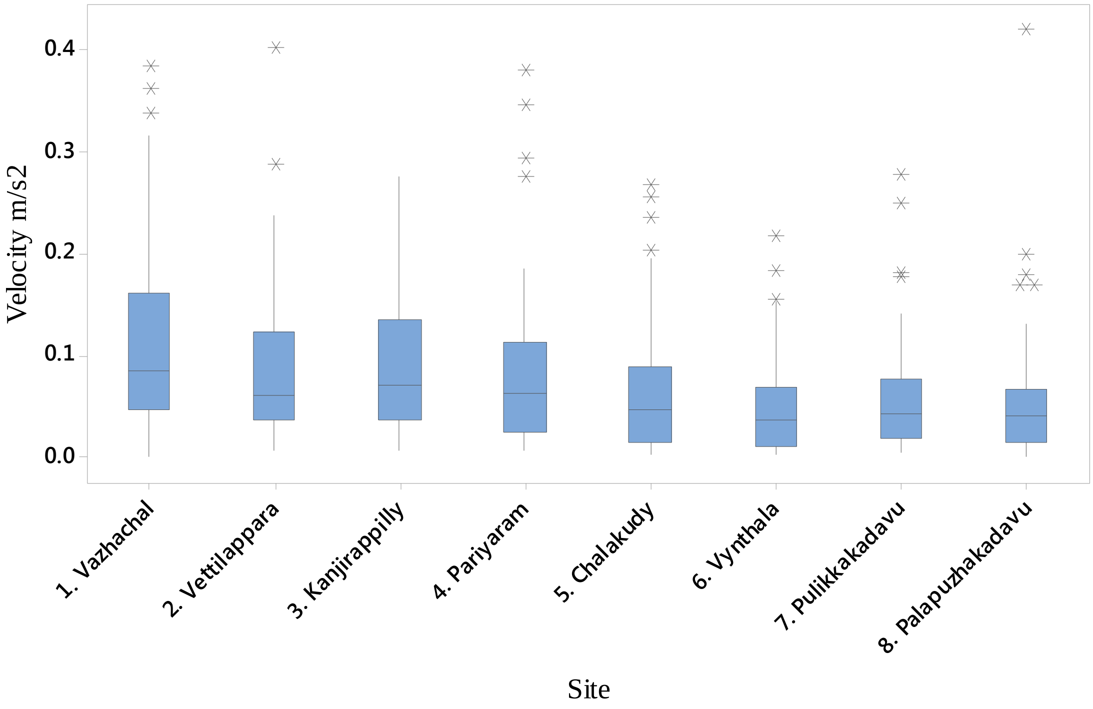

Fig.4.50: Spatial variations of mean Velocity in m/s

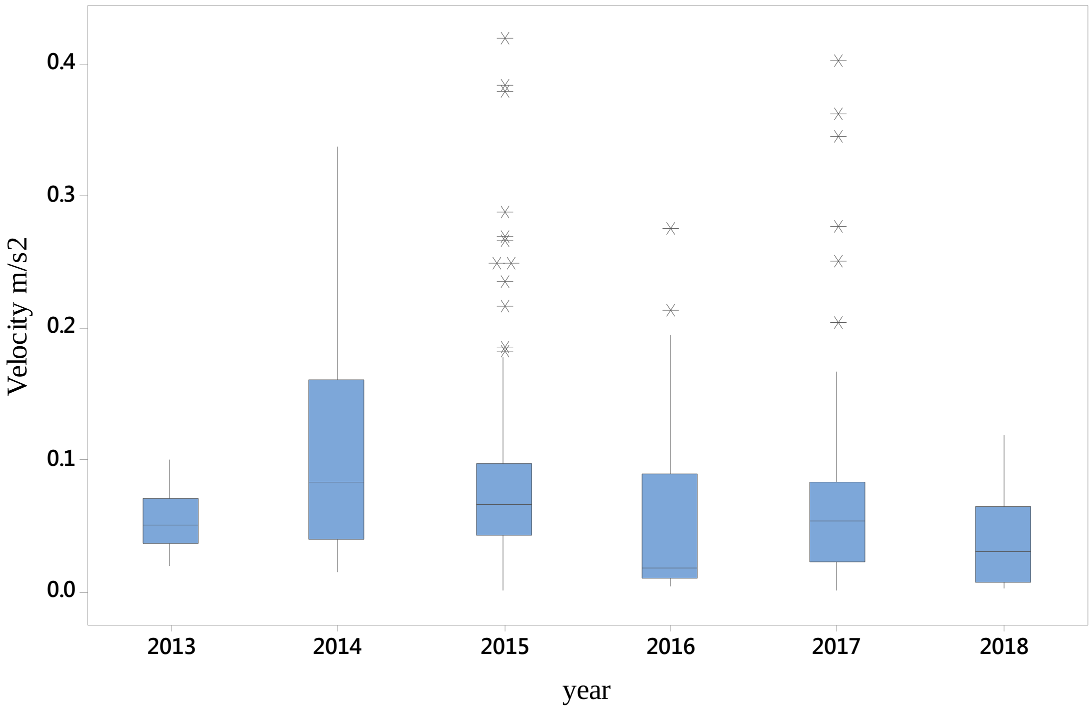

Fig. 4.51: Temporal variations of mean Velocity in m/s

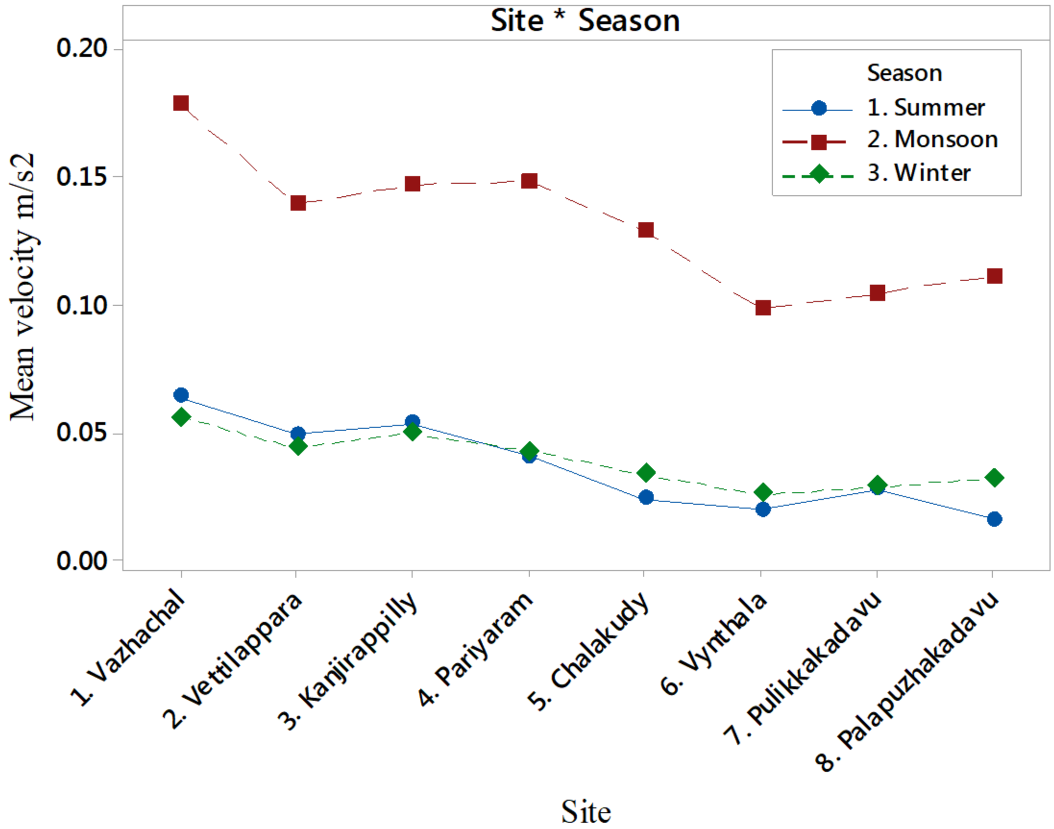

Fig. 4.52: Seasonal variations of mean flow velocity in m/s

4.2.19 Spatial and temporal variations of flow rate (Discharge)

The flow rate was calculated using the measured values of flow velocity and flow area using the equation Q= V*A. During the period of study Vettilappara, Kanjirappilly and Chalakudy sites showed comparatively high flow rate than other sites. High rate of rainfall and inadequate level management systems in the dams constructed in the river resulted in the river high rate of flow and hence the flood in August 2018. The maximum discharge was observed at Chalakudy (from the collected data from CWC Arangali) at the time of the flood was 12264 m^3/s. After September 2018 (after flood), the water discharge through the river has drastically decreased. This caused water scarcity in the basin. The main reason for this scarcity was due to less water discharge from Tamilnadu by the Parambikulam- Aaliyar project. Sand mining activities in the river also caused the low flow rate and water discharge in the river.

4.3. The Dominance of Sewage Pollution in Terms of BOD/COD Ratio and FC/TC Ratio

Organic matter present in water is easily degradable. BOD/COD ratio can help to measure the level of biodegradability of the matters present in water. FC/TC ratio is used to find the suspected bacteriological contamination from human or animal. FC/TC and BOD/COD values in the study area are shown in Tables. 4.81 & 4.82

Table.4.81: FC/TC ratio

month &Year	Vazhachal	Vettilappara	Kanjirappilly	Pariyaram	Chalakudy	Vynthala	Pulikkakadavu	Palapuzhakadavu
Nov-13	0.23	0.22	0.16	0.17	0.5	0.29	0.66	0.57
Dec-13	0.19	0.22	0.22	0.21	0.55	0.26	0.32	0.42
Jan-14	0.08	0.32	0.65	0.44	0.23	0.36	0.32	0.3
Feb-14	0.05	0.17	0.14	0.18	0.34	0.19	0.26	0.32
Mar-14	0.42	0.5	0.21	0.25	0.59	0.19	0.31	0.75
Apr-14	0.09	0.3	0.23	0.18	0.6	0.12	0.2	0.61
May-14	0.06	0.57	0.43	0.26	0.72	0.35	0.61	0.75
Jun-14	0.07	0.16	0.25	0.1	0.24	0.32	0.36	0.22
Jul-14	0.04	0.08	0.12	0.12	0.33	0.1	0.15	0.62
Aug-14	0.31	0.16	0.24	0.41	0.29	0.16	0.72	0.61
Sep-14	0.1	0.17	0.16	0.1	0.24	0.35	0.14	0.33
Oct-14	0.06	0.1	0.15	0.1	0.29	0.15	0.19	0.27
Nov-14	0.06	0.07	0.25	0.26	0.18	0.15	0.38	0.46
Dec-14	0.14	0.27	0.16	0.12	0.24	0.22	0.2	0.27
Jan-15	0.14	0.14	0.14	0.11	0.33	0.25	0.26	0.26
Feb-15	0.47	0.14	0.14	0.37	0.28	0.21	0.48	0.4
Mar-15	0.23	0.08	0.15	0.5	0.52	0.16	0.48	0.74
Apr-15	0.35	0.12	0.12	0.83	0.6	0.12	0.3	0.18
May-15	0.17	0.31	0.15	0.34	0.22	0.47	0.31	0.32
Jun-15	0.17	0.1	0.23	0.12	0.3	0.22	0.29	0.26
Jul-15	0.13	0.12	0.19	0.1	0.33	0.19	0.12	0.24
Aug-15	0.29	0.45	0.64	0.33	0.45	0.5	0.37	0.63

Sep-15	0.23	0.09	0.35	0.72	0.31	0.24	0.15	0.22
Oct-15	0.16	0.14	0.56	0.15	0.29	0.24	0.38	0.44
Nov-15	0.16	0.27	0.3	0.14	0.17	0.25	0.07	0.18
Dec-15	0.28	0.42	0.29	0.6	0.16	0.94	0.46	0.1
Jan-16	0.21	0.07	0.6	0.13	0.26	0.18	0.31	0.21
Feb-16	0.13	0.08	0.24	0.21	0.25	0.15	0.27	0.19
Mar-16	0.15	0.24	0.36	0.24	0.26	0.2	0.36	0.36
Apr-16	0.23	0.24	0.27	0.5	0.66	0.24	0.23	0.36
May-16	0.23	0.24	0.19	0.29	0.28	0.27	0.2	0.26
Jun-16	0.35	0.29	0.66	0.17	0.26	0.7	0.3	0.16
Jul-16	0.68	0.52	0.25	0.14	0.32	0.63	0.31	0.35
Aug-16	0.2	0.16	0.21	0.31	0.2	0.21	0.15	0.29
Sep-16	0.43	0.14	0.46	0.45	0.35	0.47	0.15	0.26
Oct-16	0.17	0.2	0.63	0.19	0.36	0.38	0.37	0.44
Nov-16	0.37	0.58	0.32	0.75	0.23	0.18	0.46	0.37
Dec-16	0.16	0.2	0.41	0.27	0.18	0.48	0.11	0.26
Jan-17	0.24	0.21	0.19	0.47	0.1	0.24	0.24	0.37
Feb-17	0.19	0.47	0.16	0.17	0.13	0.27	0.48	0.27
Mar-17	0.15	0.86	0.16	0.21	0.21	0.18	0.21	0.22
Apr-17	0.19	0.61	0.24	0.38	0.22	0.2	0.31	0.33
May-17	0.17	0.38	0.48	0.51	0.28	0.18	0.28	0.22
Jun-17	0.65	0.35	0.33	0.25	0.41	0.45	0.39	0.69
Jul-17	0.86	0.48	0.29	0.27	0.5	0.21	0.46	0.27
Aug-17	0.18	0.25	0.27	0.68	0.43	0.32	0.19	0.32
Sep-17	0.21	0.68	0.41	0.25	0.19	0.19	0.77	0.29
Oct-17	0.58	0.25	0.58	0.33	0.3	0.28	0.23	0.29
Nov-17	0.35	0.97	0.35	0.16	0.76	0.3	1	0.59
Dec-17	0.2	0.21	0.68	0.85	0.69	0.33	0.85	0.8
Jan-18	0.19	0.29	0.38	0.31	0.35	0.21	0.21	0.26
Feb-18	0.2	0.13	0.23	0.16	0.25	0.07	0.2	0.15
Mar-18	0.24	0.24	0.18	0.35	0.16	0.51	0.19	0.18
Apr-18	0.38	0.21	0.43	0.34	0.34	0.2	0.31	0.36
May-18	0.31	0.31	0.25	0.27	0.33	0.22	0.33	0.32
Sep-18	0.56	0.52	0.5	0.5	0.5	0.61	0.55	0.55
Oct-18	0.5	0.54	0.59	0.56	0.62	0.6	0.57	0.46

Table 4.82: BOD/COD ratio

Month &Year	*Vazhachal*	*Vettilappara*	*Kanjirappilly*	*Pariyaram*	*Chalakudy*	*Vynthala*	*Pulikkakadavu*	*Palapuzhakadavu*
Nov-13	***0.42***	***0.5***	***0.38***	***0.59***	***0.98***	***0.56***	***0.53***	***0.69***
Dec-13	0.34	0.69	0.68	0.68	0.37	0.45	0.69	0.51
Jan-14	0.7	0.68	0.28	0.28	0.28	0.74	0.14	0.47
Feb-14	0.37	0.78	0.28	0.28	0.43	0.44	0.41	0.64
Mar-14	0.61	0.63	0.61	0.61	0.31	0.25	0.7	0.38
Apr-14	0.28	0.55	0.56	0.56	0.85	0.91	0.62	0.51
May-14	0.42	0.77	0.74	0.39	0.65	0.74	0.58	0.43
Jun-14	0.24	0.29	0.89	0.55	0.67	0.63	0.78	0.67
Jul-14	0.79	0.41	0.9	0.56	0.41	0.88	0.94	0.89
Aug-14	0.45	0.76	1	1	0.44	0.56	0.25	0.82
Sep-14	0.28	0.89	0.64	1	0.66	0.13	0.35	0.33
Oct-14	0.46	0.95	0.42	0.59	0.32	0.06	0.75	0.24
Nov-14	0.23	0.92	0.5	0.5	0.52	0.52	0.65	0.52
Dec-14	0.21	0.63	0.47	0.47	0.61	0.24	0.81	0.52
Jan-15	0.66	0.68	0.88	0.85	0.77	0.38	0.58	1
Feb-15	0.76	0.78	1	1	0.86	0.78	0.81	0.52
Mar-15	0.42	0.6	0.83	0.33	0.93	0.92	0.9	0.8
Apr-15	0.64	0.91	0.8	0.66	0.98	0.68	0.86	0.65
May-15	0.19	0.7	0.23	0.71	0.7	0.94	0.52	0.56
Jun-15	0.33	0.92	0.39	0.67	0.43	0.81	0.48	0.94
Jul-15	0.99	0.61	0.82	0.48	0.49	0.69	0.88	0.51
Aug-15	0.34	0.59	0.93	0.81	0.84	0.86	0.26	0.41
Sep-15	0.91	0.84	0.83	0.27	0.23	0.41	0.71	0.86
Oct-15	0.82	0.27	0.63	1	0.95	0.21	0.7	0.71
Nov-15	0.9	0.81	0.53	0.84	0.66	0.9	0.93	0.61
Dec-15	0.59	0.47	0.69	0.42	0.63	0.82	0.67	0.65
Jan-16	0.31	0.94	0.32	0.85	0.67	0.45	0.36	0.78
Feb-16	0.27	0.73	0.67	0.47	0.77	0.68	0.49	0.63
Mar-16	0.71	0.28	0.86	0.54	0.77	0.77	0.56	0.55

Apr-16	0.86	0.6	0.23	0.42	0.96	0.73	0.08	0.77
May-16	0.96	0.55	0.98	0.79	0.73	0.85	0.56	0.29
Jun-16	0.17	0.77	0.48	0.91	0.91	0.91	0.5	0.9
Jul-16	0.82	0.83	0.84	0.65	0.98	0.32	0.5	0.79
Aug-16	0.1	0.48	0.97	0.47	0.88	0.22	0.44	0.37
Sep-16	0.38	0.74	0.88	0.41	0.97	0.54	0.58	0.87
Oct-16	0.75	0.13	0.86	0.35	0.96	0.9	0.62	0.94
Nov-16	0.46	0.86	0.31	0.63	0.9	0.38	0.62	0.81
Dec-16	0.72	0.28	0.53	0.13	0.77	0.46	0.69	0.61
Jan-17	0.56	0.64	0.84	0.96	0.58	0.65	0.8	0.31
Feb-17	0.9	0.76	0.91	0.8	0.71	0.93	0.79	0.17
Mar-17	0.67	0.95	0.31	0.87	0.44	0.87	0.64	0.35
Apr-17	0.64	0.66	0.66	0.71	0.84	0.98	0.92	0.86
May-17	0.89	0.42	0.5	0.64	0.5	0.2	0.45	0.78
Jun-17	0.25	0.66	0.64	0.82	0.74	0.45	0.67	0.97
Jul-17	0.73	0.98	0.64	0.79	0.86	0.64	0.79	0.52
Aug-17	0.71	0.13	0.61	0.12	0.46	0.84	0.9	0.71
Sep-17	0.77	0.14	0.19	0.11	0.6	0.72	0.58	0.55
Oct-17	0.43	0.32	0.33	0.42	0.12	0.61	0.58	0.75
Nov-17	0.78	0.92	0.48	0.61	0.78	0.61	0.76	0.91
Dec-17	0.55	0.61	0.12	0.26	0.56	0.4	0.78	0.69
Jan-18	0.54	0.84	0.44	0.95	0.33	0.77	0.62	0.95
Feb-18	0.66	0.89	0.46	0.91	0.38	0.59	0.9	0.62
Mar-18	0.78	0.77	0.96	0.8	0.43	0.47	0.62	0.88
Apr-18	0.61	0.8	0.31	0.82	0.61	0.59	0.97	0.66
May-18	0.97	0.86	1	0.62	0.58	0.69	0.88	0.93
Sep-18	0.27	0.39	0.68	0.6	0.35	0.58	0.7	0.62
Oct-18	0.58	0.93	0.71	0.62	0.28	0.54	0.85	0.86

Chalakudy, Vynthala, Pulikakadavu and Palapuzhakadavu sites showed comparatively high values of FC/TC and BOD/ COD (> 0.5). That means the high sewage pollution or biological pollution due to human activity is dominating in summer and monsoon seasons along the year 2014 and 2015. During June 2014, was observed high BOD/COD ratio at Kanjirappilly site. That might be due the presence of leach ate from the premises of pulp and paper industry which was shut down. During March, April, and May 2014 at Palapuzhakadavu, August 2014 at Pulikakadavu site, and March, April 2015 at Chalakudy site were observed maximum bacterial pollution due to human activity. This may be due the runoff water contained wastes from open defecation of humans and animals or due to the direct discharge of septic tank wastes or cattle farm wastes in to the river.

4.4 Parametric Correlation

Correlation analysis was carried out to identify with the dependency between each water quality parameters. Parametric correlation between the pairs of water quality parameters of samples along the study area gives an idea about the status of the water resource and it is very helpful to know the nature of pollutants. Correlation coefficients between fifteen pairs of water quality parameters were obtained using Microsoft excel and displayed in the table 4.83. These values of correlation coefficients (R) give the idea for the selection of proper treatment methods with respect to the nature of contaminants.

TDS with TUR, EC, TC, FC, NO_3^- and Cl^- showed high positive correlation between them. Significant correlations between the pairs TDS - TUR, TC- FC, TC-EC, EC-Cl^-, BOD- COD, and FC-EC, also were found during the period of study.

Table.4.83: Correlation coefficient matrix between the fifteen pairs of water quality parameters

	BOD	COD	Cl-	DO	EC	FC	NO3-	pH	PO4-	SO4-	T	TC	TDS	TH	TUR
BOD	1														
COD	0.753	1													
Cl-	-0.043	0.051	1												
DO	-0.462	-0.504	-0.12	1											
EC	0.063	0.157	0.87358	-0.3289	1										
FC	0.069	0.177	0.59141	-0.3341	0.92442	1									
NO3-	0.453	0.56308	0.42996	-0.5295	0.59744	0.59836	1								
pH	-0.268	-0.1568	-0.383	0.313	-0.43311	-0.3613	-0.51	1							
PO4-	0.321	0.262	0.59317	-0.3974	0.57345	0.47518	0.59434	-0.5273	1						
SO4-	-0.063	0.03717	0.41251	-0.22	0.67345	0.46868	0.3881	-0.2645	0.43464	1					
T	0.531	0.40942	0.04119	-0.1883	0.47065	0.03258	0.25209	-0.4403	0.24322	0.02451	1				
TC	0.112	0.38873	0.73314	-0.3474	0.83481	0.8969	0.25209	-0.46	0.57608	0.42797	0.06627	1			
TDS	0.287	0.19464	0.84315	-0.3332	0.87908	0.88936	0.75953	-0.5297	0.598	0.47755	0.21602	0.81686	1		
TH	0.447	0.38873	0.63504	-0.4336	0.79031	0.7874	0.6497	-0.4066	0.46988	0.39629	0.17759	0.68827	0.72223	1	
TUR	0.465	0.45869	0.52859	-0.5353	0.7557	0.54953	0.7462	-0.6137	0.6372	0.14766	0.26348	0.61558	0.90855	0.56216	1

4.5 Conclusion

The physico- chemical and bacteriological parameters analysis enables the assessment of pollution load in water bodies. The trend of water quality parameters and seasonal variations of each parameter in the river water samples along the period of study were analysed by the box plots, and graphs obtained from the MINITAB. The significance of site and season on each parameter were identified using ANOVA and the possible reasons for these variations in the parameters were anlysed by grouping of Tukey method (post hoc ANOVA). Significant decrease in the overall water quality of river water was observed during the period of study. Generally, fresh water availability in this river was very high. Among the studied areas, sometimes 100% DO saturation was observed in most of the sites such as Vazhachal, Vettilappara, Pariyaram, Chalakudy and Palapuzhakadavu during monsoon. This shows that self-purification rate of stream of Chalakudy river is high during monsoon. This may be attributed to the presence of waterfalls upstream to these sites. Generally, there is a fluctuating trend of overall water quality, which was observed along the study period. During summer, 2015 and 2018 comparatively bad water quality was measured at Pulikkakadavu, and Palapuzhakadavu sites. This may be attributed to the industrial discharge in to the river. After the flood affected Kerala during August 2018, the water level in this river was drastically decreased and increased the level contamination. Out of all water quality parameters analyzed, comparatively high variations were observed for some parameters such as pH, BOD, EC, BOD, TH, COD and TUR. The overall nature found based on the obtained values of pH, the river water can be considered as slightly alkaline. Pulikakadavu and Palapuzhakadavu sites were generally observed as acidic. By considering the average of total hardness values obtained during the study period, it was less than 120 mg/l. Generally, nature of this river water in the area of study can be considered as moderately hard.

During the period of study, very high presence of water quality parameters TC and FC were observed in the water. Bacteriological contamination is significantly high along the area of study in Chalakudy river. At the downstream of the river from Chalakudy town a decreasing water quality trend was observed due to high bacterial contamination. Chalakudy, Vynthala, Palapuzhakadavu sites have shown high values of total coliform and fecal coliform and all the observed values were very high and exceeding the prescribed limit (absence or 10 CFU/100ml) of IS and WHO drinking water specification. All these contamination was generally contributed by the human activity mainly septic tank waste discharge, urban waste discharge, cattle and poultry farm waste discharge in to the river. High sewage pollution due to the human activity is dominating in summer and monsoon seasons during the years 2014 and 2015. Before flood, during March 2018, high contamination due to TUR, TDS, EC, NO_3^{-}, PO_4^{-} and TH were observed. All the samples collected after flood were contaminated with high values of TC, TH, FC, BOD, COD and TUR. In general, other values except these periods, the water quality of all the parameters except TC and FC were found within the permissible limits. Pollution due to biodegradable wastes is high in this river and it was identified by analysing the BOD/COD ratio. Correlation between the water quality parameters was studied. Significant correlations between the pairs TDS - TUR, TC- FC, TC-EC, EC-Cl^{-}, BOD- COD, and FC-EC, were found by analyzing the correlation coefficient(r).

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Chapter 5

PERSISTENCE OF ORGANOCHLORINE PESTICIDES IN SURFACE WATER AND SEDIMENT

Contents

5.1 Introduction

This chapter intends to find the water quality and load of pesticide contamination in the study area. The entry of pesticides in to the water bodies is either by agricultural runoff, by accident or by misuse. Direct contamination may occur from pesticide spills, back siphoning, improper storage and disposal of pesticide containers in to the water body. Pesticides are used by wide spectrum of users such as farmers, municipalities and companies, etc. Persistence of organochlorine pesticides in surface water and sediment were analysed during the period of January 2014 – December 2016 using Gas Chromatograph technique (GC). The steps involved in the analysis are explained in the Chapter 3 in detail. Mean concentration (µg/gm) of OCP's observed in the sediment samples collected from the study area are listed in the Table 5.1, Table 5.2& Table 5.3.The seasonal and spatial variations of OCP's observed in the sediment samples during the period of study are showed in Fig. 5.1 to Fig.5.5.

Table 5.1: Mean concentration of Organochlorine pesticides (OCP's) in bottom sediments in all sites during 2014

Organochlorine pesticides	Vazhachal	Vettilappara	Kanjirappilly	Pariyaram	Chalakudy	Pulikkakadavu	Palapuzhakadavu	Vynthala
Aldrin, µg/g	ND	ND	ND	ND	ND	ND	ND	ND
Dicofol (Kethane), µg/g	ND	BDL	0.02	0.09	0.10	0.02	BDL	0.04
Dieldrin, µg/g	ND	ND	ND	ND	ND	ND	ND	ND
Op-DDT, µg/g	ND	ND	ND	ND	ND	ND	ND	ND
pp- DDT, µg/g	BDL	0.13	0.14	0.15	0.26	0.06	BDL	BDL
α BHC, µg/g	0.56	0.33	BDL	BDL	BDL	BDL	BDL	BDL
α Endosulphan, µg/g	ND	ND	ND	ND	ND	ND	ND	ND
β Endosulphan, µg/g	BDL	ND	0.11	0.22	0.22	0.07	ND	ND
δ BHC, µg/g	ND	ND	ND	ND	ND	ND	ND	ND
ϒ BHC(Lindane), µg/g	ND	BDL	0.10	0.02	0.05	BDL	BDL	BDL

Table 5.2: Mean concentration of Organochlorine pesticides (OCP's) in bottom sediments in all sites during 2015

Organochlorine Pesticides	. Vazhachal	Vettilappara	Kanjirappilly	Pariyaram	Chalakudy	Pulikkakadavu	Palapuzhakadavu	Vynthala
Aldrin, µg/g	ND	ND	ND	ND	ND	ND	ND	ND
Dicofol (Kethane), µg/g	BDL	BDL	0.05	0.05	0.05	BDL	BDL	0.35
Dieldrin, µg/g	ND	ND	ND	ND	ND	ND	ND	ND
Op-DDT, µg/g	ND	ND	ND	ND	ND	ND	ND	ND
pp- DDT, µg/g	BDL	0.05	0.06	0.26	0.07	BDL	BDL	0.09
α BHC, µg/g	0.38	0.13	ND	BDL	BDL	ND	ND	ND
α Endosulphan, µg/g	ND	ND	ND	BDL	BDL	ND	ND	ND
β Endosulphan, µg/g	ND	ND	0.09	0.17	0.21	BDL	BDL	0.05
δ BHC, µg/g	ND	ND	BDL	BDL	ND	ND	ND	ND
Υ BHC(Lindane), µg/g	ND	ND	0.05	0.047	0.08	ND	ND	ND

Table 5.3: Mean concentration of Organochlorine pesticides (OCP's) in bottom sediments in all sites during 2016

Organochlorine Pesticides	Vazhachal	Vettilappara	Kanjirappilly	Pariyaram	Chalakudy	Pulikkakadavu	Palapuzhakadavu	Vynthala
Aldrin, µg/g	ND	ND	ND	ND	ND	ND	ND	ND
Dicofol (Kethane), µg/g	BDL	BDL	0.23	0.38	0.05	0.04	0.05	0.186
Dieldrin, µg/g	ND	ND	ND	ND	ND	ND	ND	ND
Op-DDT, µg/g	ND	ND	ND	ND	ND	ND	ND	ND
pp- DDT, µg/g	0.46	0.177	0.256	0.155	0.297	0.143	0.048	0.083
α BHC, µg/g	0.259	0.244	ND	ND	ND	ND	ND	ND
α Endosulphan, µg/g	ND	ND	0.051	0.084	0.082	0.176	BDL	0.046
β Endosulphan, µg/g	ND	ND	0.087	0.167	0.209	BDL	BDL	0.046
δ BHC, µg/g	ND	ND	ND	ND	ND	ND	ND	ND
Υ BHC(Lindane), µg/g	ND	0.06	0.083	0.071	0.115	BDL	0.06	0.043

5.2 Persistence of Dicofol

The Dicofol (Kethane) concentration in bottom sediment ranged from 0 to 0.93µg/g with an average value of 0.43µg/g and with SD 0.14. The maximum concentration 0.93µg/g was observed in Vynthala site during monsoon 2015. The spatial and seasonal variations of Dicofol in the bottom sediment are shown in Fig.5.1. During the period of study, the presences of Dicofol residue in the bottom sediments were found in the sites from Kanjirappilly to Vynthala. The presence of Dicofol (Kethane) and Lindane were detected in bottom sediment of Pariyaram, Chalakudy and Vynthala sites. The maximum mean values of Dicofol were 0.24µgm/gm, 0.11µgm/gm and 0.45µgm/gm respectively. During monsoon, Pariyaram, Chalakudy and Vynthala sites were found to have an increasing trend in the case of Dicofol trace. This may be due to the surface runoff through the nearby agricultural fields. The maximum concentration of Dicofol was observed in the sediment collected from Vynthala site (0.45 µgm/gm). In Pariyaram, site bottom sediment samples were determined with the presence of Dicofol during non-monsoon 2015.

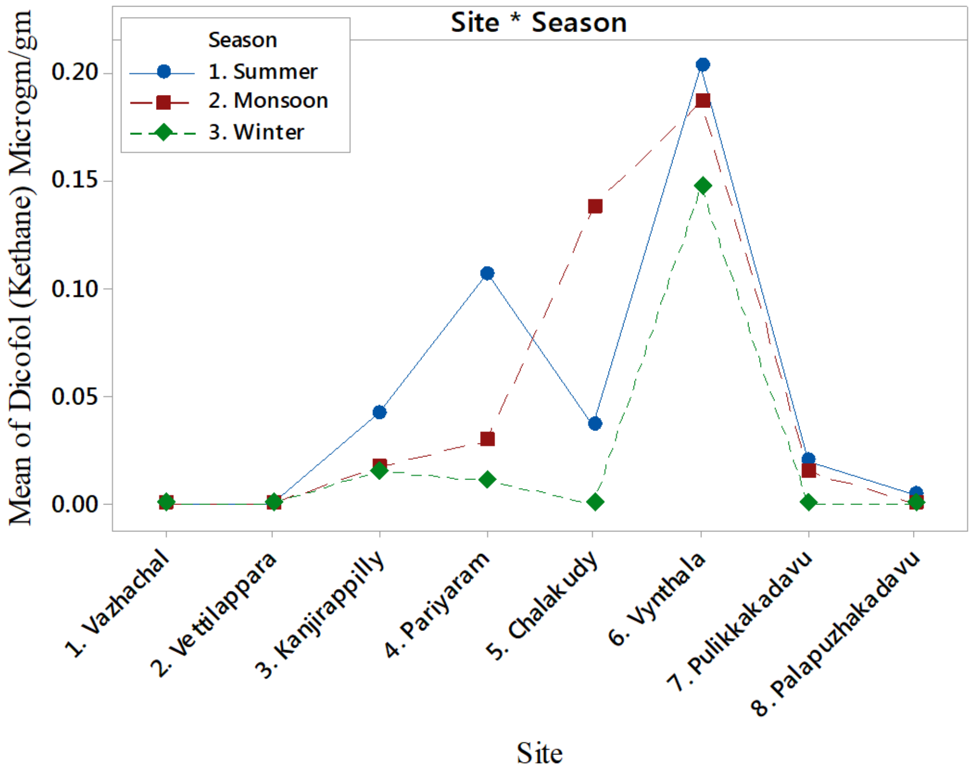

Fig. 5.1: Temporal and seasonal variations of Dicofol

ANOVA results and posthoc ANOVA (Tukey method) results are shows in Table 5.4 and Table 5.5. From these results, it is clear that (for site P=0) site is positively significant with the variation of concentration of Dicofol in the sediment samples.

Pariyaram, Chalakudy and Vynthala sites show comparatively high value of Dicofol traces in the bottom sediment. During the study period Vynthala site was found to have the maximum mean concentration of Dicofol. These values indicate that there is a predominant use of Dicofol in the study area. This may be contributed by the continuous use or misuse of this pesticide in the nearby agricultural field.

Table 5.4: ANOVA results of Dicofol in sediment samples

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Season	2	0.02	0.02	0.01	0.52	0.596
Site	7	0.92	0.87	0.12	7.15	0
Season*Site	14	0.14	0.14	0.01	0.57	0.884
Error	247	4.28	4.28	0.02		
Total	270	5.36				

Table 5.5: Grouping Information at 95 % Confidence for the presence of Dicofol in sediment, using the Tukey method

Season	N	Mean	Grouping	
Monsoon	112	0	A	
Summer	88	0	A	
Winter	71	0	A	
Site	**N**	**Mean**	**Grouping**	
Vynthala	34	0.2	A	
Chalakudy	34	0.1		B
Pariyaram	34	0.1		B
Kanjirappilly	33	0		B
Pulikkakadavu	34	0		B
Palapuzhakadavu	34	0		B
Vettilappara	34	0		B
Vazhachal	34	0		B

5.3 Persistence of pp-DDT

The maximum value of pp-DDT observed was 0.48µg/gm in the bottom sediment sample collected from Kanjirappilly site during monsoon 2015. Presence of pp-DDT ranges from BDL to 0.48 µg/gm. Kanjirappilly, Pariyaram, Chalakudy, Vynthala and Pulikkakadavu sites showed comparatively high trace of pp-DDT in the sediment samples during monsoon 2015. The maximum values were 0.48, 0.28, 0.274 and 0.382 µg/gm respectively during 2015.The spatial and seasonal variations of pp-DDT in the sediment samples collected in the study area are shown in Fig. 5.2. Table 5.6, Table 5.7, delivers the significance of site and season in the level of contamination of DDT. As per ANOVA result (P=0.01), only site is significant with the persistence level of DDT in the collected samples. DDT is classified as moderately toxic by US National toxicological program and moderately hazardous by WHO. DDT is highly toxic to aquatic life like fishes and it can lead to bioaccumulation resulting in cumulative and synergistic effects on the endocrine systems (Muttiyar et al., 2013). A higher concentration of DDT leads to neuropsychological and psychiatric symptoms (Harieth et al., 2011).

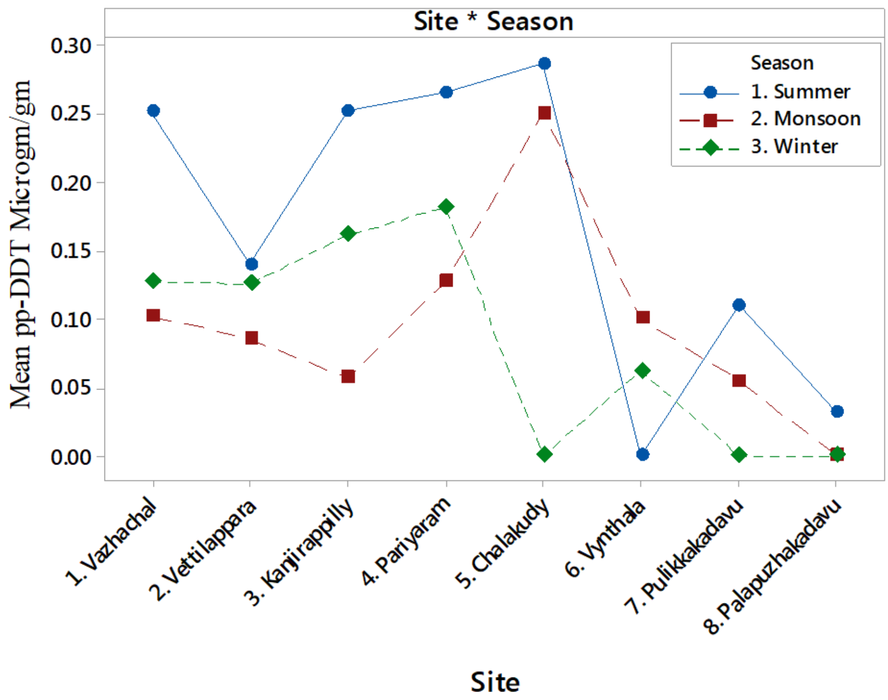

Fig. 5.2: Variations of pp-DDT with site and season

Table 5.6: ANOVA results of pp- DDT, µg/g

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Season	2	0.1	0.1	0.1	0.87	0.422
Site	7	1.1	1.1	0.2	2.55	0.015
Season*Site	14	0.9	0.9	0.1	1.06	0.393
Error	247	15.5	15.5	0.1		
Total	270	17.7				

Table 5.7: Grouping Information using Tukey Method at 95% Confidence for pp- DDT, µg/g

Season	N	Mean	Grouping	
Summer	88	0.1	A	
Winter	71	0.1	A	
Monsoon	112	0.1	A	
Site	**N**	**Mean**	**Grouping**	
Pariyaram	34	0.2	A	
Chalakudy	34	0.2	A	
Vazhachal	34	0.2	A	
Kanjirappilly	33	0.2	A	
Vettilappara	34	0.1	A	
Pulikkakadavu	34	0.1	A	
Vynthala	34	0.1	A	
Palapuzhakadavu	34	0	A	

5.4 Persistence of α BHC

In Vazhachal and Vettilappara sites, the presence of αBHC was observed. Maximum presence was 1.5µgm/gm in the sediment sample collected from these sites. The concentration ranges from BDL to 1.5µgm/gm during the study period. It is a high value according to Canadian guidelines of sediment quality. This is the one and the only site where the presence of αBHC was observed. αBHC is a byproduct of Lindane (γ-HCH) production and it is also present in commercial grade Lindane used as an insecticide. It is sparingly soluble in water. The monsoon floods carry these types of pollutants from nearby fields in to the river. Spatial and seasonal distributions of α BHC are shown in Fig.5.3.

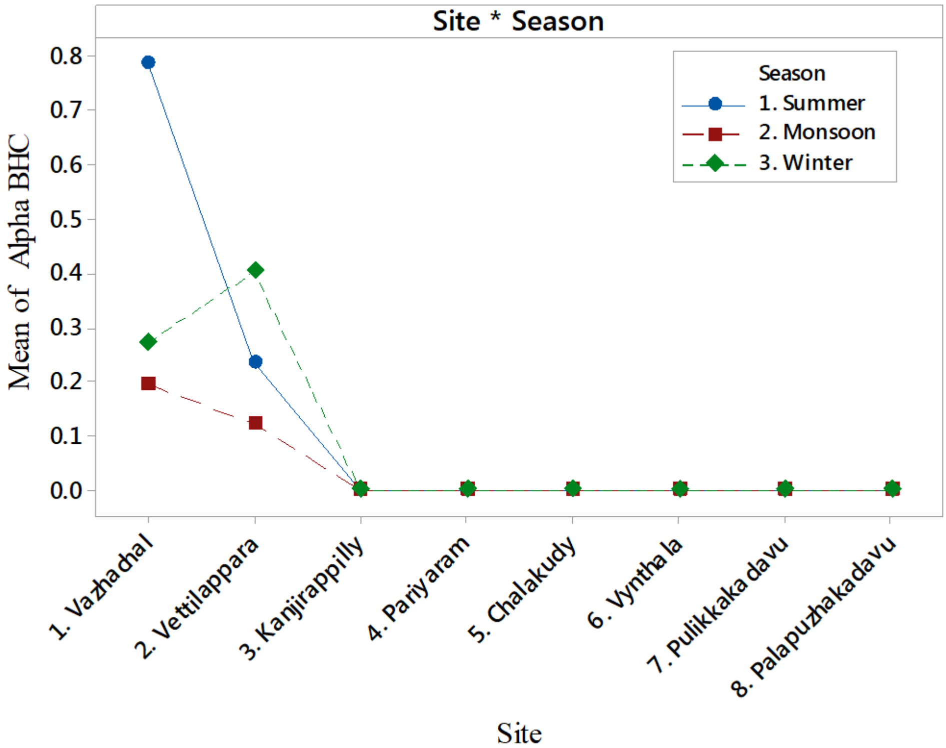

Fig. 5.3: Spatial and seasonal distribution of α BHC

5.8: ANOVA results of α BHC, μg/g

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Season	2	0.39	0.39	0.19	3.17	0.044
Site	7	5.74	6.01	0.86	14.12	0
Season*Site	14	2.43	2.43	0.17	2.85	0.001
Error	247	15.02	15.02	0.06		
Total	270	23.58				

As per the ANOVA results shown in the Tables 5.8 and Table 5.9, the entry of α BHC in to the river sediment is positively significant with the sites and season with P values, P=0.04 and P=0 respectively. Vazhachal and Vettilappara sites were found to have significant traces of α BHC in the sediment samples. It is clear that the predominant use of α BHC was carried out in the agriculture fields and in the plantations existing in the Vazhachal and Vettilappara region.

Table 5.9: Grouping Information by Tukey Methodat 95 % Confidence for α BHC, μg/g

Season	N	Mean	Grouping	
Summer	88	0.1	A	
Winter	71	0.1	A	B
Monsoon	112	0		B
Site	**N**	**Mean**	**Grouping**	
Vazhachal	34	0.4	A	
Vettilappara	34	0.3	A	
Pariyaram	34	0		B
Pulikkakadavu	34	0		B
Chalakudy	34	0		B
Vynthala	34	0		B
Palapuzhakadavu	34	0		B
Kanjirappilly	33	0		B

5.5 Persistence of β Endosulphan

Along the period of study, sediment samples collected from Kanjirappilly, Pariyaram, Chalakudy and Pulikkakadavu sites were detected to have the presence of β Endosulphan. Sediments collected from Pariyaram site showed the maximum presence of β Endosulphan. The maximum mean value was 0.45μg/gm during summer 2014. Most of the values were ND. The values varied from BDL to 0.4 μg/gm. Persistence of β Endosulphan observed in the sediment samples collected from Chalakudy site may be an evidence for the predominant application in vegetables, and in agricultural runoff. Only a few surface water samples collected from Pariyaram, Kanjirappilly and Chalakudy sites were found the traces of β Endosulphan. The maximum mean concentration of β Endosulphan was obtained 0.06 μg/l in the surface water. Most of the surface water samples were not detected the traces of organo chlorine pesticides.

Endosulphan is a highly toxic pesticide as per EPA toxicity. It may be slightly toxic if inhaled and it is carcinogenic. The solubility of Endosulphan is 0.3 mg/l with a half-life of 50 days in soil and 5 weeks in water .β isomer of Endosulphan has longer half-life i.e. 150 days under neutral conditions. The beta isomer is considered more toxic than the alpha-isomer. So Endosulphan is banned in many countries.

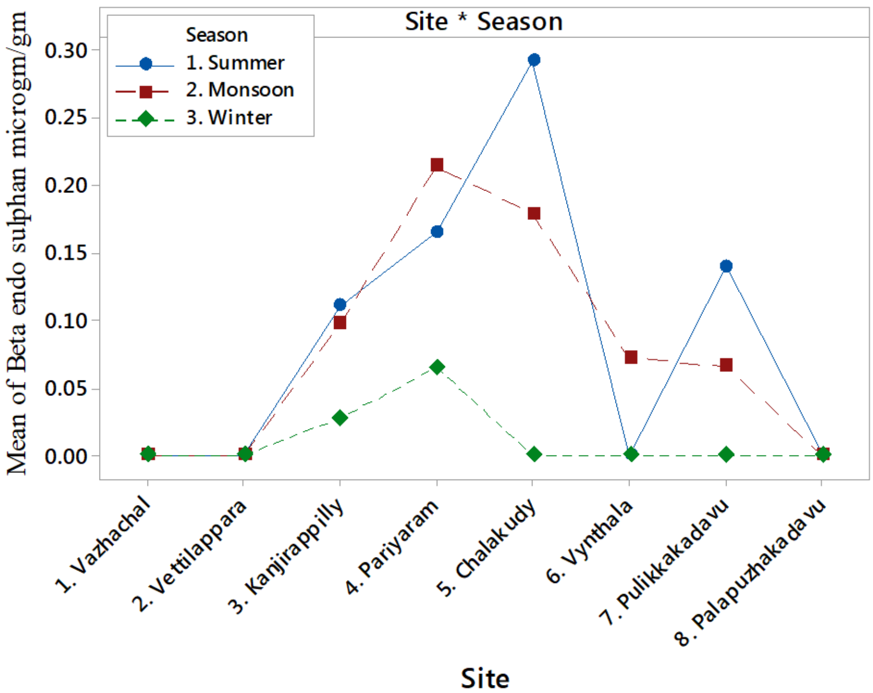

Fig. 5.4: Variations of β Endosulphan with site and season

Table 5.10: ANOVA result of β Endosulphan, µg/g

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Season	2	0.16	0.16	0.08	2.59	0.077
Site	7	1.23	1.06	0.15	4.91	0
Season*Site	14	0.54	0.54	0.04	1.24	0.248
Error	247	7.64	7.64	0.03		
Total	270	9.57				

Table 5.11: Grouping Information by Tukey Method at 95 % Confidence for β Endosulphan, µg/g

Season	N	Mean	Grouping		
Summer	88	0.1	A		
Monsoon	112	0.1	A		
Winter	71	0	A		
Site	**N**	**Mean**	**Grouping**		
Chalakudy	34	0.2	A		
Pariyaram	34	0.2	A	B	
Kanjirappilly	33	0.1	A	B	C
Pulikkakadavu	34	0.1	A	B	C
Vynthala	34	0		B	C
Vettilappara	34	0			C
Vazhachal	34	0			C
Palapuzhakadavu	34	0			C

Seasonal variations of β Endosulphan in the bottom sediment along the period of study are shown in Fig.5.4. The results of ANOVA and posthoc ANOVA (Tukey method) are listed out in the Table 5.10.and in the Table 5.11respectively. From these results, it is clear that site is more significant with the variations of β Endosulphan. Predominant use of β Endosulphan might have been carried out in the agriculture fields, especially in the middle stretch from Pariyaram to Pulikkakadavu sites in the river basin. Many crops like banana, nutmeg and tapioca are mainly cultivated in this area.

5.6 Persistence of Lindane

During the period of study Vettilappara, Pariyaram and Chalakudy site were found to have maximum mean concentration traces (0.115µg/gm, 0.09µg/gm, and 0.067µg/gm) of Lindane in the analysis of the collected sediment samples. The maximum mean concentration of Lindane was obtained 0.04 µg/l in the surface water. Most of the surface water samples were not detected the traces of organo chlorine pesticides. Lindane has not been produced or used in the United States for more than 20 years (Aquofolu et al 2004). The solubility of Lindane in water is 10 mg/l and reported half-life is of 18 hours. Lindane is “Moderately Hazardous” pesticide according to WHO and USEPA. During monsoon, at Chalakudy site was found to have traces of Lindane in the sediment sample. Presence of high concentration of Lindane can negatively affect the nervous system producing a range of symptoms from headaches and dizziness to convulsions and more rarely death (Agency for Toxic Substances and Disease Registry 2005).

The maximum concentration of Lindane 0.82µg/gm was observed in the sediment sample at Vettilappara site. The sediment samples collected from Kanjirappilly site were also found to have a maximum mean concentration of Lindane. Lindane was found to be almost absent or BDL in sediment samples collected from all other sites. The spatial variations of Lindane (mean concentration) are showed in Fig. 5.5. The ANOVA and posthoc ANOVA results are showed in Table 5.12 and Table 5.13. From these results no significant relationship was identified for the trace of Lindane to site and season. The presence of Lindane in the river might be due to the misuse of pesticide containers or that has accidently entered in to the river.

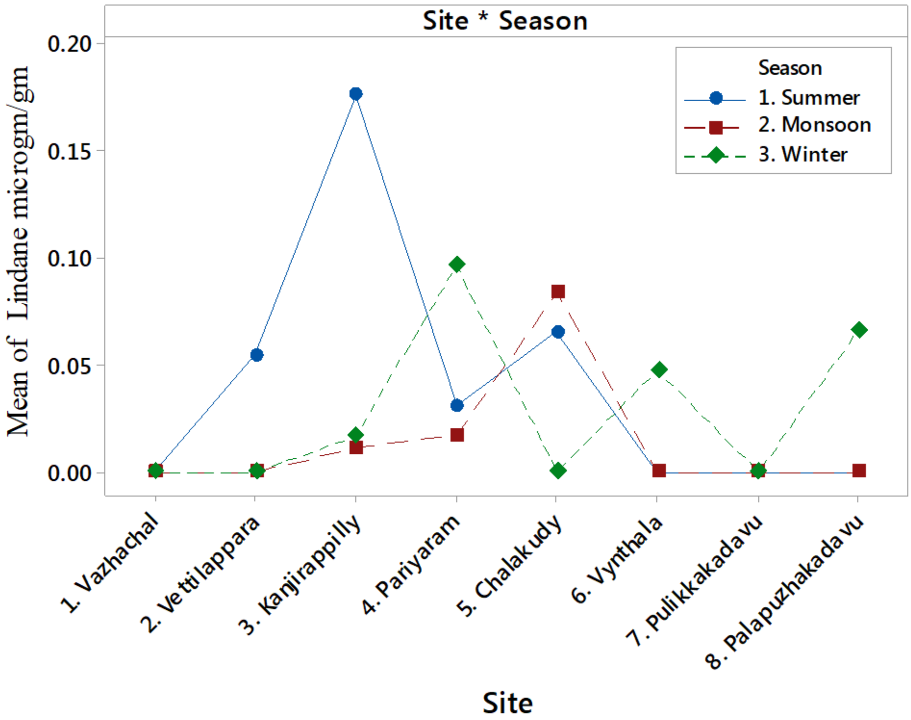

Fig. 5.5: Spatial and seasonal variations of Lindane

Table 5.12: ANOVA results of ϒ BHC (Lindane), µg/g

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Season	2	0.04	0.04	0.02	1.55	0.215
Site	7	0.15	0.14	0.02	1.71	0.107
Season*Site	14	0.31	0.31	0.02	1.89	0.027
Error	247	2.85	2.85	0.01		
Total	270	3.34				

Table 5.13: Grouping Information by Tukey Method at 95 % Confidence for Lindane, µg/g

Season	N	Mean	Grouping	
Summer	88	0	A	
Winter	71	0	A	
Monsoon	112	0	A	
Site	**N**	**Mean**	**Grouping**	
Kanjirappilly	33	0.1	A	
Chalakudy	34	0	A	
Pariyaram	34	0	A	
Palapuzhakadavu	34	0	A	
Vettilappara	34	0	A	
Vynthala	34	0	A	
Pulikkakadavu	34	0	A	
Vazhachal	34	0	A	

5.7 Conclusion

Out of the water samples collected from the study area, a few samples were detected to have the presence of OCPs. The maximum mean value of OCPs detected in surface water were β Endosulphan (0.06μg/l) and of Lindane (0.04μg/l). The presence of these OCPs in surface water was observed in the samples collected from Pariyaram site during monsoon 2015. Due to the high dilution during monsoon, persistence of OCPs in most of the surface water samples collected from the study area were BDL. Pesticides in surface water do not remain at their target site but gets distributed to the environment via soil percolation, surface runoff etc. affecting the various levels and diversity of non-target species producing a complex effect on the ecosystem. However, the bottom sediment collected from the Chalakudy river has shown the presence of OCPs. The pesticides detected in the bottom sediments were Dicofol (Kethane), pp-DDT, α BHC, ϒ BHC (Lindane), and β Endosulphan. β Endosulphan was detected in the bottom sediment collected from Kanjirappilly site, Pariyaram site, and in Chalakudy site during summer 2014 and 2015. These are results of surface runoff of pesticides which occur in the middle basin area mainly from the banana and vegetable plantations. In the case of Lindane, it was identified that there is no significant relationship with the trace of Lindane present to the parameters site and season. The presence of Lindane in the river might be due to the misuse of pesticide containers or that had accidently entered in to the river.

During the period of study, maximum concentration of β Endosulphan was detected at Pariyaram and Chalakudy sites. Kappathodu, which flows through agriculture land, joins with the river nearby Pariyaram site. The above mentioned results indicate that predominant use of β Endosulphan was carried out in these areas. The pesticide might have been carried by surface runoff water in to the river. αBHC was detected in the sediment samples collected from Vazhachal and Vettilappara sites. The monsoon floods might have transported these pesticides from the plantations. In certain stretches, mainly at middle stretch, sediment and surface water were slightly contaminated by pesticides especially with β Endosulphan and pp-DDT

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Chapter 6

FUZZY DISSOLVED OXYGEN MODEL (FDOM) OF CHALAKUDY RIVER

Contents

6.1 Introduction

The fuzzy dissolved oxygen model of Chalakudy river (FDOM) was developed based on the values of experimentally analysed water quality parameters such as temperature, phosphates, COD and nitrates along the period of study as input data. Steps involved in fuzzy modeling (Mamdani) for FDOM are shown in the chapter 3 in detail. The rules were developed for each factor by MATLAB programming which can execute a series of statements (Gesim and Okazaki., 2018). The values corresponding to the input variables generated were subdivided and recorded into groups with specific ranges and symbols. This helped in creating the membership functions for fuzzy modeling within the permitted range.

6.2 Fuzzy Dissolved Oxygen Model (FDOM)

Mamdani model using triangular membership functions of each parameter were generated. Triangular membership functions are considered as more reliable and efficient in the case of water quality modeling. The model helps to predict the level of DO using four important water quality parameters such as Temperature, Phosphates, COD and Nitrates. Prediction model of water quality DO Mamdani model using triangular membership functions are shown in Fig.6.1. The membership functions generated for each input parameters and output parameter DO are shown in Fig.6.2 to 6.6. The output viewer of fuzzy is shown in Fig. 6.7.

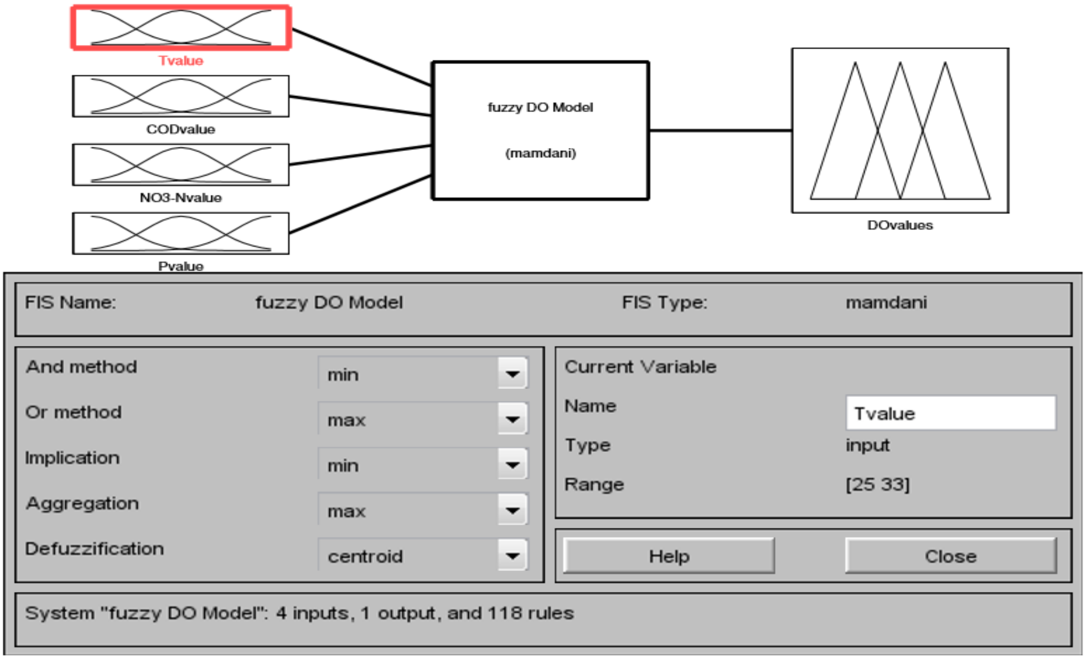

Fig. 6.1: Fuzzy dissolved oxygen model of Chalakudy river (FDOM)

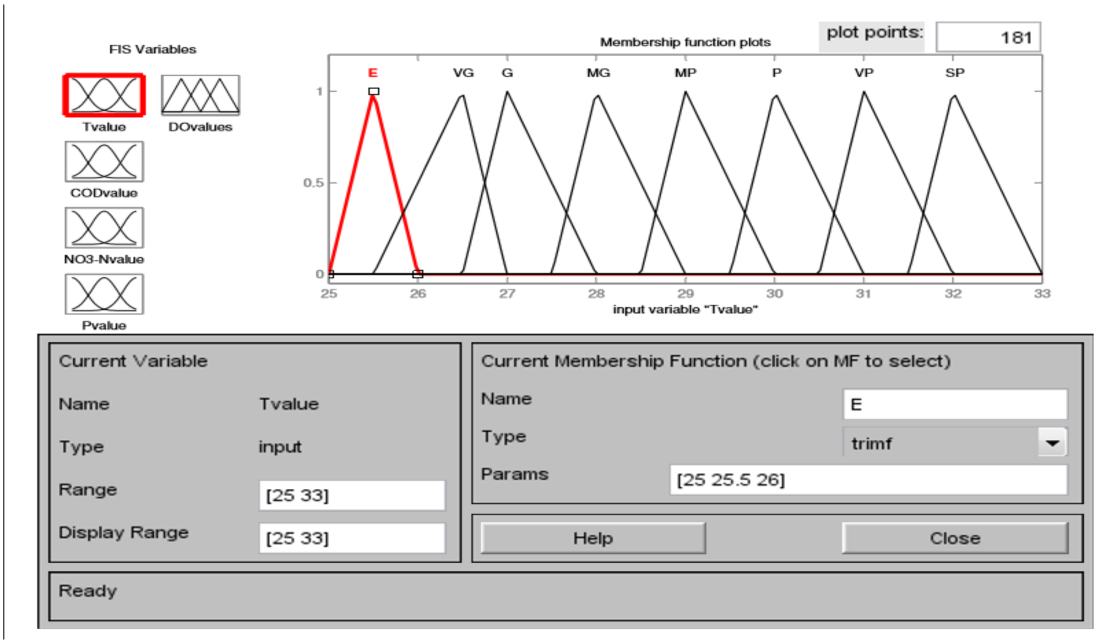

Fig. 6.2: Membership functions of T values

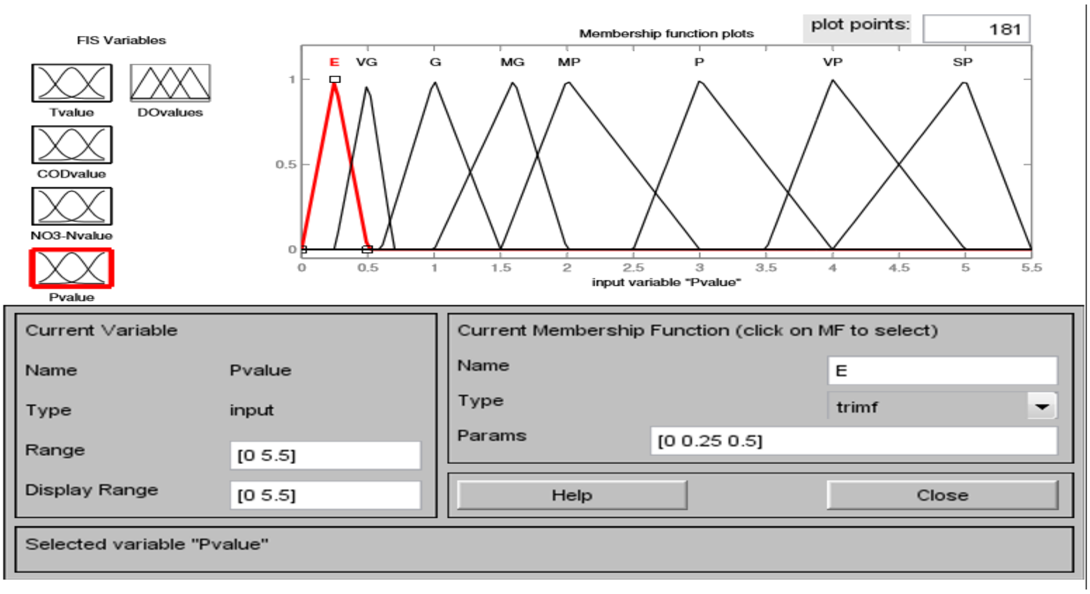

Fig. 6.3: Membership functions of Phosphates values

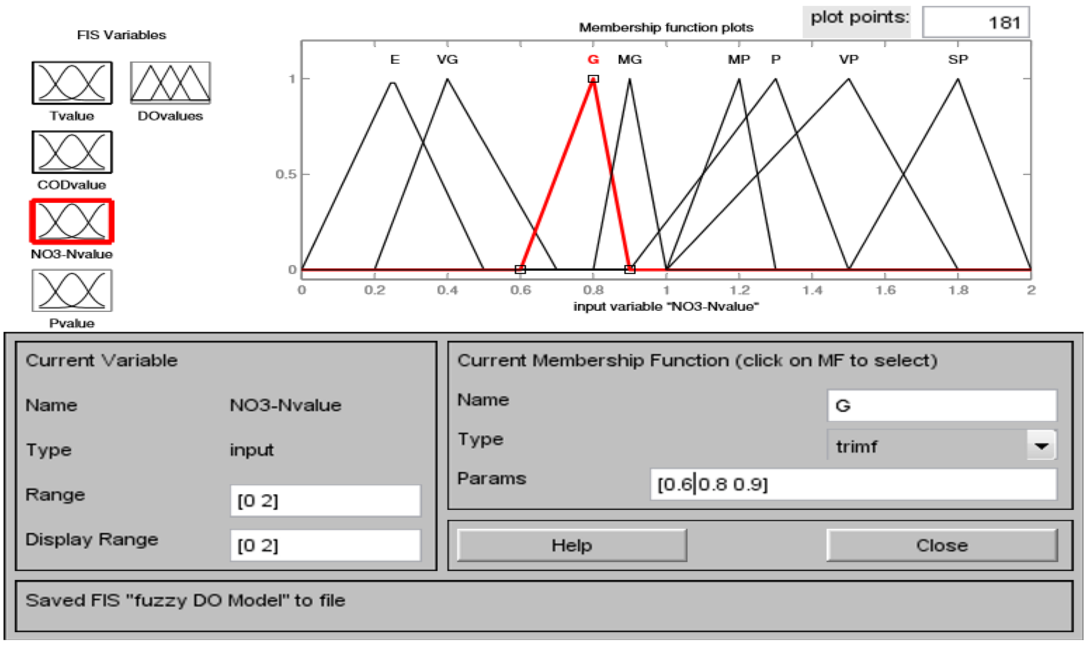

Fig. 6.4: Membership functions of NO_3^- values

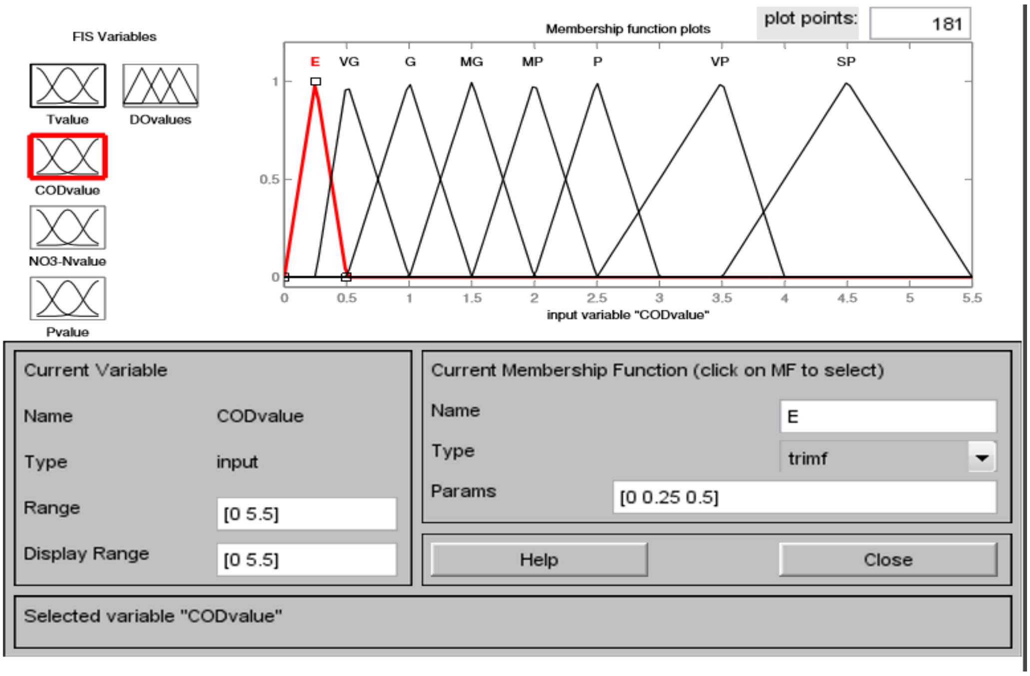

Fig. 6.5: Membership functions of COD values

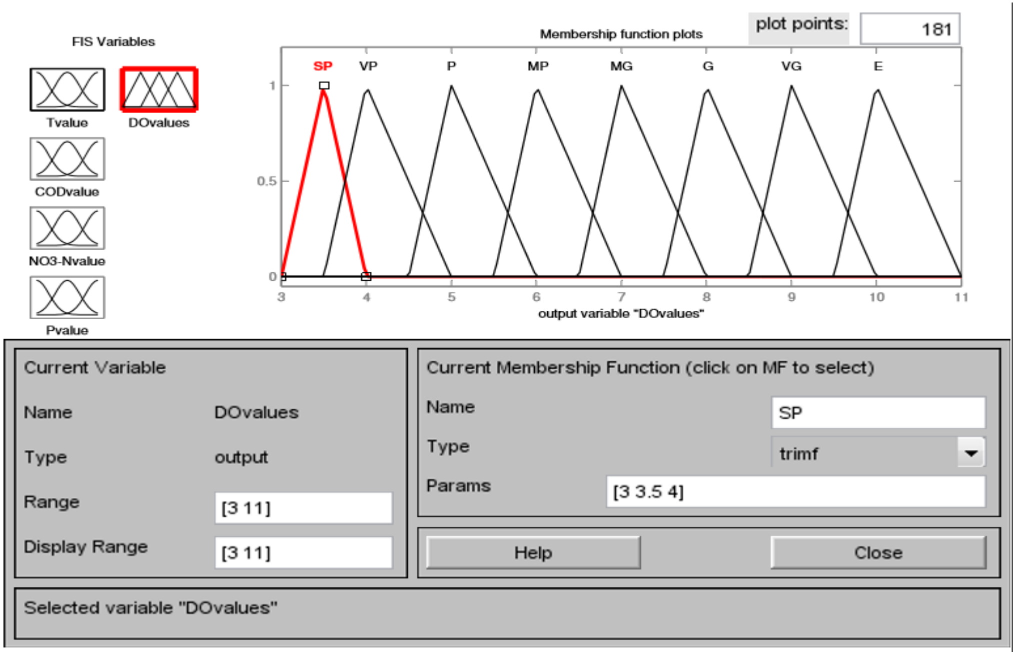

Fig.6.6: Membership functions of DO values

Fuzzy set assigned to a control DO variable at first, and then they get to transform into crisp values by comparing all the four input parameters within the range by centroid calculation, which returns the center of the area under the triangular membership functions. Predicted DO will be obtained as an output crisp value from the defuzzifier and visible in output viewer.

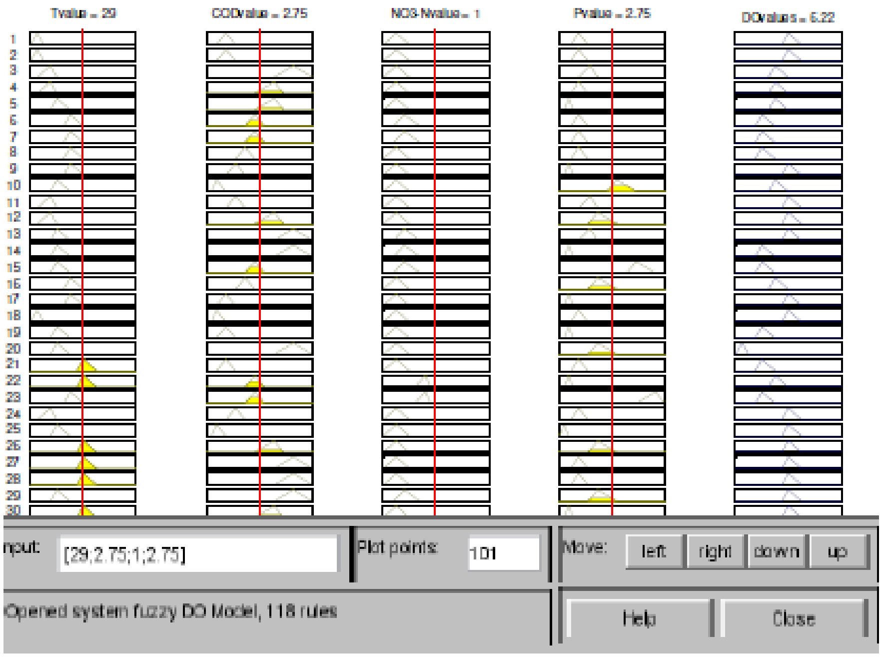

Fig. 6.7: output viewer

6.3 Validation of FDOM

Eleven sets of values were taken arbitrarily for the validation of the model as shown in Table.6.1. Predictions were made using the different combinations of these input parameters in different sites. The predicted dissolved oxygen values were compared with the experimental values in terms of average absolute relative error (AARE) and Root mean square error (RMSE).

Table.6.1: Validation of FDOM

SI No	Temperature (^oC)	NO_3-N (mg/l)	COD(mg/l)	P(mg/l)	Experimental Do(mg/l)	Fuzzy Do(mg/l)	AARE	RMSE
1	25	0.95	0.3	0.2	8.4	8.1	3.571	0.09
2	27	1.88	2.2	4	5.7	5.4	5.263	0.09
3	27.4	1.14	2.8	1.9	7	6.9	1.429	0.01
4	28	0.11	1.8	0.23	6.4	6.2	3.125	0.04
5	28	0.28	4.5	0.1	6	6.2	3.333	0.04
6	29	0.34	1.9	0.24	7.1	6.9	2.817	0.04
7	29	0.2	5.3	0.12	7.1	7	1.408	0.01
8	29.2	1.14	2.8	1.9	6.3	6.21	1.429	0.01
9	30	0.06	2.5	1.57	6.9	6.3	8.696	0.36
10	30.03	1.136	2.8	2.91	5.1	5.02	1.569	0.01
11	32	0.14	3.8	1	6.3	6.1	3.175	0.04
							3.256	0.26

The predicted DO value by FDOM was found very much closer to the actual experimental values with AARE 3.256 and RMSE 0.26.

6.4 Conclusions

FDOM model (Mamdani Model) with triangular membership functions using MATLAB is found to be an efficient fuzzy model to predict the DO level of the river water. Hence, the models can be extended to any combinations of input parameters, which influence the level of DO directly or indirectly. The model was found to be agreeing with the experimental findings statistically with AARE and RMSE values 3.256 and 0.26 respectively.

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Chapter 7

WATER QUALITY INDEX MODELS

Contents

7.1 Water Quality Index

Water quality index (WQI) can be used as a good tool to convert complex data into a simple and understandable form.WQI is a single measure of overall water quality in a specific location with a special emphasis on the time-based readings of water quality parameters. Similar types of studies related to WQI have been conducted in India. (Pathak, 2015; Chowdhary et al., 2012; Vineeta Kumari et al., 2015). Water quality monitoring and analysis of water quality index are remarkable steps in the process of managing and conserving the entire ecosystem (Smerjit Kaur and Sindhu Singh, 2012). Three water quality index models were developed to identify and predict the WQI of Chalakudy river based on the experimentally analyzed values of different water quality parameters.

This chapter focuses on the effect of some water quality parameters of river water, which helps in the development of prediction models of water quality index. WQI arithmetic model culminates in the development of numerical models for prediction of water quality index of Chalakudy river by using fuzzy logic in MATLAB and regression models using Microsoft Excel. The WQI was calculated by arithmetic method using twelve various experimentally estimated water quality parameters like pH, Chlorides, Dissolved Oxygen, Chemical Oxygen Demand, Nitrates, Sulphates, Phosphates, Total Dissolved Solids, Biochemical Oxygen Demand, Electrical Conductivity, Total Hardness and Total Coliforms of the water of Chalakkudy River, during the period of study. The WQI takes arithmetic index of these variables and synthesizes into a single number. Water quality index models such as arithmetic index model, fuzzy logic water quality index model (FWQIM) and regression models enables the assessment of pollution load and hence the prediction of risk of water consumption. This effective water quality index models such as arithmetic index model, fuzzy logic water quality index model (FWQIM) and regression models in terms of total coliforms (TC) enables the prediction of the risk of water consumption and the assessment of a load of pollution in Chalakudy River. The performance of the model in predicting the water quality index has been tested by comparing with calculated water quality index value for the year 2018 and found to be good enough with an Absolute Average Relative Error (AARE) and Root Mean Square Error (RMSE).

7.2 Water Quality Arithmetic Index Model

The effect of twelve water quality parameters of river water such as pH, Cl^-, % DO, TUR, NO_3^-, SO_4^-, PO_4^-, TDS, BOD, EC, TH and TC which helps in the calculation of water quality index was studied. The calculation of WQI using arithmetic index method is shown in Table7.1 and Table.7.2. By keeping the standard value for total coliform as 10 CFU/100ml and 50 CFU/100ml, two sets of water quality indices of Chalakudy river were developed along the period of study.

Table 7.1: WQI calculation by arithmetic method considering standard TC limit as 50 CFU/100ml

Parameters	***Range***		***1/Vs***	***Unit Weight (Wn)***	***Observed value***	***wn*Qn***
	limit	***best***				
BOD, mg/l	3	0	0.333	0.3714	1.88	23.274
Chlorides, mg/l	250	0	0.004	0.0045	22	0.039
DO saturation, %	50	100	0.02	0.0223	63	1.649
Electrical Conductivity, µmhos/ cm	300	0	0.003	0.0037	69	0.085
Nitrates mg/l	45	0	0.022	0.0248	0.56	0.031
pH	8.5	7	0.118	0.1311	6.4	5.243
Phosphates, mg/l	6	0	0.167	0.1857	6.7	20.736
Sulphates, mg/l	200	0	0.005	0.0056	1.05	0.003
Total Coliform CFU/100ml	50	0	0.02	0.0223	50	2.228
Total Dissolved Solids, mg/l	500	0	0.002	0.0022	56	0.025
Total hardness as CaCO3, mg/l	200	0	0.003	0.0037	49	0.061
Turbidity NTU	5	0	0.2	0.2228	0.67	2.986
			0.898	**1**		**56.33**
		K=	1.114			

Table 7.2: WQI calculation by arithmetic method considering standard TC limit as 10 CFU/100ml

Parameters	Range		1/Vs	Unit Weight (Wn)	Observed value	wn* Qn
	Limit	Best				
BOD, mg/l	3	0	0.333	0.341	1.88	21.369
Chlorides, mg/l	250	0	0.004	0.0041	22	0.036
DO saturation, %	50	100	0.02	0.0205	63	1.514
Electrical Conductivity, µmhos/cm	300	0	0.003	0.0034	69	0.078
Nitrates mg/l	45	0	0.022	0.0227	0.56	0.028
pH	8.5	7	0.118	0.1204	6.4	4.814
Phosphates, mg/l	6	0	0.167	0.1705	6.7	19.039
Sulphates, mg/l	200	0	0.005	0.0051	1.05	0.003
Total Coliform CFU/100ml	10	0	0.1	0.1023	50	51.149
Total Dissolved Solids, mg/l	500	0	0.002	0.002	56	0.023
Total hardness as CaCO3, mg/l	200	0	0.003	0.0034	49	0.056
Turbidity NTU	5	0	0.2	0.2046	0.67	2.742
			0.978	**1**		**100.85**
		K=	1.023			

During the period of study, WQI of Chalakudy river was found to be between 166 to 4745 and 47 to 996 considering TC standard values as 10 CFU/100ml and 50 CFU/100 respectively. The calculated values of WQI during the period of study are shown in Table. 7.3 and Table.7.4. The mean with SD, maximum and minimum values of WQI obtained along the period of study are listed out in Table7.5.From the analysis of WQI it was found that, during the period of study Chalakkudy site had the poorest values of WQI.

Table 7.3: WQI (at TC limit 10 CFU/100ml) along the period of study by the arithmetic index method

Month& Year	Vazhachal	Vettilappara	Pariyaram	Chalakudy	Vynthala	Pulikkakadavu	Palapuzakadavu
Nov-13	276	925	1148	485	1121	412	852
Dec-13	836	898	710	1365	1123	516	930
Jan-14	651	925	490	1001	465	1048	1224
Feb-14	556	534	1127	881	294	750	1380
Mar-14	166	259	611	442	652	655	354

Apr-14	1182	803	955	234	1349	1116	489
May-14	983	620	855	1229	1305	408	709
Jun-14	926	650	1462	1131	1036	755	1170
Jul-14	1206	765	1078	697	1237	994	346
Aug-14	649	791	623	1282	1072	367	493
Sep-14	635	611	1376	1525	647	1231	863
Oct-14	1282	907	1205	479	1237	1017	612
Nov-14	827	1056	863	1441	1198	668	725
Dec-14	889	981	1804	1388	1145	1602	1030
Jan-15	1052	726	952	662	909	1135	1227
Feb-15	455	556	1393	1220	735	961	828
Mar-15	653	1225	224	1107	1391	611	458
Apr-15	613	669	552	1706	1228	1537	1811
May-15	172	195	785	1497	437	1379	1254
Jun-15	755	1098	756	1129	1180	527	1423
Jul-15	1275	1482	1253	1003	1533	1225	1191
Aug-15	534	292	470	426	254	244	312
Sep-15	1642	1211	415	565	1077	1020	832
Oct-15	1018	1282	833	1126	1196	423	945
Nov-15	702	1009	1048	1115	1296	1191	1036
Dec-15	637	708	279	1112	230	179	1207
Jan-16	618	1518	707	1300	975	500	742
Feb-16	1156	1178	840	2278	789	708	2008
Mar-16	1006	689	1176	1949	918	979	1134
Apr-16	547	491	394	464	741	650	965
May-16	512	1092	547	2031	1749	1836	1990
Jun-16	509	1007	882	681	271	551	792
Jul-16	438	388	1133	1295	395	580	987
Aug-16	740	769	507	957	557	598	649
Sep-16	878	848	658	534	581	984	681
Oct-16	978	888	691	938	759	770	426
Nov-16	484	725	360	1195	707	745	1004
Dec-16	992	646	636	846	714	1642	1143
Jan-17	756	907	927	1624	633	1570	1735

Feb-17	1494	751	1887	669	574	853	1833
Mar-17	1210	202	891	2217	2036	1869	2233
Apr-17	807	638	486	1570	583	1841	1767
May-17	887	436	822	1676	971	1810	2373
Jun-17	257	521	504	720	663	866	616
Jul-17	195	433	667	394	606	643	619
Aug-17	709	814	435	802	928	1011	568
Sep-17	612	516	712	895	872	552	975
Oct-17	506	1012	388	1506	1265	1571	1630
Nov-17	432	395	1127	484	403	572	998
Dec-17	754	787	516	956	549	602	660
Jan-18	880	804	736	1502	1988	2219	1929
Feb-18	883	580	1057	1380	768	792	1778
Mar-18	288	647	1002	2370	1227	2320	3693
Apr-18	771	549	608	1123	512	758	546
May-18	980	1153	475	1174	2306	526	1395
Sep-18	2245	2622	3498	4484	4365	4543	4745
Oct-18	2609	2613	2864	3604	2619	2868	2997

Table7.4: WQI (at TC limit 50 CFU/100ml) along the period of study by arithmetic index method.

Month& Year	Vazhachal	Vettilappara	Kanjirappilly	Pariyaram	Chalakudy	Vynthala	Pulikkakadavu	Palapuzhakadavu
Nov-13	59	195	165	240	110	233	96	181
Dec-13	175	188	340	158	280	235	112	200
Jan-14	138	195	74	105	212	110	219	257
Feb-14	122	120	225	239	191	87	178	295
Mar-14	47	81	247	137	107	139	152	78
Apr-14	254	171	236	205	76	284	248	114
May-14	204	137	160	184	262	279	102	157
Jun-14	196	147	286	317	253	227	173	262
Jul-14	259	163	240	229	165	260	224	89
Aug-14	136	170	143	140	266	223	81	118

Sep-14	132	137	253	290	331	134	255	183
Oct-14	266	196	142	258	104	260	218	129
Nov-14	176	227	180	182	297	251	155	162
Dec-14	188	211	336	374	293	257	349	221
Jan-15	223	164	262	212	159	199	247	279
Feb-15	100	142	143	308	263	172	221	187
Mar-15	140	259	237	66	269	296	137	122
Apr-15	139	156	155	147	354	261	343	380
May-15	53	67	198	174	313	121	294	267
Jun-15	164	240	234	164	241	253	123	338
Jul-15	269	318	205	267	213	339	258	263
Aug-15	120	75	131	115	100	76	57	76
Sep-15	340	264	202	99	121	229	221	190
Oct-15	219	276	80	191	238	249	107	205
Nov-15	150	239	242	229	237	290	254	227
Dec-15	144	166	219	82	244	72	51	260
Jan-16	145	324	73	165	293	206	115	169
Feb-16	258	260	368	179	473	177	155	430
Mar-16	216	156	200	248	410	218	210	246
Apr-16	123	116	153	98	119	169	137	216
May-16	117	244	190	132	433	368	386	411
Jun-16	114	228	137	191	159	73	127	180
Jul-16	102	102	113	245	279	99	136	217
Aug-16	157	167	160	122	207	143	134	145
Sep-16	188	197	167	155	140	137	215	158
Oct-16	208	198	146	158	218	167	178	110
Nov-16	109	163	153	84	258	154	163	234
Dec-16	212	143	91	163	185	161	349	265
Jan-17	174	216	195	206	342	140	346	364
Feb-17	310	169	182	397	156	130	192	383
Mar-17	253	64	231	201	461	428	389	467
Apr-17	186	155	172	121	337	149	391	385
May-17	197	100	216	181	354	201	380	499
Jun-17	60	126	125	109	167	160	186	142
Jul-17	57	108	117	154	98	142	150	145
Aug-17	157	173	139	100	180	208	222	134
Sep-17	139	122	99	159	204	192	127	206
Oct-17	111	233	110	92	312	278	328	347

Nov-17	97	99	119	239	119	107	128	228
Dec-17	172	185	148	131	206	135	138	157
Jan-18	190	183	164	164	318	419	463	419
Feb-18	192	136	261	248	294	176	190	396
Mar-18	80	163	315	223	496	299	544	832
Apr-18	169	134	151	144	245	118	176	161
May-18	211	265	178	110	256	481	131	310
Sep-18	469	550	689	735	932	912	952	996
Oct-18	537	542	642	595	743	547	599	629

Table 7.5: Maximum, minimum, and mean ±SD of WQI values of each site

	WQI, TC limit: 10 CFU/100ml				Mainly contributing by
Sites	**Mean**	**SD**	**Max**	**Mini**	
Vazhachal	819.39	445.5	2609	166	TC
Vettilappara	838.54	451.6	2622	195	TC
Kanjirappilly	931.68	545.9	3254	221	TC
Pariyaram	901.75	566.4	3498	224	TC, TH
Chalakudy	1225.72	738	4484	234	TC, BOD,TH
Vynthala	1024.05	671.5	4365	230	TC,BOD
Pulikkakadavu	1057.9	728.5	4543	179	TC, BOD
Palapuzhakadavu	1216	814.6	4745	312	TC, BOD

7.2.1 Classification of river water quality based on WQI

Based on the classification in Table7.6 (Ramakrishnah et al 2009), most of the samples lie within the class ‘not suitable for drinking purpose’. This is mostly due to the presence of high values of TC. During the period of study, variations in all other parameters had not affected WQI much. Most of the parameters analyzed in the river water samples were found to be within the permissible limits according to the drinking water standards. Vazhachal, Vettilappara and Pariyaram sites had less TC values as compared to Chalakudy, Vynthala, Pulikkakadavu and Palapuzhakadavu sites and their mean values of WQI were in turn low.

Table 7.6: Water quality classification based on WQI values

The range of WQI Value	Water quality	% of water samples	
		TC limit 10 CFU/100ml	TC limit 50 CFU/100ml
WQI < 50	Excellent	0	1
50 < WQI <100	Good	0	40
100 < WQI <200	Poor	5	209
200<WQI <300	Very Poor	15	135
WQI >300	Not suitable for drinking	436	71

7.2.2 ANOVA results of WQI

Two-way analysis of variance (ANOVA) of WQI with Tukey post hoc analysis results during the period of study is shown in Fig. 7.1 and in Table 7.7 and Table 7.8. Prior to analysis, all the data were checked for normality. According to ANOVA results, it was identified that maximum WQI was observed at Chalakudy and Palapuzhakadavu sites due to the presence of coliform bacteria. The P value for the site was obtained as 0.001 ($P < 0.05$) and season 0.212.

It means the site is positively significant with the WQI and season is not significant. The impact of urbanization-flats, hotels, waste from a cattle farm, poultry farms, thickly populated human stay situated very close to the river resulted in an adverse effect on the water quality. This leads to the inference of load of pollution in Chalakudy site is due to the influence of untreated sewage discharge from the nearby area.

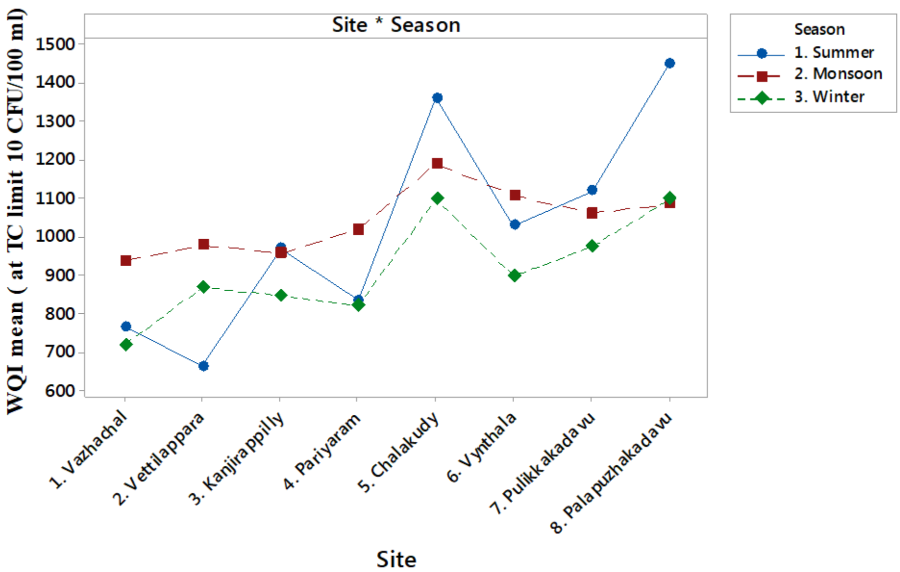

Fig. 7.1: Mean value plot of WQI by two way ANOVA

Table 7.7: Two-way ANOVA result

Source	DF	Adj SS	Adj MS	F- Value	P-Value
Site	7	10209959	1458566	3.93	0.001
Season	2	959882	479941	1.29	0.276
Site * Season	14	3587578	256256	0.69	0.785
Error	432	160423302	371350		
Total	455	1755062433			

Table 7.8: Grouping Information at 95 % Confidence for WQI, using the Tukey Method

Season	N	Mean	Grouping	
Monsoon	176	1042	A	
Summer	160	1024	A	
Winter	120	914.8	A	
Site	**N**	**Mean**	**Grouping**	
Chalakudy	57	1216	A	
Palapuzhakadavu	57	1210	A	
Pulikkakadavu	57	1051	A	B
Vynthala	57	1011	A	B
Kanjirappilly	57	923.8	A	B
Pariyaram	57	891.1	A	B
Vettilappara	57	836.3		B
Vazhachal	57	807.1		B

7.2.3 Spatial and temporal variations of WQI

The spatial and temporal variations of WQI are shown in Fig.7.2. The highest WQI values of 4454, 4543, 4745 and 4365 were noticed at Chalakudy, Pulikkakadavu, Palapuzhakadavu,and Vynthala sites respectively during September 2018. After the flood (August 2018) in Kerala, water level in this river had drastically decreased. This resulted in a high level of deterioration of water quality. The study shows that the major reason for the poor quality of the water in the river is the high presence of coliform bacteria. BOD, pH and TH also affect water quality but not as much as TC. Sometimesdeviation of parameters from standard values were observed at Palapuzhakadavu and Pulikkakadavusites.In addition, the same sites were found to have high values of TC and BOD. The resultant changes in water quality might be attributed to the influence of anthropogenic sources like domestic sewage effluent and settling after runoff. Specifically, this area is residential and agricultural. The least value for pH (4.2) and DO (5.1) were observed at Kanjirappilly site during 2016. It may be attributed to the percolation ofleachate from the settled sludge from thepulp and paper industry. All the other parameters analyzed except these were found to be within Indian standard and WHO standard.

A flourishing dicalcium phosphate industry located near the river is directly discharging its treated effluent in to the river. Contaminants may also be carried in through one small stream called Perumthodu, which meets Chalakudy river almost a few meters upstream of Pulikkakadavu site. Though the industry has well-established ETP with online monitoring meters and ensures the quality of effluent discharge, still effluent discharge to the river at this area may have turned harmful to the quality of water. At Pulikkakadavu site pH value was found as 5.9. The variation of pH at Pulikakadavu site may be due to the salinity (Chlorides) and temperature effect due to the treated effluent discharge on the site. (Chauhan., 2010). The maximum seasonal average of pH is 7.2. Most of the values of water pH are within the permissible limit. It is specified that pH range 6.7 to 8.4 is very essential for the growth of aquatic biota. pH values of most of the samples were within the pH range assigned by WHO and Indian standard for drinking water (6.5 - 8.5; IS. 2012).

According to the classification based on WQI already given, the water quality of the Vazhachal and Vettilappara sites had displayedcomparatively less biological pollution because of the freshwateravailabilitydue to the high rainfall in the forest area and high level of DO during winter and monsoon. During monsoon seasons, it was also noticed that water samples collected from this site contained the presence of nitrates and phosphates. That may be from natural sources like rocky surface and land drainage (Johne and Burt., 1993). Moreover, the study indicates that the most affected parameter on WQI is the presence of a high value of TC throughout the period of study. Chalakudy and Palapuzhakadavu sites were found to have the worst water quality due to the high contamination of coliform bacteria. Spatial and seasonal variations of WQI are shown in Fig.7.2. From this figure it is clear that the flood made a strong impact in the water quality of this river.

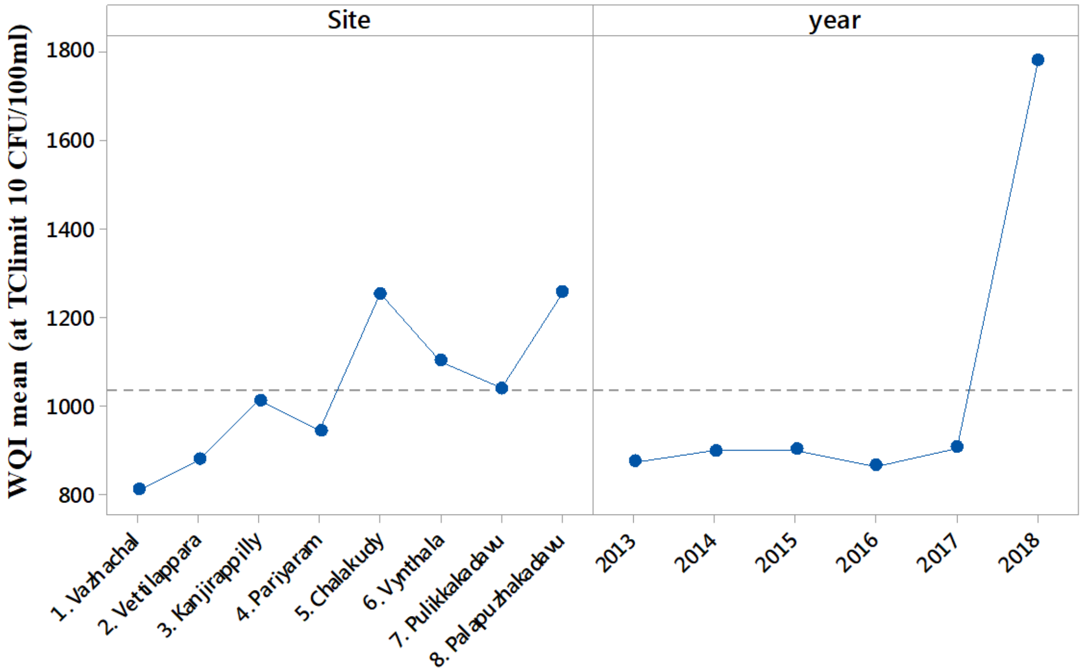

Fig. 7.2: Temporal and spatial variations of WQI

For all seasons along the period of study, Vynthala site was found to show a mean WQI above 1000. Pallithodu, which flows from Chalakudy town area, is a natural water source through which the excess rain water reaches Parayanthodu. Therefore, there are all possibilities that a portion of the untreated sewage waste reaches the river through Pallithodu in to Parayanthodu, which ultimately joins the river about 1km upstream of Njaralakadavu at theVynthala site. This may in effect deteriorate the water quality and affects the bio-diversity of the Chalakkudy river (Chattopadhyay., S. 2005).In addition, this might turn harmful to the two major drinking water pumping stations that are located near Vynthala site, which caters the purpose of domestic supply for more than ten local bodies. At this site, KWA treatment plant having 26.1 Million Cubic Meter capacity is also functioning.

Moreover, during the period of study, TC values of this river water were not found to comply with the permissible standards (absent or less than 10 CFU/100ml, or 50CFU/100 ml in the absence of alternate source). Remarkably all other values used for computing WQI except TC, at all the sites, was found to be within the permitted standards meant for human consumption. But TC is an essential and important parameter for the drinking water quality assessment of human concern because this parameter is an indication of disease-causing pathogens. And it was identified that total coliform is the major pollutant which worsens river water quality.

The flood that occurred in August 2018 made a high impact on the quality and quantity of the river water. After the flood, the quantity of water in the river has drastically decreased. This is also a reason for high biological contamination in the river. Towards downstream, the water quality of the Chalakudy river varied and was assessed to be poor quality. But at the same time, due to a comparatively good flow of fresh water in the river during monsoon, the rate of dilution of wastes was also high.

7.3 Fuzzy Water Quality Index Model (FWQIM)

A numerical model for prediction of water quality index of Chalakudy River was developed using fuzzy logic in MATLAB. Calculated values of WQI by an arithmeticmethod using twelve various experimentally estimated water quality parameters pH, Cl^-, % DO, TUR, NO_3^-, SO_4^-, PO_4^-, TDS, BOD, EC, TH and TC were used as inputs to develop FWQIM. The FWQIM was developed for Chalakudy river shown in Fig.7.9. FWQIM Mamdani model with triangular membership functions is a good prediction model for water quality index. For environmental modeling using Fuzzy, triangular membership function was found more efficient than using other membership functions. The triangular membership functions generated for each variable (for 12 water quality input parameters) are shown in Fig.7.3 to Fig.7.15. Membership functions of output variable WQI are shown in Fig.7.16. The output viewer of the FWQIM is shown in Fig.7.17. When we enter the combinations of each set of input variables, the model will gives the predicted value of WQI for each combination.

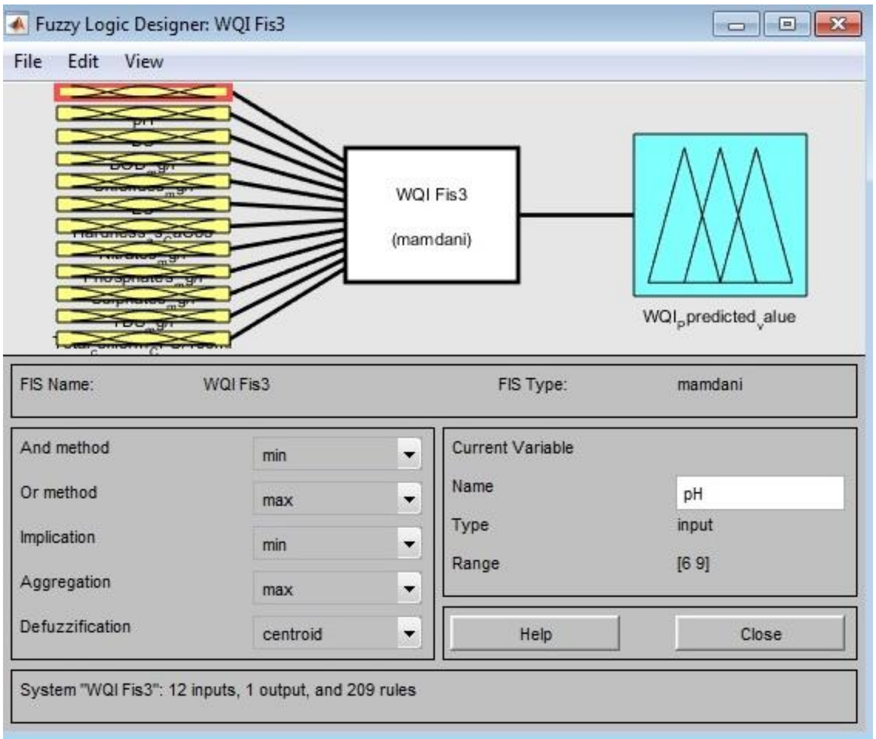

Fig.7.3: Fuzzy Water Quality Index Model

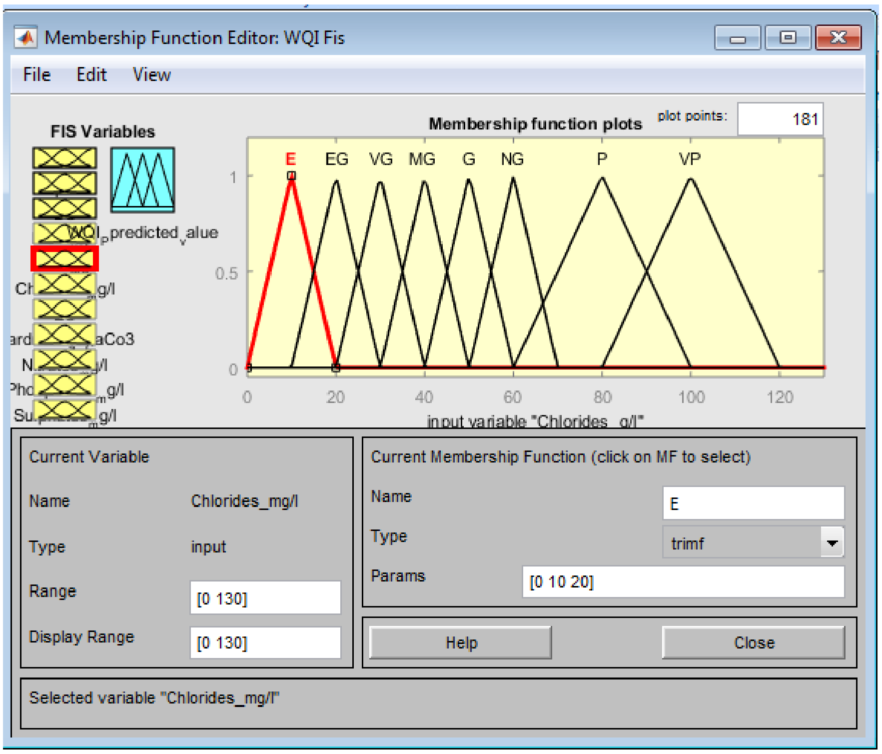

Fig.7.4: Membership functions for Cl^-

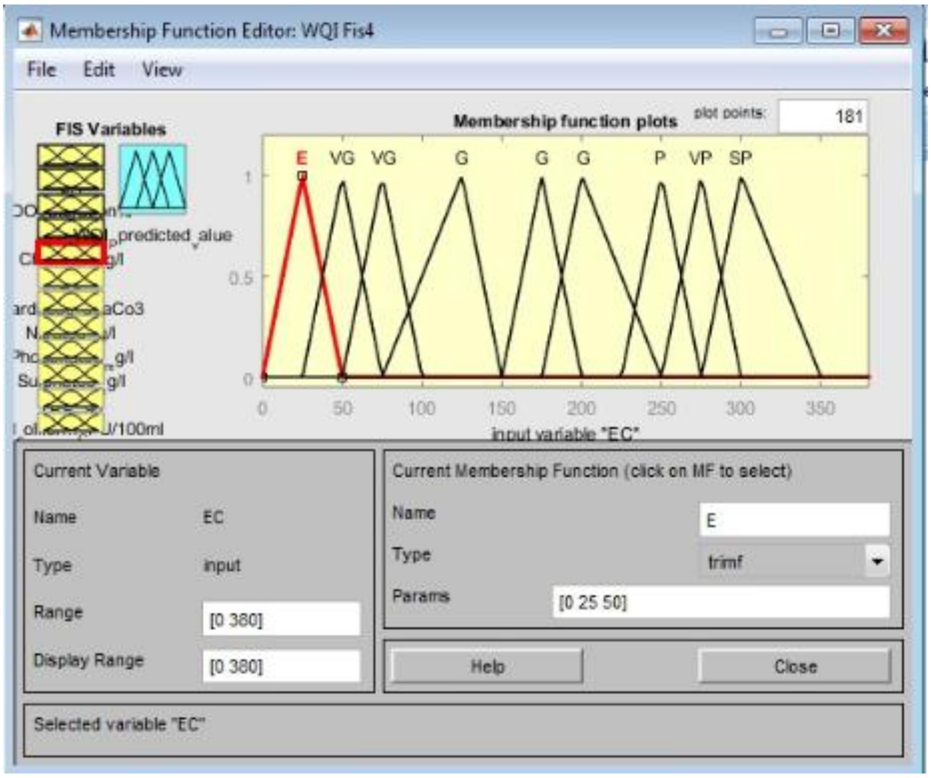

Fig.7.5: Membership functions for EC

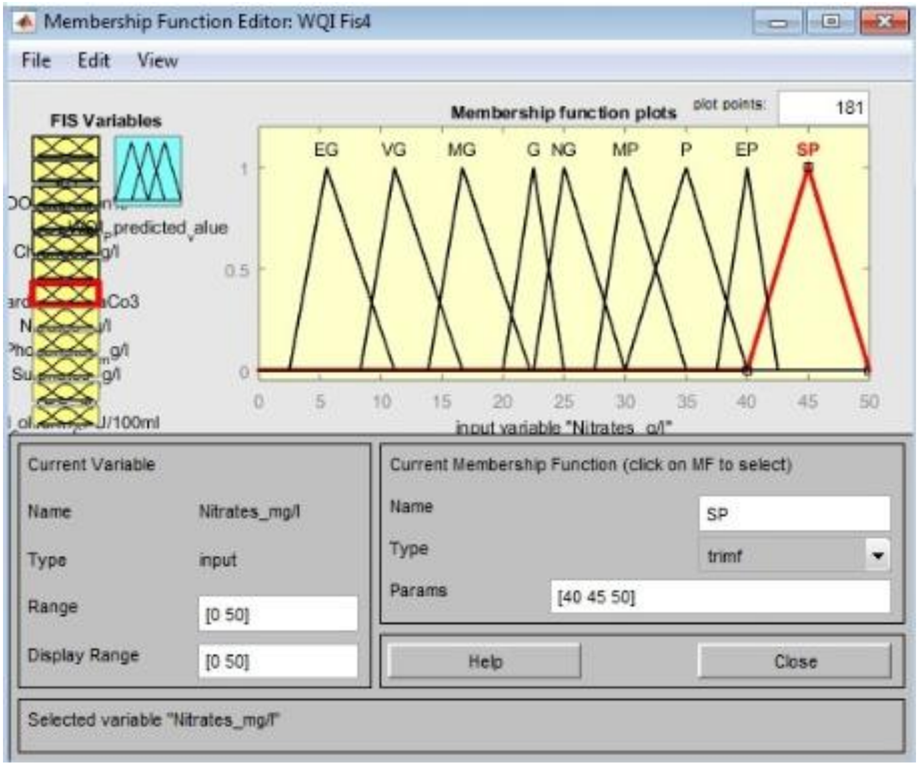

Fig.7.6: Membership functions for NO_3^-

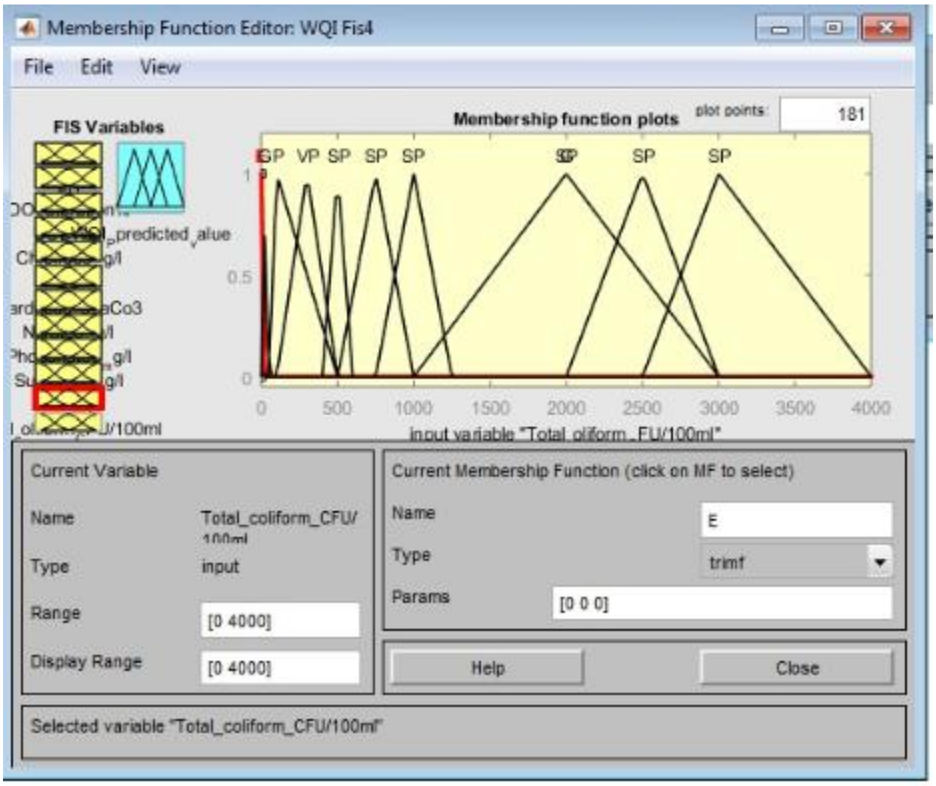

Fig.7.7: Membership functions for TC

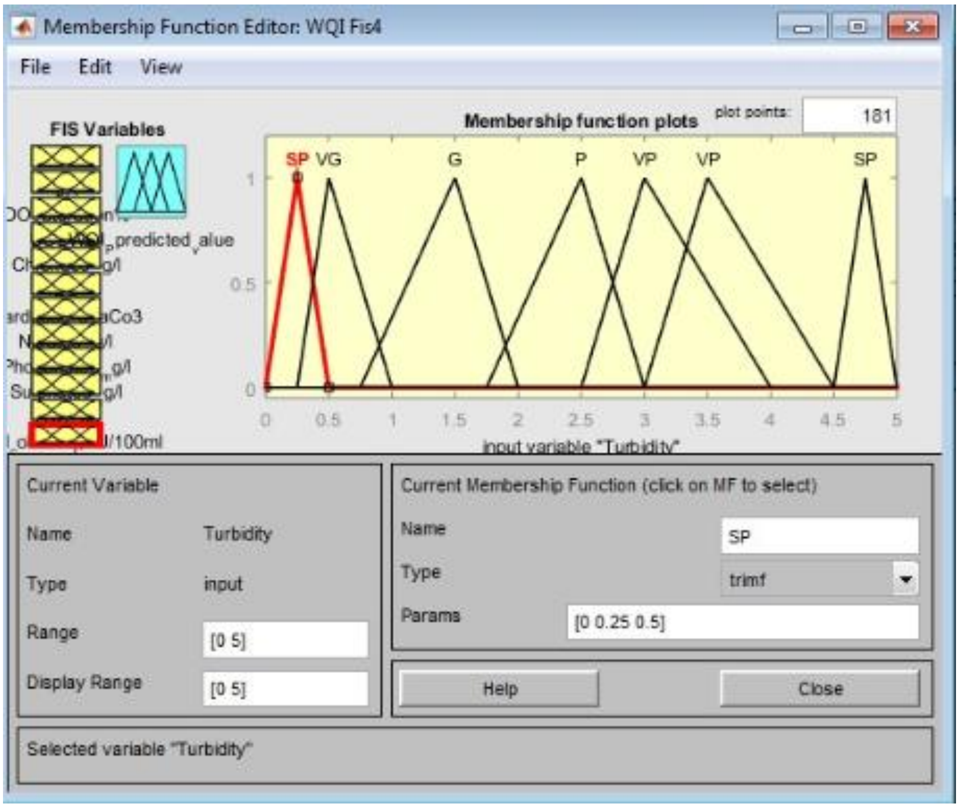

Fig.7.8: Membership functions for Turbidity

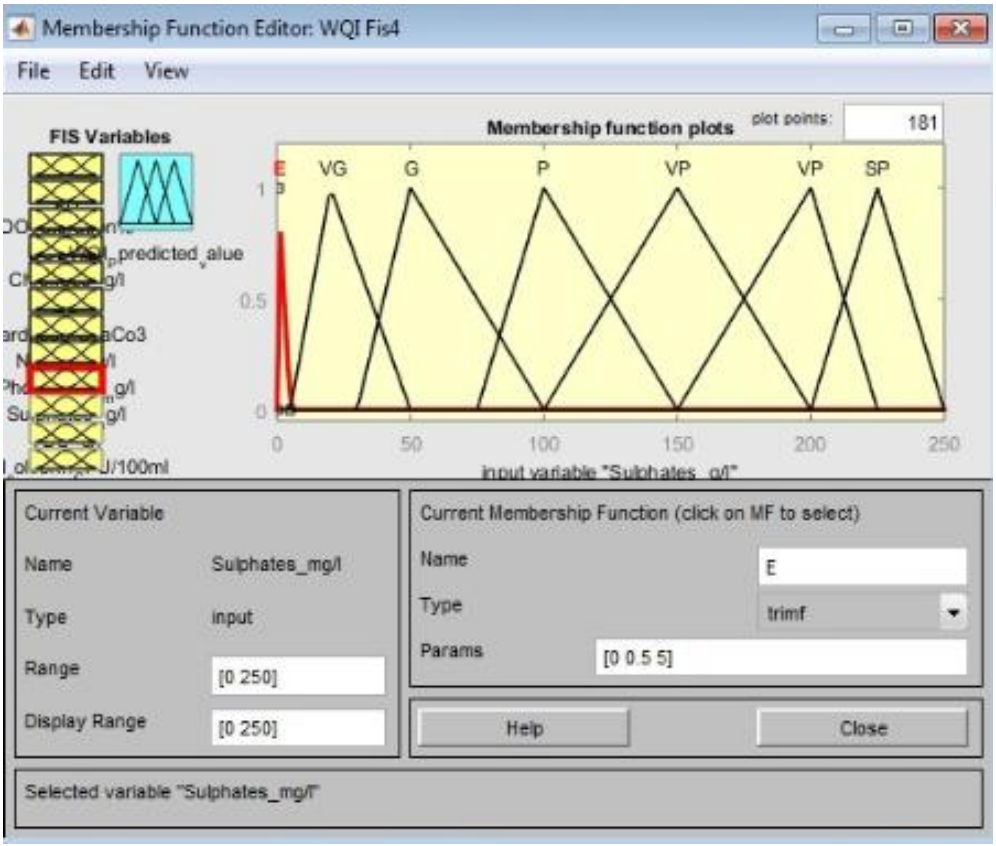

Fig.7.9: Membership functions for SO_4^-

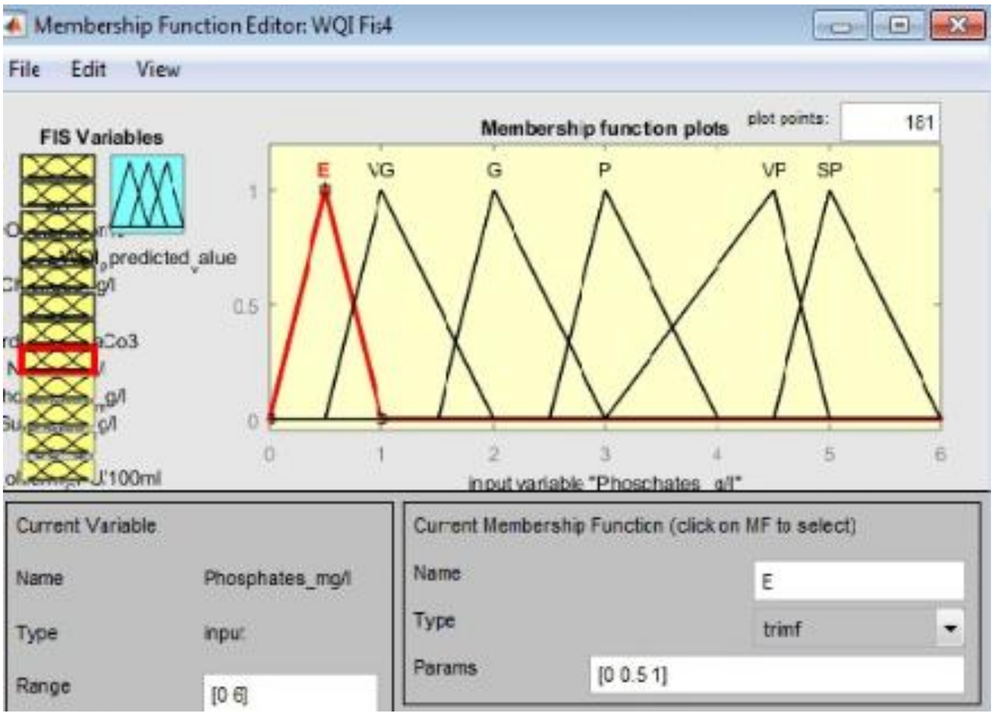

Fig.7.10: Membership functions for PO_4^-

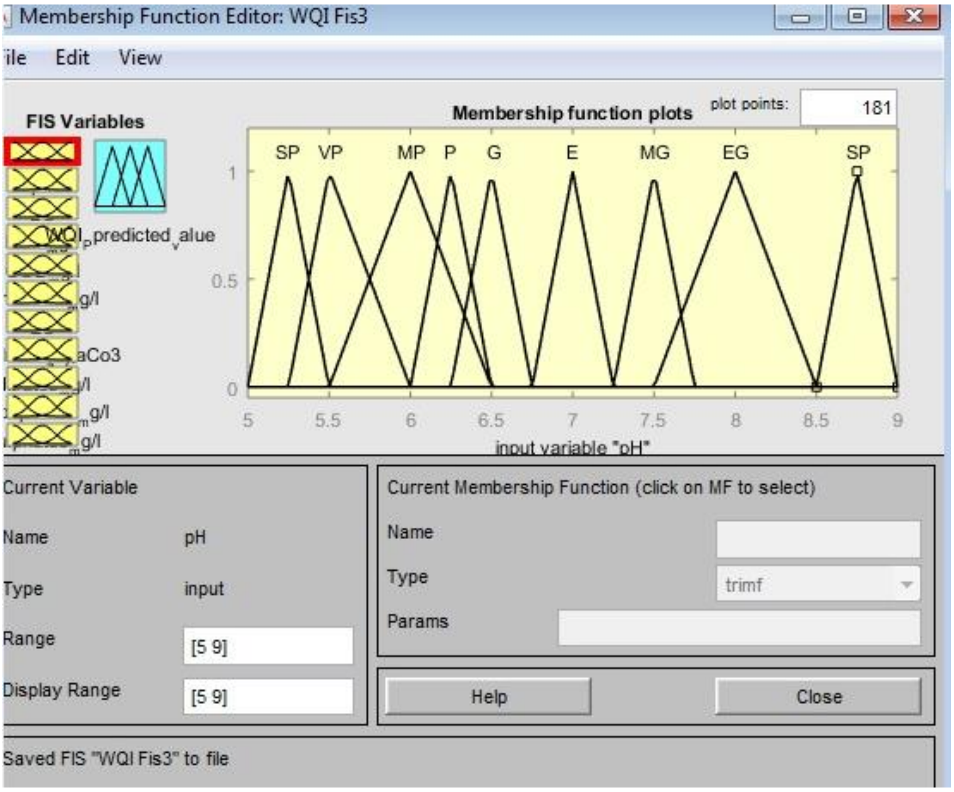

Fig.7.11: Membership functions for pH

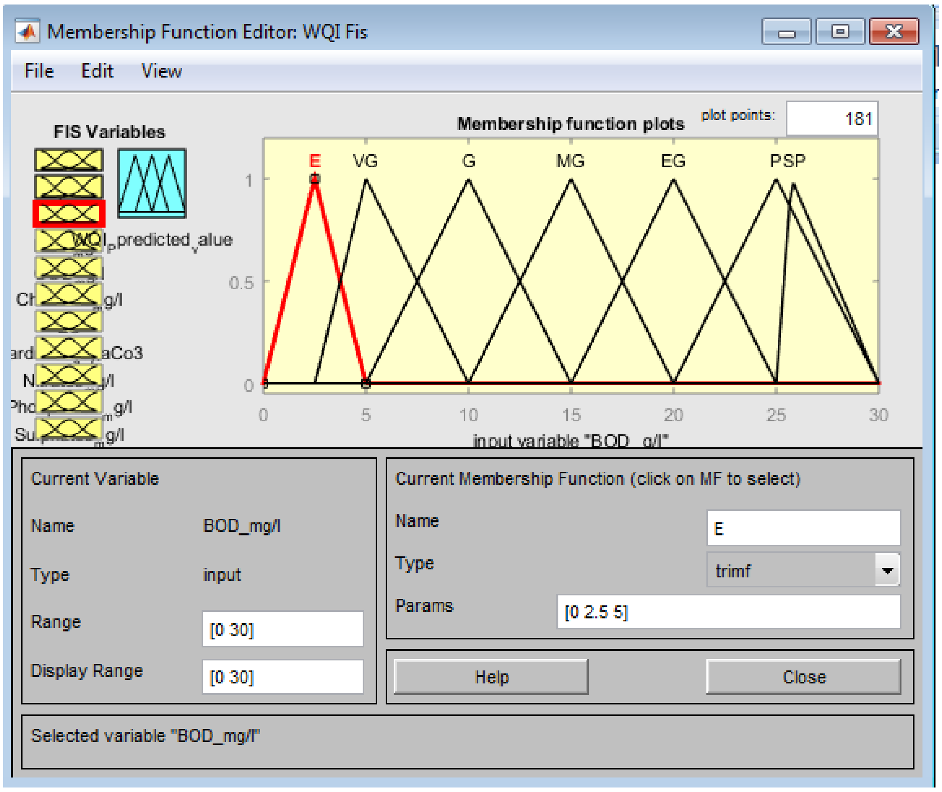

Fig.7.12: Membership functions for BOD

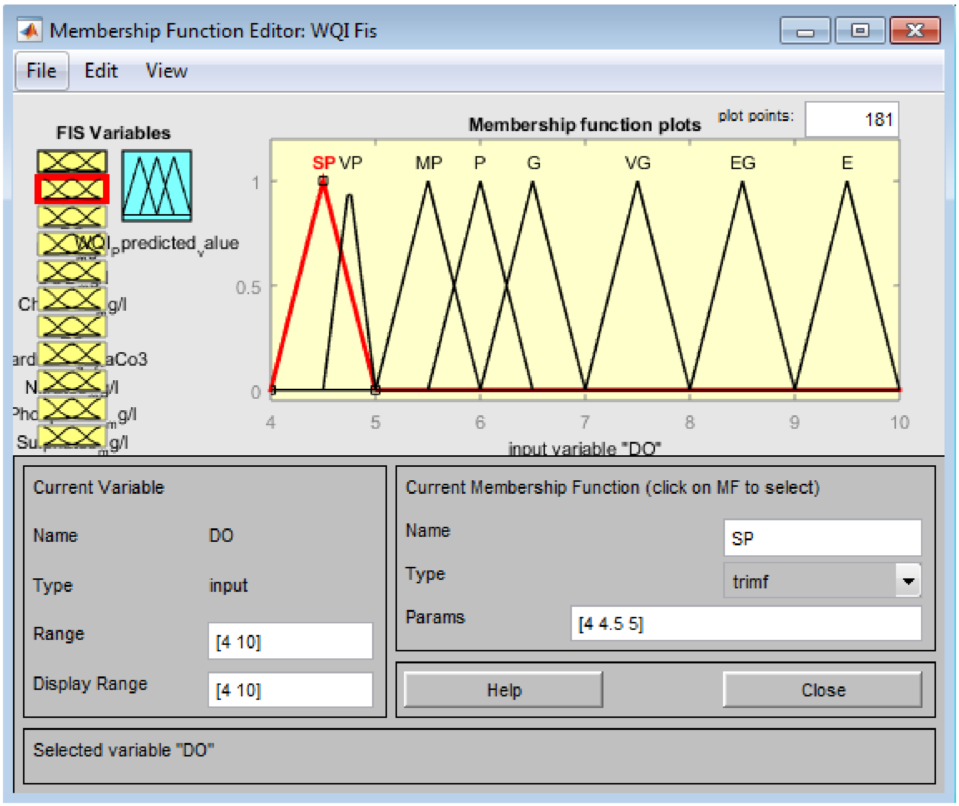

Fig.7.13: Membership functions for input DO

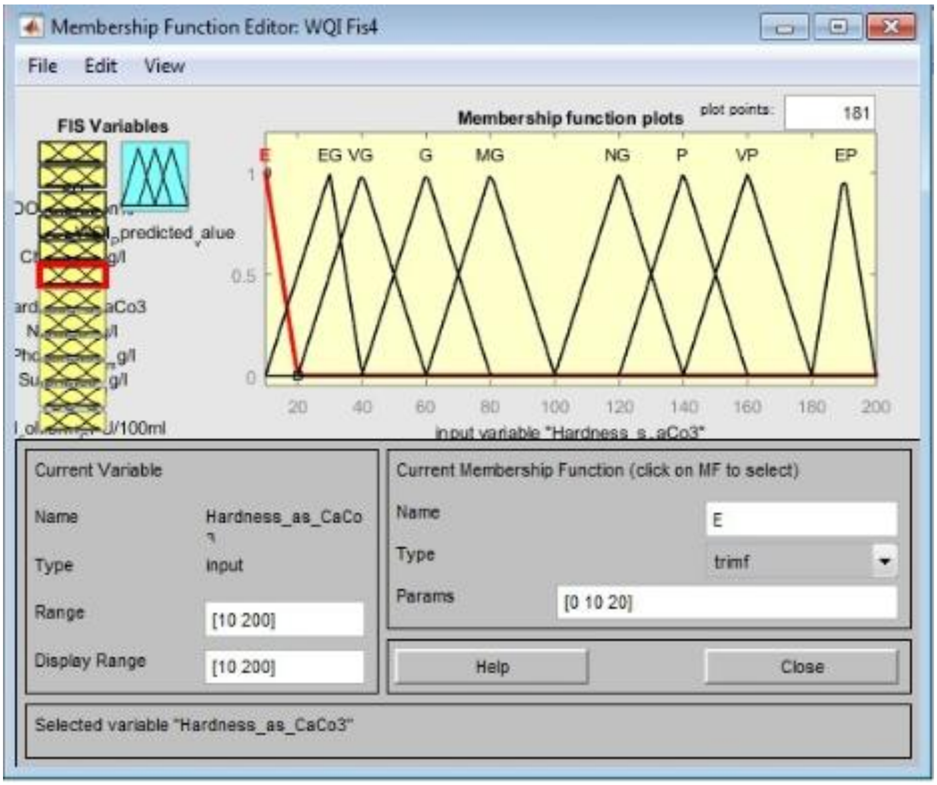

Fig.7.14: Membership functions for input TH

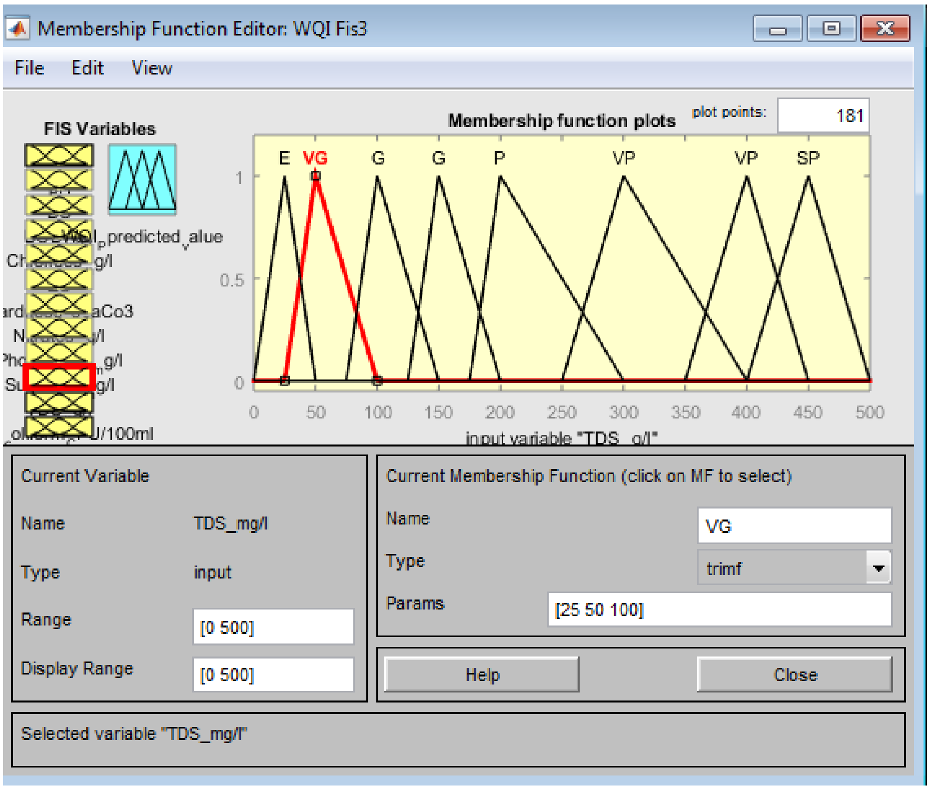

Fig.7.15: Membership functions for input TDS

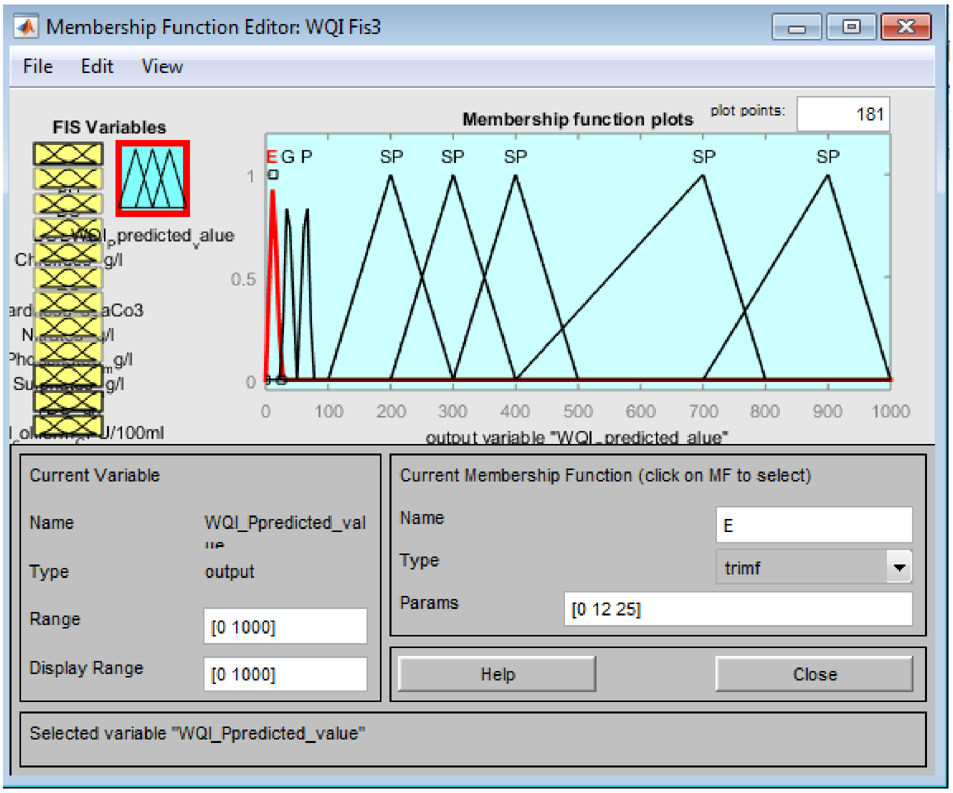

Fig.7.16: Membership functions for output WQI

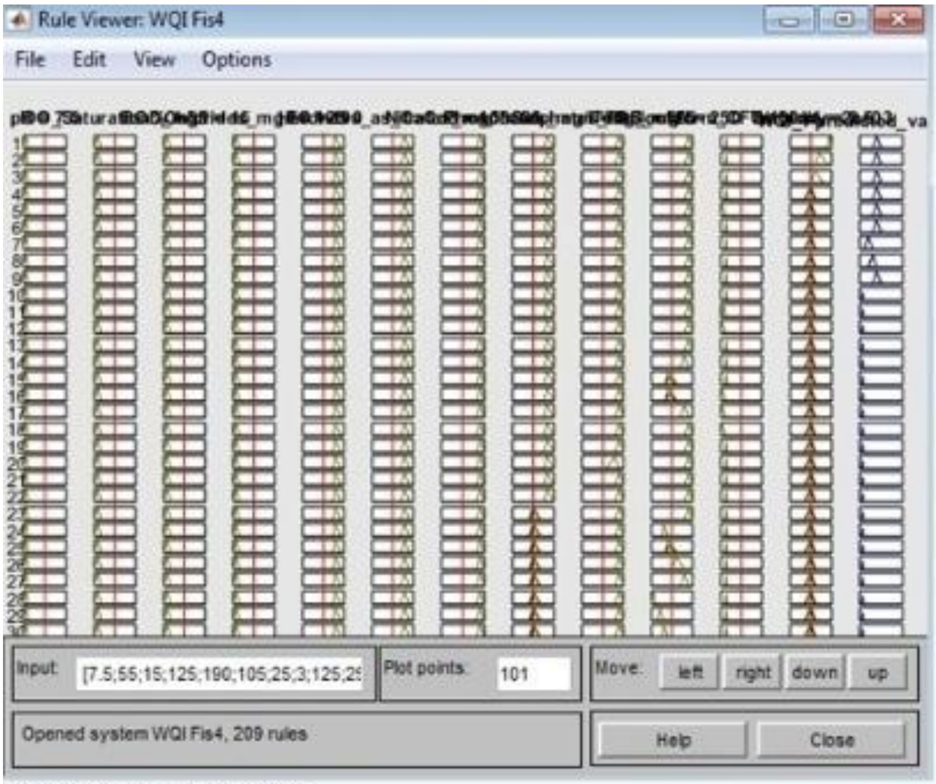

Fig.7.17: Rule viewer of FWQIM

FWQIM is a good fuzzy model to predict the WQI of the river. It is applicable to any river system using the same input parameters or using more combinations of inputs. The performance of the model was tested by comparing with calculated values of WQI in the year 2018. In this case study, it was identified that the TC value has affected WQI more than other water quality parameters. At all the sites, observed values of TC are out of standard. Most of the other parameters are observed within the prescribed limit. The predicted WQI value is not much closer to the actual experimental values with AARE 4.71and RMSE0.371.However, the predicted value of WQI was found within the range of same class as per the WQI classification.

7.4 Regression Model

The linear regression model of the WQI of Chalakudy river is shown in Fig.7.18 and Fig.7.19. The regression analysis gives the following model equations Eqns. (7.1 & 7.2) with the value coefficient of regression R^2. This gives the relationship between WQI and TC of the Chalakudy river.

$$WQI_{(at\ TC50\ CFU/100ml)} = 0.253*TC+18.53, \text{ with } R^2=0.993. \tag{7.1}$$

$$WQI_{(at\ TC10\ CFU/100ml)} = 1.240*TC+18.45, \text{ with } R^2=0.999. \tag{7.2}$$

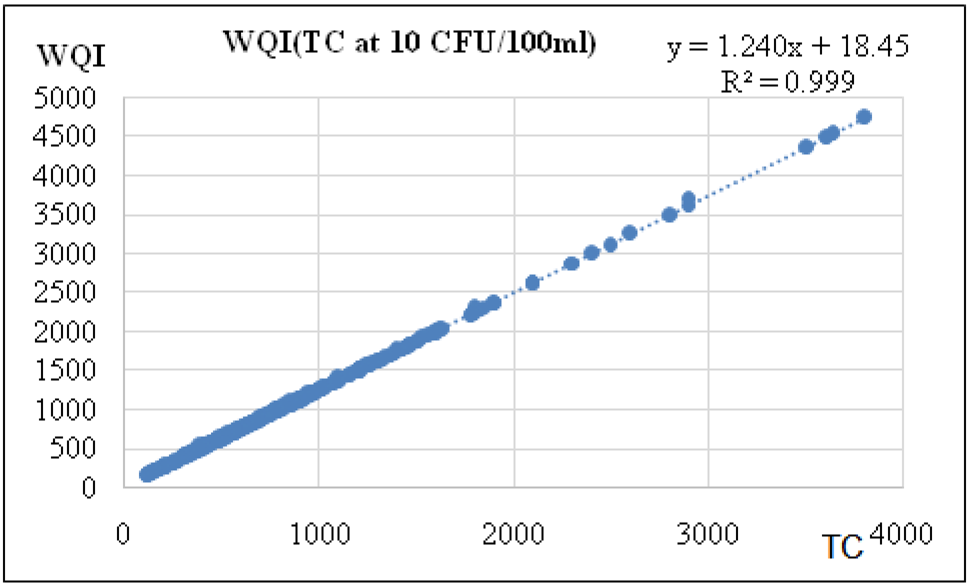

Fig.7.18: The regression model of WQI by considering TC limit as 10 CFU/100ml

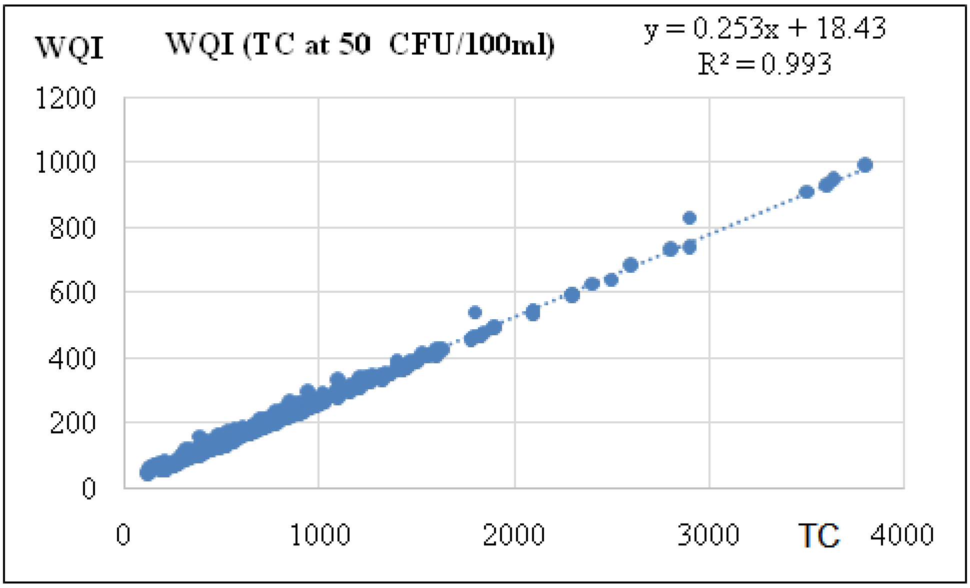

Fig.7.19: The regression model of WQI by considering TC limit as 50 CFU/100ml

7.4.1 Validation of regression model

The closeness of the arithmetic Index value of WQI $_{(at\ TC\ standard\ 10\ CFU/100ml)}$ and WQI $_{(at\ TC\ standard\ 50\ CFU/100ml)}$ with the predicted value of WQI using regression equations (7.1) and (7.2) are shown in Table.7.9.

Table.7.9: The closeness of calculated value with the predicted value of WQI

TC CFU/100ml	WQI (TC limit 10 CFU.100ml)	Predicted WQI	WQI (TC limit 50 CFU.100ml)	Predicted WQI
700	880	886.45	190	195.55
630	804	799.65	183	177.84
560	717	712.85	164	160.13
1200	1502	1506.45	318	322.05
1780	2219	2225.65	463	468.79
1530	1929	1915.65	419	405.54
1590	1988	1990.05	419	420.72
700	883	886.45	192	195.55
450	580	576.45	136	132.3
1010	1258	1270.85	261	273.98
820	1057	1035.25	248	225.91
1100	1380	1382.45	294	296.75
610	792	774.85	190	172.78
1400	1778	1754.45	396	372.65
600	768	762.45	176	170.25
210	288	278.85	80	71.58
490	647	626.05	163	142.42
1200	1499	1506.45	315	322.05
790	1002	998.05	223	218.32
1900	2370	2374.45	496	499.15
1800	2320	2250.45	544	473.85
2900	3693	3614.45	832	752.15
940	1227	1184.05	299	256.27
610	771	774.85	169	172.78
420	549	539.25	134	124.71
510	654	650.85	151	147.48
470	608	601.25	144	137.36

890	1123	1122.05	245	243.62
590	758	750.05	176	167.72
390	546	502.05	161	117.12
400	512	514.45	118	119.65
780	980	985.65	211	215.79
900	1153	1134.45	265	246.15
530	701	675.65	178	152.54
370	475	477.25	110	112.06
930	1174	1171.65	256	253.74
400	526	514.45	131	119.65
1100	1395	1382.45	310	296.75
1850	2306	2312.45	481	486.5
1800	2245	2250.45	469	473.85
2100	2622	2622.45	550	549.75
2600	3254	3242.45	689	676.25
2800	3498	3490.45	735	726.85
3600	4484	4482.45	932	929.25
3640	4543	4532.05	952	939.37
3800	4745	4730.45	996	979.85
3500	4365	4358.45	912	903.95
2100	2609	2622.45	537	549.75
2100	2613	2622.45	542	549.75
2500	3108	3118.45	642	650.95
2300	2864	2870.45	595	600.35
2900	3604	3614.45	743	752.15
2300	2868	2870.45	599	600.35
2400	2997	2994.45	629	625.65
2100	2619	2622.45	547	549.75

The Performance of the two regression models in predicting the WQI has been tested by with the year 2018. It was found to be significantly good with an absolute average relative error of first model (AARE) as 0.693 and root mean square error (RMSE) of 0.5, and for the second model also found to be significantly good with an AARE of first model 1 and RMSE 0.028.

7.5 Conclusion

During the period of study, TC values of this river water were not found to comply with the permissible standards (absent or less than 10 CFU/100ml, or 50CFU/100 ml in the absence of alternate source). Remarkably all other values used for computing WQI except TC, at all the sites, were found to be within the permitted standards meant for human consumption. However, TC is an essential and important parameter for the drinking water quality assessment of human concern because this parameter is an indication of disease-causing pathogens. And it was identified that total coliform is the major pollutant which makes the river water quality worst.

Based on the classification of WQI, most of the samples lies within the class 'not suitable for drinking purpose'. This is mostly due to the presence of high values of TC. The water quality of the Vazhachal and Vettilappara sites had displayed comparatively less biological pollution because of the fresh water availability due to the high rainfall in the forest area and high level of DO during winter and monsoon. During some season, it was also noticed that water samples collected from this site contained the presence of nitrates and phosphates. Natural sources like rocky surface and land drainage may be a reason for these variations. Moreover, the study indicates that the parameter that highly affected WQI is the presence of a high value of TC , throughout the period of study. Chalakudy and Palapuzhakadavu sites were found to have the worst water quality due to the high contamination of coliform bacteria.

FWQI model is a good model for the prediction of water quality index for any river system. In the present study, at all sites the measured values of TC were found to be much higher than the drinking water quality standards. With these twelve inputs, the model takes more time to be executed than the other fuzzy model FDOM. The predicted WQI value using FWQI is not much closer to the actual experimental values with AARE 4.71 and RMSE 0.371. However, the predicted value of WQI was found within the range of same class as per the WQI classification.

The performance of the two regression models $WQI_{\text{(at TC standard 10 CFU/100ml)}}$ and WQI (at TC standard 50 CFU/100ml) were found to be significantly good with an AARE of first model of 0.693 and root mean square error RMSE of 0.5,and for the second model with an AARE of 1 and RMSE 0.028 respectively. In the developed numerical models of Chalakudy river water quality, most adoptable and efficient models for predicting water quality index of Chalakudy river are the arithmetic index model and linear regression models in terms of TC than FWQIM. However, FWQIM, arithmetic index model and linear regression models were found to be very efficient models for the prediction of water quality of all river systems.

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Chapter 8
CONCLUSION

The present study has focused on the assessment and modeling of pollution load in Chalakudy river, Kerala, India during November 2013 to October 2018. The spatial, temporal and seasonal effect of 16 qualitative parameters such as Potential Hydrogen (pH), Total dissolved solids (TDS), Temperature (T), Turbidity (TUR), Chemical oxygen demand (COD), Dissolved Oxygen (DO), Electrical conductivity (EC), Nitrates (NO_3^-), Phosphates (PO_4^-), Sulphates (SO_4^-),Total Hardness (TH), Biochemical oxygen demand (BOD), Chlorides (Cl^-), Total Coliform (TC), and Fecal Coliform (FC), 3 quantitative parameters (flow area, Velocity and discharge) and persistence of Organo- chlorine pesticides (OCP's) in the river water and sediment has been investigated. Fuzzy dissolved oxygen model and fuzzy water quality index model with triangular membership functions using MATLAB was developed to predict the DO level of the river water. By keeping the standard value for total coliform as 10 CFU/100ml and 50 CFU/100ml, two sets of water quality indices of Chalakudy river were developed by using arithmetic index method. Two regression models WQI (at TC standard 10 CFU/100ml) and WQI (at TC standard 50 CFU/100ml) of Chalakudy river also were developed.

Out of the parameters studied, pH, BOD, EC, TH, and TUR were found to have a varying trend. BOD, TC and FC showed an increasing trend. During summer of 2015 and 2018, comparatively bad water quality was measured at Pulikkakadavu, and Palapuzhakadavu sites. This may be attributed to the industrial discharge in to the river. The overall nature of the river water was slightly alkaline. Pulikakadavu and Palapuzhakadavu sites were measured as acidic. By considering the average of total hardness values obtained during the study period, the river water is found to be moderately hard. The results indicate that measures are to be taken to stop the treated water discharge from the effluent treatment plants and sewage treatment plants in to the natural water bodies. Waste discharge in to the river should be treated as a punishable offence and with high penalties.

Very high values of the water quality parameters, TC and FC were measured during the period of study. This indicates that bacteriological contamination is significantly high along the area of study in Chalakudy River. ANOVA, post-hoc ANOVA and BOD/COD ratio revealed that the part of the river downstream from Chalakudy town showed a decreasing water quality trend due to high bacterial contamination. Chalakudy, Vynthala and Palapuzhakadavu sites have shown high values of total coliform and fecal coliform and all the measured values were very high and exceeded the prescribed limit (absence or 10 CFU/100ml) of IS and WHO drinking water specifications. All these contamination was mainly contributed by human activity, mainly septic tank waste discharge, urban waste discharge, cattle and poultry farm waste discharge in to the river. High sewage pollution due to the human activity had occurred in summer and monsoon seasons during the years 2014 and 2015. And it was identified that total coliform is the major pollutant which makes the river water quality worst. These findings compels the concerned authorities be always vigilant and make sure that there is no direct waste discharge through the tributaries (‘thodu’s) which connects with the river. In the urban area especially in Chalakkudy town, proper septic waste treatment plant should be established.

Generally in the upstream of Kanjirappilly site, fresh water is available. 100% DO saturation was observed in most of the upstream sites during monsoon. Significant correlations between the pairs TDS - TUR, TC- FC, TC-EC, EC-Cl^-, BOD- COD, T-DO and FC-EC, were found along the study area.

Out of the water samples collected from the study area, a few samples were detected to have the presence of OCPs. The presence of these OCPs in surface water was observed in the samples collected from the Pariyaram site during monsoon 2015. Most of the surface water samples indicated persistence of OCP’s below detectable limits. The pesticides detected in the bottom sediments were Dicofol (Kethane), pp-DDT, α BHC, ϒ BHC (Lindane), and β Endosulphan. The pesticides might have been carried by surface runoff or the monsoon floods might have transported these pesticides from the plantations and agriculture fields. In certain stretches, mainly at middle stretch, sediment and surface water were slightly contaminated by pesticides especially with β Endosulphan and pp-DDT. Strict prohibition of the use of banned pesticides for cultivation and reduction in the use of organochlorine and organophosphate pesticides in the river basin can only alleviate this problem.

The FDOM model was found to be an efficient fuzzy model. The model was found to be agreeing with the experimental findings, statistically with AARE and RMSE values 3.256 and 0.26 respectively. During the period of study, WQI of Chalakudy river was found to be between 166 to 4745 and 47 to 996 considering TC standard values as 10 CFU/100ml and 50 CFU/100 respectively. The classification of river water based on the values of WQI, most of the samples lies within the class 'not suitable for drinking purpose'. This is mainly due to the presence of high values of TC. The study shows that water for domestic purposes can be done only after the complete disinfection processes.

FWQIM is a good model for the prediction of water quality index for any river system. The predicted WQI value using FWQI is not much closer to the actual experimental values. However, the predicted value of WQI was found within the range of same class as per the WQI classification.

In the regression models developed were found to be significantly good. In the above mentioned prediction models of Chalakudy river water quality, most adoptable and efficient models for predicting water quality index of Chalakudy river are the arithmetic index model and linear regression models in terms of TC than the FWQIM.

Significant decrease in the overall water quality of river water was observed during the period of study. After flood in 2018, trend of water quality of the river water was found drastically changed as compared with that of previous years. This had resulted in serious drinking water scarcity. It is high time for the formation of proper water management systems and rules to conserve river water. During summer, crops consuming less amount of water can be promoted. Awareness programs for the society need to be conducted to avoid open field defecation and discharge of septic tank waste in to the river.

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3. Divya A.H., Soloman P A, (2016) , Effects of Some Water Quality Parameters Especially Total Coliform and Fecal Coliform in Surface Water of Chalakudy River, *ELSEVIER, Proceedia Technology,* 631 – 638. Presented in International Conference on Advances in Chemical Engineering (ICAChE-2015) organized by Govt. Engineering College, Trichur.
4. Divya A H ., Soloman P A., *(ICAChE-2018)*, River Water Quality Dissolved Oxygen Model of Chalakudy River in India Using Fuzzy Inference System, presented and published in proceedings of *International Conference on Advances in Chemical Engineering*, organized by Govt. Engineering College, Trichur.
5. Divya A H ., Soloman P A., Assessment of Dominance of Organic Pollution in pre and post flood situation in Surface Water of Chalakudy River, India, A case study, presented and published in proceeding of *International Conference on Chemistry and Physics of Materials (ICCPM-2018)*, organized by St. Thomas College, Trichur.

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