ASSESSMENT OF ENVIRONMENTAL QUALITY OF

RIVER GANGA CATCHMENT AREA USING MODELLING TOOLS

DISSERTATION

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OF

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Submitted by:

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CANDIDATE'S DECLARATION

I, Vinay Prabhakar, Roll No. 2K17/ENE/17 student of M.Tech Environmental Engineering, hereby declare that the Project Report titled "Assessment of Environmental Quality of River Ganga Catchment Area Using Modelling Tools" which is submitted by me to the Department of Environmental Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title or recognition.

Place: Delhi **(VINAY PRABHAKAR)**

Date: 28th October 2019

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CERTIFICATE

I hereby certify that the Project Report titled "Assessment of Environmental Quality of River Ganga Catchment Area Using Modelling Tools" which is submitted by Vinay Prabhakar, Roll No. 2K17/ENE/17, Department of Environmental Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the students under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

Place: Delhi **(Prof. S.K. SINGH)**

Date: 28th October 2019 **SUPERVISOR**

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ABSTRACT

River Ganga which originates from Gaumukh and travels through Gangotri Glacier, Devprayag, Rudraprayag, Haridwar, Prayagraj, Varanasi, Patna, Rajmahal, Howrah and finally meet the Bay of Bengal accounts for 26% of India's drainage area with its stretch of 8,62,769 Km^2. The self-purification capacity of River Ganga is stressed out due to industrialisation and river lost its ability to digest organic waste by its own. The data for the research was collected from CPCB ENVIS and interpolation tool of ARCGIS software and statistical tools of MINITAB is used for water quality and air quality of River Ganga and nearby areas. The BOD value varies from 0 to 6 mg/L in the entire region except at Kanpur region. The BOD varies from 6 mg/L to 80 mg/L at Kanpur region in 2016. The DO value varies from 4 to 6 mg/L in the state of West Bengal which tells that the water quality of River Ganga in West Bengal is slightly polluted to moderately polluted in terms of dissolved oxygen present in it. The water quality of West Bengal stretch and between Prayagraj and Mirzapur has medium quality of water and WQI ranges from 50 to 70. The air quality near River Ganga in Uttar Pradesh and remaining part of Bihar is poor with AQI score in the range of 201-300 due to industrial emission and stubble burning. At temperature 18˚C, DO available is 9 mg/L and DO present at 27˚C is 7.5 mg/L. The pH, EC, Temperature, Nitrate-N, BOD, TC, FC, WQI, SO_2, NO_2, PM_{10} and AQI doesn't follow the normal distribution based on Anderson-Darling Normality test while DO and $PM_{2.5}$ follow the normal distribution. It can be concluded based on the study that the environmental pollution near River Ganga may falls in moderately polluted area and some remedial action be able to lead to good quality of air as well as water. With the emergence of the effort of NGRBA it can be concluded that the water quality of River Ganga improves day by day from 2007 to 2016. The ANN model developed can be improved by providing better training dataset.

Keywords: Water Quality, Air Quality, BOD, GIS, Dissolved Oxygen, Emission, ANN

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Rivers which accounts for about 2,115 km^3 volume are the prime surface water resources in the world (Groombridge and Jenkins, 1998). Perennial rivers are used for the domestic, agricultural and industrial use. They are necessary for navigation, marine life and generation of electricity. With urbanisation and industrialisation dependency on rivers increased. They are crucial for maintaining the ecological balance and betterment of human beings (Daniel J. Hillel, 1991).

1.2 RIVER GANGA DRAINAGE SYSTEM

Ganga is Holy River and achieves its fame in the India as well as in worldwide. River Ganga is one of the principal river systems of the world. The Ganga-Brahmaputra-Meghna composite river system is one of the substantial river systems of the world based on drainage area. It drains around 1.7 million Km^2 (Arnold, 2014). The trans-boundary river has basin over China, India, Nepal and Bangladesh. River Ganga flows perennially due to snow melting of Himalayan glaciers, sub-surface flows and Plateau Rivers. It is the 39^{th} longest flowing river in the world as it covers 2525 Km during it journey from Gaumukh (18 Km from Gangotri) to Bay of Bengal. It also hold 2^{nd} rank in terms of total suspended load (524 Mega tonnes/year) (Tandon *et al.*, 2008). The perennial flowing river found to be source of development in its basin like the barrages and dams which are made on it to generate energy and for food production and in some areas it is used for navigation. Uttar Pradesh, known for most fertile alluvial plains in the world as River Ganga carried it with fertile alluvial sediments from Himalayan Glacier and deposits in these plains (Taneja *et al.*, 2014). The River Ganga Basins assist around 600 million people and contribute 40% to India's GDP. There are numerous benefits of River Ganga like properties which are believed to be vulnerable and unique and its ability for remain fresh for so long.

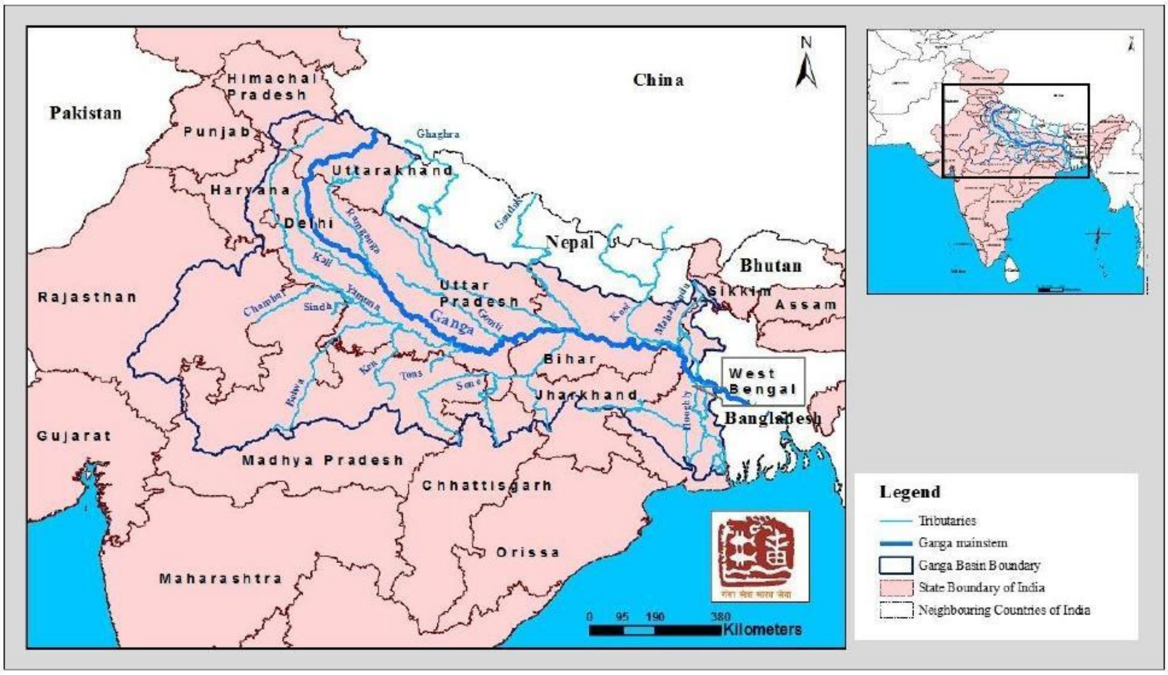

Figure 1.1 River Ganga Drainage System

(National Mission for Clean Ganga)

The Ganga River basin has a stretch of 8, 62,769 Km^2 and contribute 26% of drainage area of India. It flows in the five states of India before finally meeting to sea water in Bay of Bengal. It has five major tributaries apart from main streams i.e. Bhagirathi and Alaknanda which are snowmelts stream from the Himalayan Glacier. River Bhagirathi emerge from Gaumukh and gushing out from under the Gangotri Glacier travelled for 18 Km to reach Gangotri and further travel for 75 Km to reach first time hydroelectricity generation plant on it at Maneri and further rapidly come down the Himalayan slopes for another 113 Km to confluence with Alaknanda at Devprayag. River Alaknanda emerge from Santopath Glacier. Saraswati is the first tributary of Alaknanda to join at Mana Village and travels for 5 Km to reach Badrinath. Dhauliganga is the second tributary which confluence with Alaknanda around 35 Km downstream of Badrinath. River Alaknanda travels for another 150 Km to connect with River Bhagirathi at Devprayag. After confluence of both the rivers at Devprayag, it is called River Ganga. It come down to the Shivaliks and reaches the town of Rishikesh. Bhimgoda barrage constructed on River Ganga at Haridwar diverts about 80% of water which make River Ganga to flow in braided manner and with diminish discharge. It flows in south direction from Haridwar and past Bijnore city to reach Narora. It head down in south-east direction from there to meet River Ramganga at Kusumkher and also Kali River confluence with it at

Kannauj for augmenting the flow of River Ganga. It moves in to known urban industrial centres of Kanpur, Allahabad and Varanasi where the quality of the river is affected by industrial as well as domestic. The Upper Ganga Canal and Lower Ganga Canal meets at Kanpur again. It meets with River Yamuna at Prayagraj known for its mythology and famous Kumbh Mela. The River turns east and joined by River Tons at Sirsa and heading towards Varanasi. It flows 1000 Km in the State of Uttar Pradesh and also form the natural state border of 110 Km between UP and Bihar. It is also joined by River Gandak and Sone near Patna City. Kosi is also Himalayan tributary of Ganga confluence with it at Kursela. It flows 405 Km in Bihar before entering into State of West Bengal. It splits into two streams. The first stream Hooghly River continues to flow in Southwards in India into Bay of Bengal. The Hooghly River forms the Sunderbans Delta which is the native of largest halophytic mangrove forests in the world. Gangasagar symbolised the mouth of the Ganga and is the largest islands in the Sunderbans. The other stream is Ganga-Brahmaputra complex which crosses the international border and enter into Bangladesh.

1.3 WATER QUALITY OF RIVER GANGA

Since the past few decades Ganga basin in particularly the regions along the River Ganga has been distinguished by rapid urbanization and industrialisation. River is a crucial natural resource but due to rapid urbanisation and industrialisation impacting all of its natural and physical characteristics. Water quality of River Ganga and also synergistic environment of the River have been impacted by anthropogenic activities like discharge of effluent from industries without proper treatment. River should be considered as dynamic and synergistic river system for understanding the water quality and its properties of River Ganga. There are numerous factors which impact the water quality of River Ganga directly or indirectly.

1.4 INDUSTRIAL IMPACT ON WATER QUALITY OF RIVER GANGA

A perennial river such as Ganga gives birth to urban centres, agriculture, trade and industries. Many small towns have fattened into large cities since last four decades. Zoning and unavailability of large swaths of flat land in Uttarakhand State is the major region for slowing the rate of industrialisation. The Rishikesh to Haridwar stretch of river had created Drug and heavy electrical industries. Gangetic plain is the most industrialised region as it consists of agro-based industries majorly distilleries and sugar mills. Kanpur city is well known for its leather and textile industries and accounts for 80-90% of leather sell overseas of India. Patna and Kolkata which are major urban area in the lower plains and deltaic region respectively have multitudinous industries cover all industrial sectors. The industrial sewage discharged into River Ganga on an average is 260 MLD. Hundreds of major industries located on the banks of river and out of them 68 industries have been classified as grossly polluting industries (CPCB, 2013). The self-purification capacity of River Ganga is stressed out due to industrialisation and river lost its ability to digest organic waste by its own.

1.5 AIR QUALITY OF THE CITIES SURROUNDING NEAR RIVER GANGA

Notwithstanding the land and water, air is the prime asset for sustenance of life. With the innovative progressions, a tremendous measure of information about surrounding air quality is created and used to set up the nature of air and to direct proper air contamination restorative activities any place fundamental. Such an undertaking would result in comprehensive volumes of information that may neither give a reasonable picture to a chief nor to a normal man who just needs to know how fortunate or unfortunate the air. One approach to portray air quality is to report the focuses of all toxins with adequate dimensions (models). As the quantity of inspecting stations and contamination parameters (and their inspecting frequencies) increment, such depictions of air quality will in general become mistaking notwithstanding for the logical and specialized network. Concerning the overall population, they for the most part won't be fulfilled with crude information, time arrangement plots, factual investigation, and other complex discoveries relating to air quality. The outcome is individuals will in general free intrigue and can neither value the condition of air quality nor the contamination moderation endeavours by administrative offices. Likewise, attention to every day dimensions of urban air contamination is frequently imperative to the individuals who experience the ill effects of diseases brought about by presentation to air contamination. Further the achievement of the responsibility of a country to improve air quality relies upon the help of residents who are very much educated about neighbourhood and national air contamination issues and about the advancement of moderation endeavours. To address the above concerns, the idea of an Air Quality Index (AQI) has been created and utilized adequately in numerous created nations for in the course of the most recent three decades (Shenfeld, 1970). An AQI is characterized as a general plan that changes weighted estimations of individual air contamination related parameters (SO_2, CO, perceivability, and so on.) into a solitary number or on the other hand set of numbers. Throughout the years there has been a colossal increment in human populace, street transportation, vehicular traffic and enterprises in Haridwar district, has led to expand the centralization of vaporous and particulate poison. Industrialization and urbanization carry with them the undesirable unfavourable air poisons, to be specific suspended particulate issue (SPM), sulphur dioxide (SO_2) and nitrogen dioxide (NO_2) (Reddy and Suneela, 2001). Air contamination has for some time been perceived as a possibly deadly type of contamination. Passage of contamination into the environment happens as gases or particles (Kaushik *et al.*, 2006). The development of populace, industry, number of vehicles and ill-advised execution of stringent outflow measures make the issue of air contamination still more regrettable (Ravindra, Mittal and Van Grieken, 2001).Vehicular contamination adds to 70% of absolute contamination in Delhi, 52% in Mumbai and 30% in Calcutta (Gokhale and Patil, 2004). The vast majority of the metropolitan urban communities are confronting genuine air contamination issue because of grouping of engine vehicles, human populace, restricted street surface prompts street blockage and poor street surface conditions add to the contamination issues essentially in urban regions. Urban air contamination not just speaks to dangers to human wellbeing and the urban condition, yet it can likewise add to genuine local and worldwide barometrical contamination.

1.6 OBJECTIVES OF THE STUDY

The objectives of the study are as follows:

i. To study the water quality of River Ganga.
ii. To study the air quality around the catchment of River Ganga based on upon various important parameters.
iii. To perform the multivariate interpolation and interpretation for water quality of River Ganga and air quality around the city surrounded the River Ganga for year 2016.
iv. To perform general statistical analysis for water quality of River Ganga and air quality of city around them for knowing the trend it follow.
v. To perform multivariate statistical analysis for water quality of River Ganga and air quality of city surrounded them for knowing the major pollutant and its source responsible for pollution in the study area for year 2016.
vi. To find out the trend of water quality of River Ganga changes with time.
vii. To develop artificial neural network (ANN) model for prediction of water quality of River Ganga.

CHAPTER 2

REVIEW OF LITERATURE

2.1 WATER QUALITY INDEX OF RIVER GANGA

A study was conducted on the banks of River Ganga in Uttar Pradesh (UP) as it comprises of the maximum area in water pollution in River Ganga. 13 monitoring station along the River Ganga in UP was chosen for the evaluation of water quality using WQI analysis by C++ program. The concentrations of BOD, TH, PO_4, NO_3, EC and pH were found to be outside the specified and acceptable range of WHO standards (Aenab and Singh, 2013).

The quality/potability of consumable water establishes the baseline of safeguard against many diseases and infections. Water Quality Index (WQI) was calculated by the analysis of sixteen physico-chemical parameters on the basis of River Ganga index of Ved Prakash, weighted arithmetic index and WQI by National Sanitation Foundation (NSF) to assess the fitness of drinking water, water for irrigation purposes and other human uses. To estimate the variation in the quality of the River Ganga these three water quality indices have been used at monitored locations over an 11-year period. The application shows minor variations in water quality. Index values as per River Ganga Index by Ved Prakash estimated as ranged between medium to good from 2000 to 2010, NSF Index indicates good water quality for period 2000–2010, while Index values as per the Weighted Arithmetic Index method for the study period indicate poor water quality (Bhutiani *et al.*, 2016).

2.2 THE IMPACT OF WATER QUALITY DETERIORATION OF RIVER GANGA ON ENVRONMENT

The sediment and water of the river are adversely affected by Municipal waste and industrial effluents. Sediments of the bank of Mirzapur region were undergone analysis that revealed the presence of toxic metals, some of them present in greater concentration than those recorded in average scale. The maximum concentrations of Pb, Cu, Zn and Ni in the region, 226, 931, 717 and 24ppm, respectively, were recorded near the Oliar Ghat (landing steps), whereas 138 ppm of Cr was found at the same Ghat. Likewise, the maximum value of Co (20 ppm) occurs opposite to the Fathua Ghat. Though these metals present no direct danger to the ecosystem as long as they are tightly bound to the sediments as these metals may pass to water and thus may cause a health issue (Srivastava, Mehrotra and Tiwari, 1993).

The exhaustive water quality studies on the River Ganga were embarked at Fatehgarh and Kannauj, Uttar Pradesh during 1987-1990. The data unveiled significant seasonal variations in the physico-chemical and bacteriological properties of the river water and the peculiar high level of coliforms, *Faecal coliforms*, and *Faecal streptococci* resonate the poor quality of the water. These pollutants reduce the potability of water and using it for bathing may pose serious problems related to public health (Malik *et al.*, 1995).

Water quality deterioration has severe entanglement for the supply of potable water, irrigation, industrial use, and is a vital qualitative indicator of public health. The negative effects of liquid waste disposal, untreated sewer water and cremation ground (Manikarkna Ghat) of Varanasi city has an adverse effect on the quality of the most important and holiest river, Ganga. The numerous studies conducted in the realm of environment degradation issues suggest that cremation activity is predicted to have one of the biggest impacts on the environment in Varanasi. It badly affects the environment, human health and economy of the country (Geetika Verma and Shrivastav, 2018). Faecal Coliform Counts of more than 4 MPN/100 ml have been recorded at the downstream end of the city near the Varuna confluence. Numerous studies reveal that there is significant relativity between water-borne diseases and the use of the river water for potable uses like bathing, laundry, washing of utensils etc. A study with an objective to unveil the increasingly worsening situation and to find out the possible solution to bring back the health and glory of River Ganga (Kumar *et al.*, 2012). The River Ganga has an alarming risk of endangering level of pollution from sewage as a result of cremation along the bank of city Varanasi. Thus it arises as a great concern to save and clean the River Ganga along with the Ghats in its vicinity.

2.3 WATER QUALITY OF RIVER GANGA AT MAHA KUMBH

The water quality of River Ganga was evaluated during mass bathing in Haridwar at the time of Maha Kumbh (2010). The study comprises microbiological and molecular analysis for determining the water quality of River Ganga. Sample collection from River Ganga was done during the period of Makar Sankranti to Shakh Poornima to estimate the faecal indicator bacteria, *Escherichia coli* along with *Standard Plate Count* (SPC) to ascertain the total bacterial load in the river. The water was notably infected and not at all portable on Somvati Amavasya, Maghi Poornima, Maha Shivratri and Baisakhi. Through the outcome of the study, it is evident that the mass bathing coupled with ritual activities performed by bathers was the most probable cause of increased values of different parameters(Kumbha, 2013).

The mass gathering is an evitable event in Indian society. Thus there is a need for proper environmental management in a mass gathering. A case study of Maha Kumbh 2013 at Prayag, India was used for the analysis of this scenario and collection of information regarding the event, which concludes that although such gatherings can result in significant health risks, there are ways of curbing the adverse effects, which can be implemented in other rallies, political events, sporting events, conferences, award ceremonies, other religious gatherings like Haj, Rath Yatra, fairs and fates etc. (Singh and Bisht, 2014).

2.4 REMOTE SENSING (RS) and GEOGRAPHICAL INFORMATION SYSTEM APPROACH FOR WATER QUALITY OF RIVER GANGA

In the absence of a productive framework for water quality, a noteworthy boundary has been observed in water quality. Conventional water quality inspection is tedious, costly, and must be taken for small size examples. Likewise, moment and exact water quality information can't generally be given to fulfil the requests of water quality displaying and parameter alignment. In this way, we need a cutting edge approach which depends on Remote Sensing (RS) and Geographical Information System (GIS) for water quality patterns. A basic leadership device has been created for water quality mapping of Ganga River in part of Kanpur area of Uttar Pradesh, India. Water test has been gathered from nine stations and examined in the research centre which gives aftereffects of different water quality parameters. Advanced numbers (DN values) for four groups Blue, Green, Red and NIR of LANDSAT 8 pictures have been determined. Watched DN values on those nine testing stations of each band alongside chief segment investigation and band proportions are contrasted and estimated water quality parameters. The water quality parameters incorporate pH, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Dissolve oxygen (DO), Total Solids (TS), Complete Dissolve Solids (TDS), Total Solids (TS), Ammonical Nitrogen, Fluoride, Chloride, Magnesium, Turbidity, Conductivity and Phosphorus. Utilizing DN estimations of LANSAT 8 pictures and in situ, estimated information of water quality parameters connection and different straight relapse models have been produced which depends on most proper band blends having most astounding various relationship coefficient, R^2 value. Utilizing these multiple relapse models, water quality parameters can be anticipated for the whole investigation region. At that point, applying straightforward direct separate capacity to every pixel in study territory, gathering of these needy water quality factors into discrete classes accomplished the order to deliver water quality maps (Kumar, 2015).

Reasonable administration of water assets includes hold maintaining, capable use, and greatness the executives. In spite of the fact that exercises identifying with amount examination and the board as far as waterway release and water assets arranging are given consideration at the bowl level, water quality appraisal is as yet being done at explicit areas of significant concern. The best pay of utilizing remote detecting information for hydrological examinations and checking is its capacity to create data in spatial and transient space, which is urgent for blasting investigation. The GIS innovation gives appropriate options in contrast to capable supervision of enormous and complex databases. Data from satellites is ending up increasingly more significant for characteristic assets the executives and research (Panwar *et al.*, 2015).

An exertion has been made to build up a philosophy to coordinate the Water Quality Index (WQI) with Geographic Information System (GIS) for a compelling elucidation of the quality and wellbeing status of the Ganga River Basin (GRB). GRB has been taken as a contextual analysis. The physical, substance and organic investigation have been deciphered utilizing WQI. In light of the consequences of the investigations, spatial circulation maps of chosen water quality parameters were readied utilizing GIS stage. A critical degradation in the WQ of the stations situated in the lower ranges of the waterway bowl is watched. Allahabad is the most dirtied station pursued by Kanpur and Varanasi. The most substandard WQ with OIP estimation of 4.18 (dirtied class) is seen in the pre-monsoon period of 2010 at Varanasi station. The OIP based on the individual file esteems was assessed giving the values regarding contamination lists (Shukla, Ojha and Garg, 2017).

To understand the assessment and monitoring of surface water quality of the River Ganga at Allahabad, UP, India a study was conducted using open-access earth observation data set. The Landsat 7 (Enhanced Thematic Mapper Plus, ETM+) data has been used for this subject with the use of band rationing technique and water samples collection was done in accord of satellite passing. In situ measurements of water quality parameters were done for validating the obtained ratio of the radiances at sampling sites. The water quality parameters were appraised viz. turbidity, pH, chemical oxygen demand (COD), biological oxygen demand (BOD), dissolved oxygen (DO), temperature, alkalinity, and total hardness. The result depicts that water quality parameters were significantly correlated with the radiance values of the ETM+image except for turbidity. The study implemented multiple linear regression equations models on ETM+ bands for estimating water quality parameters and creating water quality maps for a different study area. The study suggests that the Landsat 7 ETM+image can be efficiently utilized for the assessment of water quality parameters of a river system (Sharma *et al.*, 2019).

2.5 MULTIVARIATE STASTICAL TECHNIQUES FOR WATER QUALITY OF RIVER GANGA

Assessment of water samples collected from Jalsansthan Benajhawar Kanpur sampling station on the Ganga River within Kanpur city during April'08 - March'09 were examined for 14 water quality variables (physico-chemical) parameters, standardized data were subjected to principal components analysis (PCA) to determine the parameters liable for the main variability in water quality variance for Ganga River within Kanpur city. The principal component analysis was able to produce two main components which explain more than 99.316% of the variance (where 64.470 % - anthropogenic effect and 34.846% - industrial effect of the total variance of water quality in Ganga River). Outcomes explicate that total dissolved solids, total alkalinity, total hardness were the parameters that are most important in assessing variations of water quality in October, November, December, January, February, March, April (Post-monsoon season) in the river and turbidity, suspended solid were the parameters that are most important in assessing variations of water quality in June, July, August and September in the river (Monsoon season). Hence study advises that the PCA technique is a serviceable tool for identification of important river water quality monitoring months and parameters. Also, the study was able to endow non-principal water quality parameters like Ca^{+2}, Cl^{-}, SO_4^{-2}, Temperature, Fluoride, pH, Fe, Oxygen Consumption(O_2), Mg^{+2} (Thareja, Choudhury and Trivedi, 2011).

The seasonal variation of 18 water quality parameters for River Ganga and Yamuna of Uttarakhand State were primarily monitored to identify the potential sources of pollution and clustering of monitoring stations with similar characteristics. The collected data was used with Wilcoxon Signed-Rank test, Paired t-test and Multivariate Statistical Techniques (Principal Component Analysis and Cluster Analysis) for separate summer and winter period analysis. The seasonal variability in data set with high pollution level during summer than winter was estimated by Wilcoxon signed-rank test and paired t-test. The CA clubbed 15 monitoring stations of River Ganga and 5 monitoring stations of river Yamuna into 2 clusters of similar characteristics. Principal component analysis indicates four major sources of pollution for River Ganga and three for river Yamuna. The study provides great insight and interpretation of complex datasets and adequate information for water quality assessment. It also identifies the sources and factors of pollution effectively with the added advantage of giving insight towards temporal and spatial variations of water quality for prudent and efficient river water quality management (Sharma *et al.*, 2015).

The land surrounding the river has a great impact on the water quality of the river as many pollutants find their way through the land to water. A study to establish and explore the relationship between land use and water quality of River Ganga in Varanasi district was conducted. The land use land cover (LULC) data was used for performing hierarchical cluster analysis which results in two major land use categories, viz., urban and agriculture. Principal component analysis (PCA) on LULC data revealed that metals are obtained in majority from urbanized, organic matter flowed into the river are originated from agricultural land. As per the Spearman correlation study, it is evident that with rising urbanisation, the amount of pollutant load in the river has a significant rise. The statistical analysis projected that the water quality of River Ganga at Varanasi was a function of adjacent land utility and it provides an anticipated insight for the Indian government to embrace the relationship of land use to river water quality while formulating policies for upcoming river regulation zone (Sharma, Roy and Agrawal, 2016).

Evaluation of spatial variations and analysis of enormous complex water quality data set of Ganga river basin was generated during one year (2013-2014) via Multivariate statistical techniques such as cluster analysis and principal component analysis (PCA). The study was conducted with monitoring of eight water parameters at seven different sites. On conducting Hierarchical cluster analysis on dataset seven sampling sites were clubbed into three clusters i.e. relatively low polluted (LP), moderately polluted (MP) and highly polluted (HP) sites based on water quality characteristic features. Moreover, PCA produced three significant principal components which explained more than 82.9% of the variance that present 57.1%, 13.8% and 12% respectively of net water quality variance of Ganga River. The result highlights that Turbidity, Biochemical Oxygen Demand (BOD) and Dissolved Oxygen are the most important parameters for assessing water quality variations. The water quality index based on eight parameters (Turbidity, BOD, DO, pH, COD, TSS, TS and TDS) computed for all sites came out to be medium to bad. Therefore, the study embellishes the application of Multivariate Statistical Techniques for understanding spatial variations and complex data interpretation in water quality for adequate water quality management. The study unveils that the major source of Ganga river pollution is untreated industrial and municipal discharge and for tackling Ganga river pollution suitable management plan along with a proper sewage treatment network, artificial aeration, maintaining enough dilution flow and watershed management is required (Kumar, Kaushal and Nigam, 2016).

With significant achievement through Multivariate statistical techniques such as cluster analysis (CA) and principal component analysis (PCA), Factor Analysis (FA) and Discriminant analysis (DA) came into the picture for evaluation and interpretation of temporal/spatial variation of large complex variable surface water quality data set. Factor analysis conducted on the data set of three different groups obtained from Hierarchal cluster analysis intimates that parameters accountable for water quality variations are majorly related to discharge and temperature (natural), for relatively less polluted areas organic pollution (point source: domestic wastewater); nutrients (non-point sources: agriculture runoff) and organic pollution in medium polluted areas; and organic pollution and nutrients (point sources: domestic wastewater, wastewater treatment plants and industries) in highly polluted areas in the river basin. Discriminant analysis gave the high-grade results for both temporal and spatial analysis. DA allowed a reduction in the dimensionality of the large data set, delineating a few indicator parameters bound for large variations in water quality. Thus, this study demonstrates the utility of multivariate statistical techniques for water quality assessment via analysis and interpretation of complex data sets. The technique aid in the identification of sources and factors of pollution with a greater understanding of temporal or spatial variations for efficient river water quality management strategy (Y, G and R, 2018).

2.6 NEURAL NETWORK APPROACH FOR WATER QUALITY OF RIVER GANGA

A combined model of PCA and wavelet neural network (WNN) was utilized as a water quality method. It first establishes the water quality evaluation index system followed by PCA to remove the relevance, redundant information of indicators. Then the emblematic indexes obtained were standardized and imported into the wavelet neural network model, the result of the network is used for the comprehensive water quality monitoring (Ma *et al.*, 2010).

2.7 WATER QUALITY OF INTERNATIONAL RIVER

Water and wastewater frameworks in Iraq have altogether been harmed in the First and Second Gulf Wars. In addition, the Hussein routine in Iraq left the water framework to crumple and made it is in urgent need of modernization, redevelopment and improvement. The motivations behind this investigation, tests were gathered from two stations along the

Diyala River inside Baghdad City. They utilized Detection of Violation to decide the water nature of the Diyala River and Al-Rustumiya Wastewater Treatment Plant (WWTP). Violation for Diyala Waterway demonstrates the parameters (BOD, SO_4, PO_4 and Cl) are 100% infringement and that most extreme dimension of contamination. Al-Rustumiya Wastewater Treatment Plant was having elevated amounts of infringement for the years (2005, 2006 and 2007) what's more, the qualities were between (55% - 87%) (Aenab and Singh, 2014)

2.8 AIR QUALITY OF RIVER GANGA CATCHMENT AREA

The study was conducted to calculate air quality index (AQI) for the city of Kanpur which uses maximum operator concept to evaluate the overall AQI, which is the maximum value of sub-indices (of each pollutant). The mathematical function for computing the sub-indices are proposed based on health criteria of the USEPA and Indian air quality standards. The pollutants included in the AQI are SO_2, SPM (suspended particulate matter), O_3, NO_2, PM_{10} and CO. The interpretation of AQI for Kanpur city has projected that air quality worsens (very poor to severe) in winter and early summer months (March-early May) characterized as dusty winds resulting in high SPM and improves in monsoon and a post-monsoon period (good to moderate) as pollutants are washed away by rain (Sharma *et al.*, 2003).

Air Quality Index (AQI) method using air monitoring data of Haridwar was carried out to analysed three major pollutants viz. SO_2, NO_x and SPM presented in ambient air at residential, industrial and rural areas of Haridwar during 2005-2006. It revealed that all the parameters were found to be within the permissible limit except SPM at site-1 and site-2, where site 1 AQI was Heavy Air Pollution (HAP) and Moderate Air Pollution (MAP) during the study period, while at site-2 it was Light Air Pollution (LAP) during the study period and site-3 showed clean air (CA) (Chauhan, Joshi and Vishwavidyalaya, 2007).

Atmospheric pollutants concentration is dependent upon temporal factors. Experiment was conducted to measure pollutants concentration including ozone (O_3), sulphur dioxide (SO_2), oxides of nitrogen (NO_x), carbon monoxide (CO), and inhalable particulate matter (PM_{10}) in the central Indo-Gangetic Basin (IGB) at Patna, India, from 1st March 2013 to 31st December 2014, and notable variability was observed in the temporal patterns of these pollutant concentrations. Over the study period the mean O_3, SO_2, NO, NO_2, CO (trace gases: TG), and PM_{10} (PM) concentrations were computed as 14.5 ± 4.8, 5.9 ± 4.8, 23.1 ± 22, 20.6 ± 14.6 ppb, 1.5 ± 0.7 ppm, and 192.0 ± 132.8 µg/m^3, respectively. It was examined that the highest concentrations of these species were during the post-monsoon and winter seasons except O_3 and SO_2 that displayed the highest concentrations during the pre-monsoon. The concentration of TG and PM were lowest during the monsoon season as a result of wash away by rain. Oxides of Nitrogen (NO and NO_2) along with PM concentrations decreased by ~76, 19, and 63% when the wind speed (WS) was N 0.5 m/s. However, for O_3, the trend was opposite with ~14% higher concentrations. The wind speed was negatively correlated with PM during the winter (−0.48) and post-monsoon (− 0.32) seasons. Trajectory Analysis showed that during the biomass burning period (post-monsoon), TG and PM concentrations were around three-fold higher (flow from the IGB) than the other seasons. The mitigation measures should be designed to reduce emissions from both local and regional sources to improve air quality over IGB (Tiwari *et al.*, 2016).

CHAPTER 3

METHODOLOGY

3.1 STUDY AREA

The data of different water quality parameters for River Ganga for year 2007 and 2016 is taken from Central Pollution Control Board (CPCB) Environmental Information System (ENVIS) for 64 National Water Quality Monitoring Programme (NWMP) stations on River Ganga (ENVIS Centre on Control of Pollution Water, Air and Noise). The water quality parameters include pH, Electrical Conductivity (EC), Biochemical Oxygen Demand (BOD), Dissolved Oxygen (DO), Temperature, Nitrate-Nitrogen (NO_3-N), Total Coliform (TC) and Faecal Coliform (FC). There are eleven, twenty, twenty two, one and ten NWMP stations in state of Uttarakhand, Uttar Pradesh, Bihar, Jharkhand and West Bengal respectively in the River Ganga stretch from Gaumukh to Bay of Bengal.

The data of different air quality parameters for nearby areas of River Ganga for year 2016 is taken from Central Pollution Control Board (CPCB) Environmental Information System (ENVIS) for 40 National Ambient Air Quality Monitoring Programme (NAMP) stations near River Ganga (ENVIS Centre on Control of Pollution Water, Air and Noise). The ambient air quality parameters include Nitrogen Dioxide (NO_2), Sulphur Dioxide (SO_2) and Particulate Matter of aerodynamic size equal or less than 10 microns (PM_{10}) and of aerodynamic size equal or less than 2.5 microns ($PM_{2.5}$). There are two, thirteen, two and twenty three NAMP stations in state of Uttarakhand, Uttar Pradesh, Bihar and West Bengal respectively near the River Ganga stretch from Gaumukh to Bay of Bengal.

Figure 3.1 Sampling Point of River Bhagirathi at Gangotri

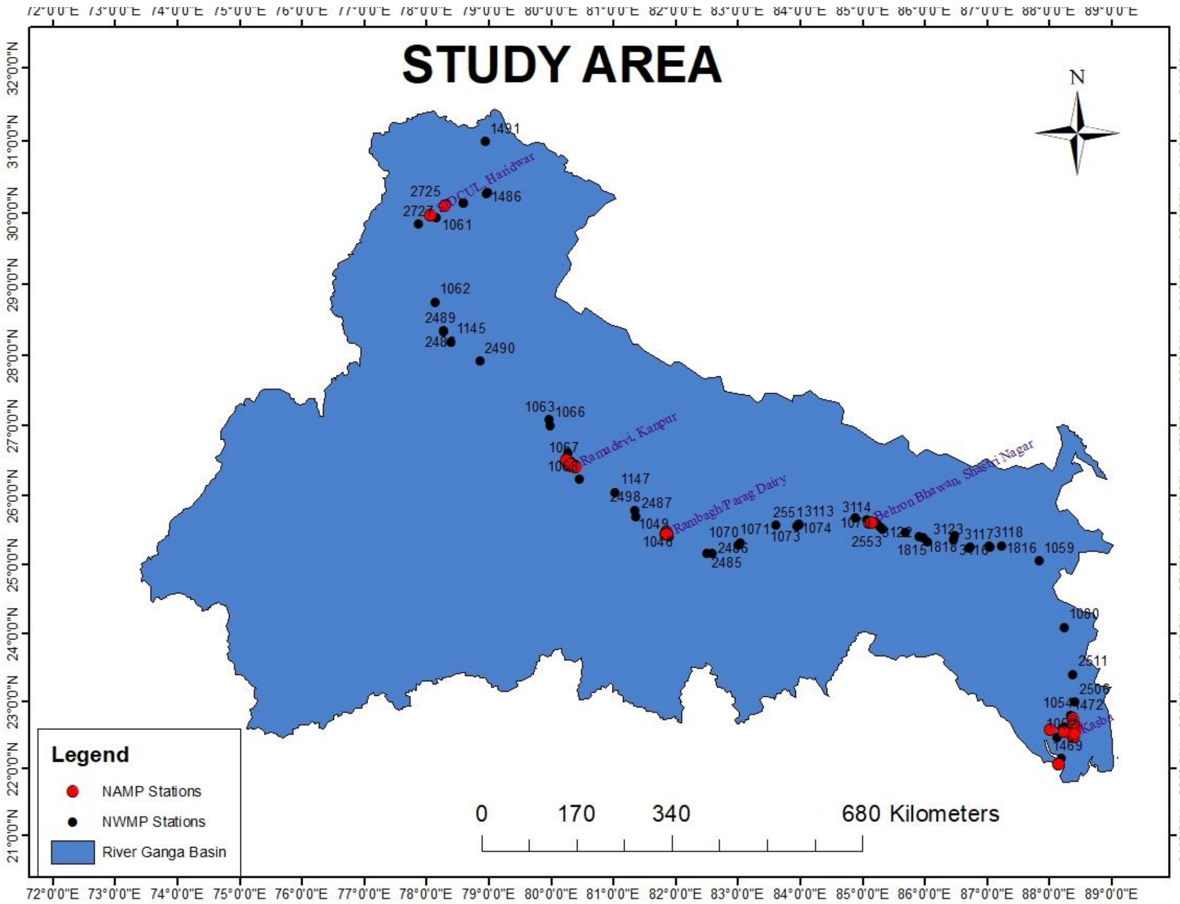

Figure 3.2 NWMP and NAMP Stations located in River Ganga and nearby it

Figure 3.3 River Ganga at Assighat, Varanasi

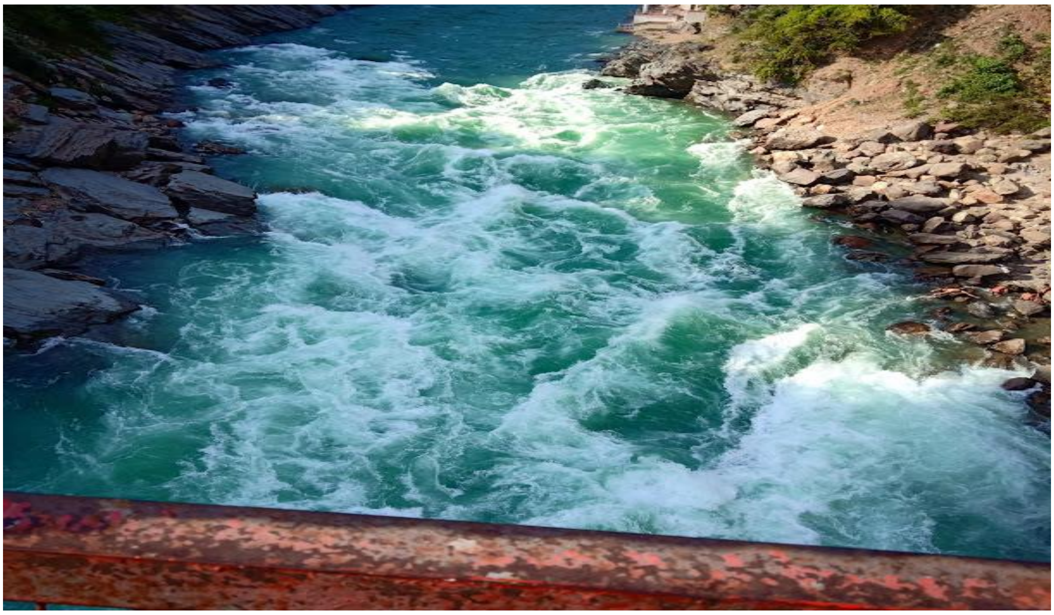

Figure 3.4 River Bhagirathi at Devprayag

Figure 3.5 River Ganga at Bithoor, Kanpur

Figure 3.6 River Ganga at Devprayag

Figure 3.7 River Ganga at Malviya Bridge, Varanasi

3.2 WATER QUALITY INDEX

The Water Quality Index (WQI) is the unique and valuable rating to illustrate overall water quality scenario in the single term which will helped in selecting appropriate treatment technology for cleaning the River Ganga. It can be calculated based on the rating scale (Table 3.1) and assigned unit weight for each parameter (Table 3.2). The sub-index is calculated by multiplying the V_r with assigned unit weight (W_i). The overall water quality index (WQI) is calculated by aggregating the sub-indices of each parameter for a particular NWMP station.

Table 3.1 Rating Scale for Calculation of WQI (Shah and Joshi, 2017)

Parameters	Range				
pH	7.0-8.5	8.5-8.6 6.8-6.9	8.6-8.8 6.7-6.8	8.8-9.0 6.5-6.7	>9.0 <6.5
DO (mg/L)	>6.0	5.1-6.0	4.1-5.0	3.0-4.0	<3.0
BOD (mg/L)	0-3	3-6	6-80	80-125	>125
Electrical Conductivity (mmhos/cm)	0-75	75-150	150-225	225-300	>300
Nitrate Nitrogen (mg/L)	0-20	20-50	50-100	100-200	>200
Total Coliform (MPN/100 mL)	0-5	5-50	50-500	500-10,000	>10,000
Faecal Coliform (MPN/100 mL)	0-2.5	5-25	25-250	250-5000	>5000
V_r	100	80	60	40	0
Class	I	II	III	IV	V
Extent of Pollution	Clean	Slight	Moderate	Excess	Severe

Table 3.2 Assigned Unit Weights for Water Quality Parameters for Calculation of WQI (Shah and Joshi, 2017)

Parameters	Unit Weight (W_i)
pH	0.165
DO (mg/L)	0.281
BOD (mg/L)	0.234
Electrical Conductivity (mmhos/cm)	0.009
Nitrate Nitrogen (mg/L)	0.028
Total Coliform (MPN/100 mL)	0.281

3.3 AMBIENT AIR QUALITY INDEX

An ambient air quality index (AQI) is defined as an overall plan that change the weighed values of individual air pollutant concentrations into a single number or set of numbers to display the quality of air based on effects on human health. The sub-index of individual pollutant is calculated based on breakpoints (Table 3.3) for a particular NAMP station and maximum of sub-indices for a particular NAMP station give the overall AQI.

Table 3.3 Breakpoints for AQI (units: μg/m^3 unless mentioned otherwise)
(Government of India and Ministry of Environment, 2014)

AQI Category	PM_{10} 24-hr	$PM_{2.5}$ 24-hr	NO_2 24-hr	O_3 8-hr	CO 8-hr (mg/m^3)	SO_2 24-hr	NH_3 24-hr	Pb 24-hr
Good (0-50)	0-50	0-30	0-40	0-50	0-1.0	0-40	0-200	0-0.5
Satisfactory (51-100)	51-100	31-60	41-80	51-100	1.1-2.0	41-80	201-400	0.5-1.0
Moderately polluted (101-200)	101-250	61-90	81-180	101-168	2.1-10	81-380	401-800	1.1-2.0
Poor (201-300)	251-350	91-120	181-280	169-208	10-17	381-800	801-1200	2.1-3.0
Very Poor (301-400)	351-430	121-250	281-400	209-748*	17-34	801-1600	1200-1800	3.1-3.5
Severe (<400)	430+	250+	400+	748+*	34+	1600+	1800+	3.5+
*One hourly monitoring (for mathematical calculation only)								

3.4 INTERPOLATION APPROACH

The interpolation approach was conducted using the geostatistical analyst extension within the geographical information system ArcGIS 10.1.

3.4.1 INVERSE DISTANCE WEIGHTING (IDW)

The IDW interpolation combines the idea of accessibility adopted by Thiessen polygons (THIESSEN, 2006) with the slight change of trend surface. That measured value which is more close to the prediction location than those farther away has more impact on the predicted value. There is assumption by the IDW that with each measured point has some local impact that decline with distance. The general expression for IDW is,

$$\hat{Z}(s_o) = \frac{\sum_{i=1}^{N} w(d_i) Z(s_i)}{\sum_{i=1}^{N} w(d_i)} \qquad \text{….. (3.1)}$$

where $\hat{Z}(s_o)$, $Z(s_i)$ represents the predicted and observed value at location s_o, s_i, N is the number of measured sample points used in the prediction, w(d) is the weighting function and d_i is the distance from s_o to s_i. Interpolation results are significantly affected by the choice of weighting function based on the framework of IDW expression (Luo, Taylor and Parker, 2008).

3.5 MULTIVARIATE STATISTICAL METHODS

Ganga River water quality and its nearby air quality along with source identification were carried out using two multivariate statistical methods like factor analysis and principal component analysis (PCA). All mathematical computations are done using MINITAB 19.

3.5.1 PRINCIPAL COMPONENT ANALYSIS (PCA)

The hidden information from the data set can be extracted using the multivariate statistical perspective for possible influence of water and air quality on and around River Ganga. It is a method which provides a unique solution for reconstruction of original data from the results. It adjusts the data in such a way that maximum variability is observed. Also, find the most important pollutant responsible for water and air quality (Kumar, Kaushal and Nigam, 2016).

3.5.2 FACTOR ANALYSIS (FA)

This tool removes the surplus information and easier the handling of complex data set. It is based on Eigen correlation or covariance matrix analysis for converting the many indicators to a few negligible composite indicators and illustrate the meaning of each principal factor(Shrestha and Kazama, 2007). Assuming that there are m cross-sections and each cross-section portray p strong correlation variables. Mathematically, it can be written as:

$$x_1 = a_{11}f_1 + a_{12}f_2 + \cdots + a_{1p}f_p + \epsilon_1 \qquad \text{….. (3.2)}$$

$$x_1 = a_{11}f_1 + a_{12}f_2 + \cdots + a_{1p}f_p + \epsilon_1 \qquad \text{….. (3.3)}$$

:

$$x_1 = a_{11}f_1 + a_{12}f_2 + \cdots + a_{1p}f_p + \epsilon_1 \qquad \text{..... (3.4)}$$

$$x_m = a_{m1}f_1 + a_{m2}f_2 + \cdots + a_{mp}f_p + \epsilon_m \qquad \text{..... (3.5)}$$

where $X = (x_1, x_2, \ldots, x_m)^T$ is standardized data vector; $F = (f_1, f_2, \ldots, f_m)^T$ is principal vector (PF); aij is factor loading reflecting correlation between xi and fi; ϵ_i is other factors which are generally ignored in actual analysis (Gao *et al.*, 2011).

3.6 BASIC STASTICAL ANALYSIS

The graphical representation of basic statistics like mean, variance, standard deviation, Anderson-Darling Normality Test etc. are computed by MINITAB 19 for water and air quality parameters. An extension of work by Anderson and Darling(Anderson and Darling, 2007) on normality test on its named is proposed by Stephens based on empirical scatteredness. The Anderson-Darling normality test for normally scattered arbitrary observations y with mean of the observation μ and variance 2σ is given by

$$A^2 = -\left(1 + \frac{0.75}{n} + \frac{2.25}{n^2}\right)\left[\frac{\sum_{i=1}^{n}[(2i-1)\log\{\hat{z}_i(1-\hat{z}_{n+1-i}\}]}{n} + n\right] \qquad \text{..... (3.6)}$$

Where $\hat{z}_i = \varphi\left[\left(y_{(i)} - \hat{\mu}\right)/\,\hat{\sigma}\right]$ and φ (.) is the apportionment function of N (0, 1) random variables. They also provided the points for percentage(Stephens, 1974).

3.7 DEVELOPMENT OF ARTIFICIAL NEURAL NETWORK (ANN) MODEL FOR WATER QUALITY PREDICTION OF RIVER GANGA

An ANN is made up of highly interconnected set of neurons carrying simple information in a known pattern. In accordance with the pre-set non-linear function, neuron collects single as well as multiple inputs to produce output. The known input and output are feed to the model in a systematic manner for training or learning of model for interconnection of neurons. An error convergence technique is used to strengthen the interconnections between neurons for producing desired output for a known input (Sarkar and Pandey, 2015). In the present study, an ANN model is developed for water quality prediction of River Ganga using MATLAB R2015a. The training of model for 8 inputs (water quality parameters including pH, DO, BOD, Temperature, TC, FC, EC and NO3-N) to give 1 output (WQI) of River Ganga for year 2007 is feed to the developed model.

CHAPTER 4

RESULTS and DISCUSSION

4.1 MULTIVARIATE INTERPOLATION AND INTERPRETATION OF RIVER GANGA AND ITS NEARBY AREAS IN 2016

4.1.1 pH

The whole stretch of River Ganga has clean water w.r.t pH from Gangotri to Diamond Harbour, West Bengal in 2016. It falls in the prescribed limit of 6.5 to 8.5 and therefore, the possibilities of damaging the mucous lining of tissues in biological organisms has a rare chance to see. The average value of year 2000- 2010 (11 years) was found as 7.17 ± 0.06 mg/l at Haridwar (Bhutiani *et al.*, 2016) and also in this study it is within the range of 7-8.5. It can be said that the water quality w.r.t pH is within the limit from decades.

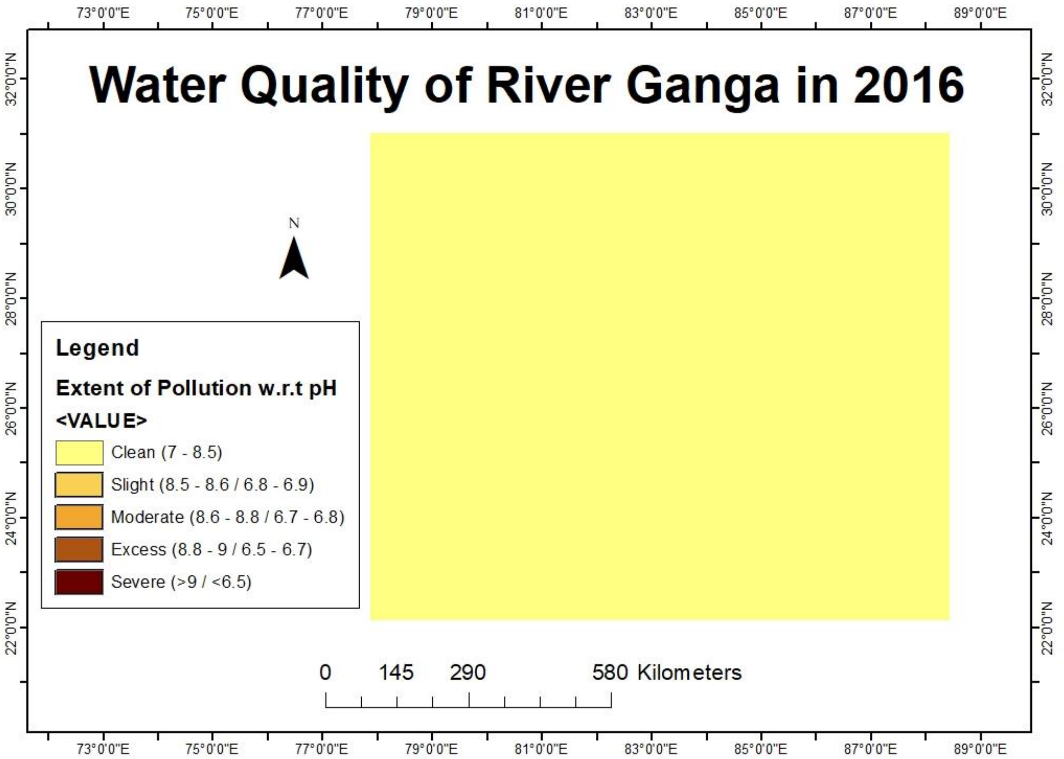

Figure 4.1 Water Quality of River Ganga w.r.t pH in 2016

4.1.2 Electrical Conductivity (EC)

The River Ganga stretch in state of Uttarakhand w.r.t Electrical Conductivity is found clean water in 2016. It is also observed that in the state of Uttar Pradesh it varies from clean water to severe water quality with the values varies from 0 to more than 300 mmhos/cm. The water quality w.r.t EC have mostly severe water quality starting from state of Uttar Pradesh to West Bengal. As the conductivity is directly related to the presence of dissolved salts and its magnitude can give the idea of the dissolved solids present in the water. A factor 0.65 can be employed to convert the electrical conductivity value into dissolved solids present in the water. The dissolved solids present in the River Ganga varies from 0 mg/L to more than 200000 mg/L for clean to severe extent of water w.r.t EC.

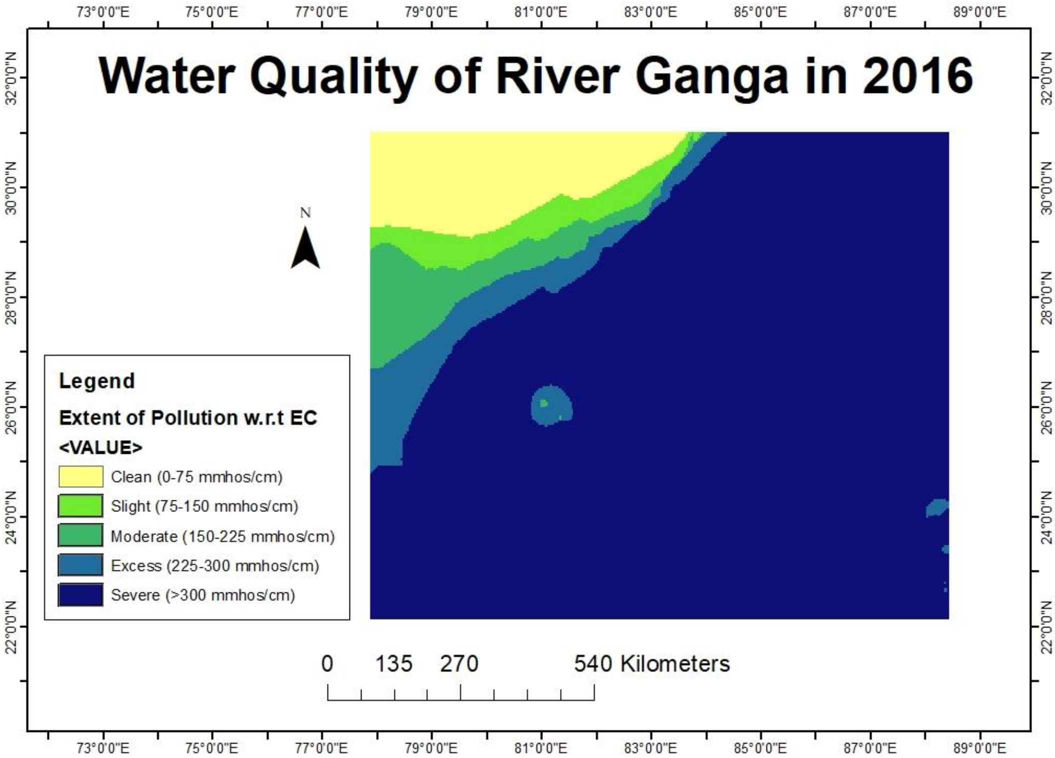

Figure 4.2 Water Quality of River Ganga w.r.t Electrical Conductivity in 2016

4.1.3 Biochemical Oxygen Demand (BOD)

The River Ganga have clean and slight polluted water throughout its path from Gangotri to Diamond Harbour in 2016 except at Kanpur region where it is moderately polluted due to discharge of tannery treated effluent and domestic sewage. The average value of year 2000- 2010 (11 years) was found as 1.84 ± 0.32 mg/l at Haridwar(Bhutiani *et al.*, 2016) which shows the river falls under the clean water zone. The BOD value varies from 0 to 6 mg/L in the entire region except at Kanpur region. The BOD varies from 6 mg/L to 80 mg/L at Kanpur region in 2016.

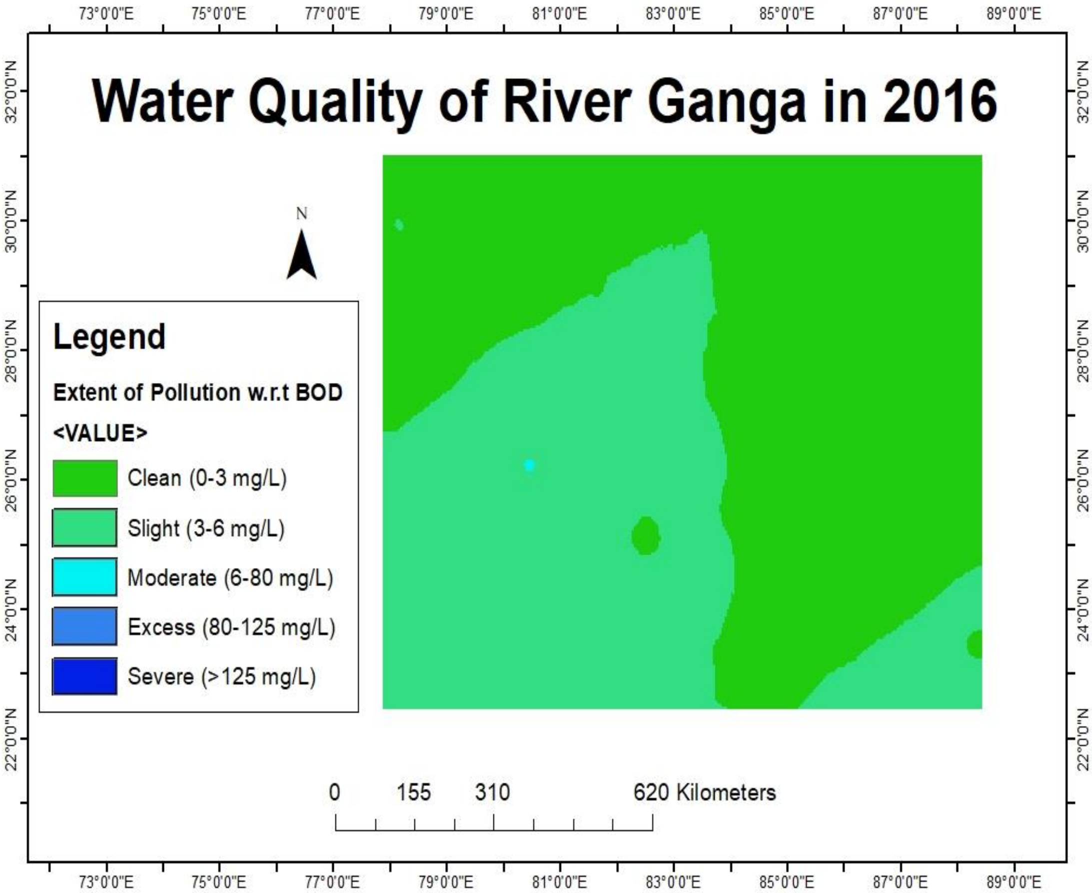

Figure 4.3 Water Quality of River Ganga w.r.t Biochemical Oxygen Demand in 2016

4.1.4 Dissolved Oxygen (DO)

The River Ganga has clean water throughout its path from Gangotri to Diamond Harbour in 2016 except in the state of West Bengal. It shows that the minimum required DO for aquatic life to exist in the River Ganga is maintained throughout the stretch. The average value of year 2000- 2010 (11 years) was found as 10.26 ± 0.69 mg/l at Haridwar(Bhutiani *et al.*, 2016) which shows the river falls under the clean water zone. The DO value varies from 4 to 6 mg/L in the state of West Bengal which tells that the water quality of River Ganga in West Bengal is slightly polluted to moderately polluted in terms of dissolved oxygen present in it. In the remaining stretch the DO value is found greater than 6 mg/L.

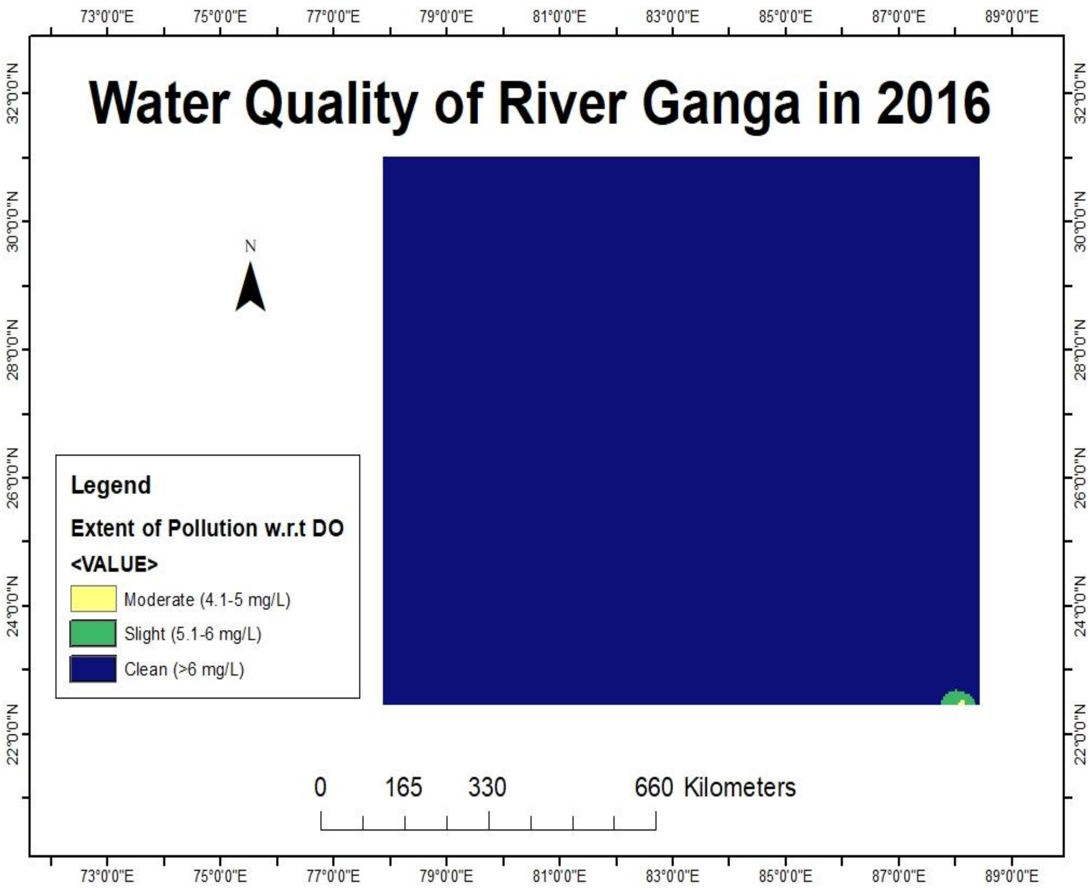

Figure 4.4 Water Quality of River Ganga w.r.t Dissolved Oxygen in 2016

4.1.5 Nitrate Nitrogen (NO_3-N)

The River Ganga has clean water throughout its path from Gangotri to Diamond Harbour in 2016. It is found that the Nitrate-N concentration in the River Ganga has value less than 45 mg/L and so, the cases of disease caused by consumption of Nitrate-N called methaemoglobinaemia (blue baby syndrome) is very rare. The range of Nitrate-N for year 2000- 2010 (11 years) was found to be 0.02 to 0.07 mg/L at Haridwar(Bhutiani *et al.*, 2016) which shows the river falls under the clean water zone. It can be said that the water quality w.r.t NO_3-N is within the limit from decades.

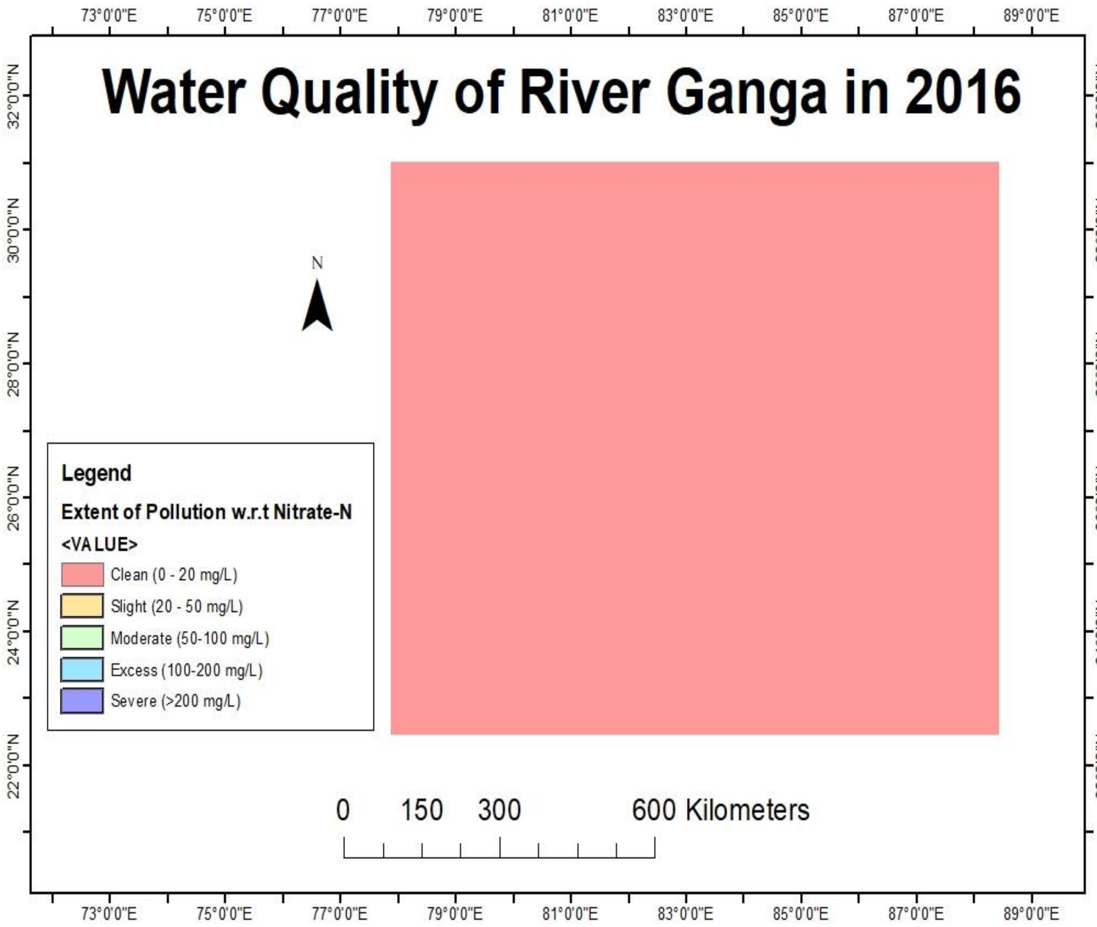

Figure 4.5 Water Quality of River Ganga w.r.t Nitrate-N in 2016

4.1.6 Total Coliform (TC)

The River Ganga stretch has clean to severely polluted water throughout its path from Gangotri to Diamond Harbour in 2016 w.r.t total coliform. In the Uttarakhand stretch the river has clean to moderately polluted water quality w.r.t total coliform. In Uttar Pradesh and Bihar stretch the river has excess polluted stream to severely polluted stream. In West Bengal stretch it is severely polluted due to untreated discharge of sewage into river water and also due to practice of defecating in river stream. Total Coliform varies from 0 to 500 MPN/100 mL, greater than 500 MPN/100 mL and more than 10,000 MPN/100 mL for Uttarakhand, UP & Bihar and West Bengal respectively.

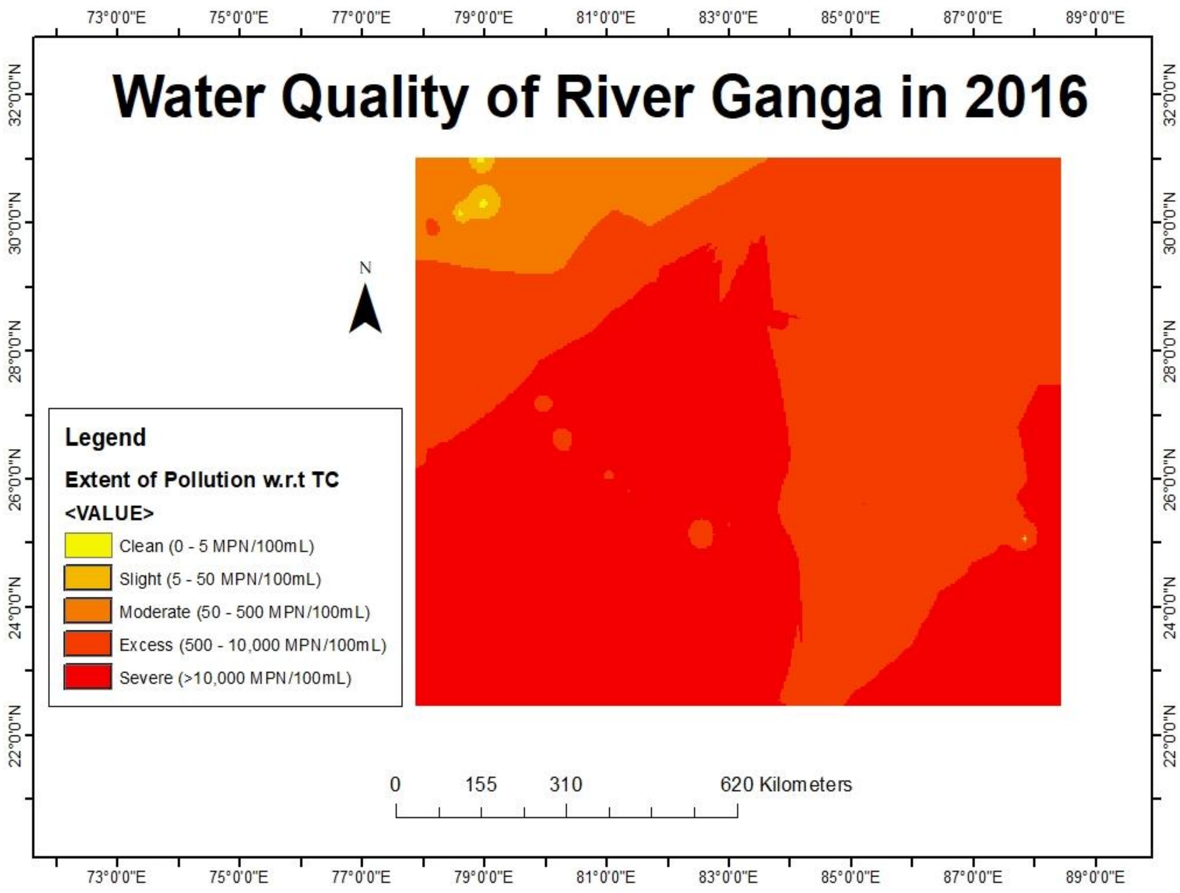

Figure 4.6 Water Quality of River Ganga w.r.t Total Coliform in 2016

4.1.7 Faecal Coliform (FC)

The River Ganga stretch has clean to severely polluted water throughout its path from Gangotri to Diamond Harbour in 2016 w.r.t faecal coliform. In the Uttarakhand stretch the river has clean to moderately polluted water quality w.r.t faecal coliform. In Uttar Pradesh and Bihar stretch the river has excess polluted stream to severely polluted stream. In West Bengal stretch it is severely polluted due to untreated discharge of sewage into river water and also due to practice of defecating in river stream. Faecal Coliform varies from 0 to 250 MPN/100 mL, greater than 250 MPN/100 mL and more than 5000 MPN/100 mL for Uttarakhand, UP & Bihar and West Bengal respectively.

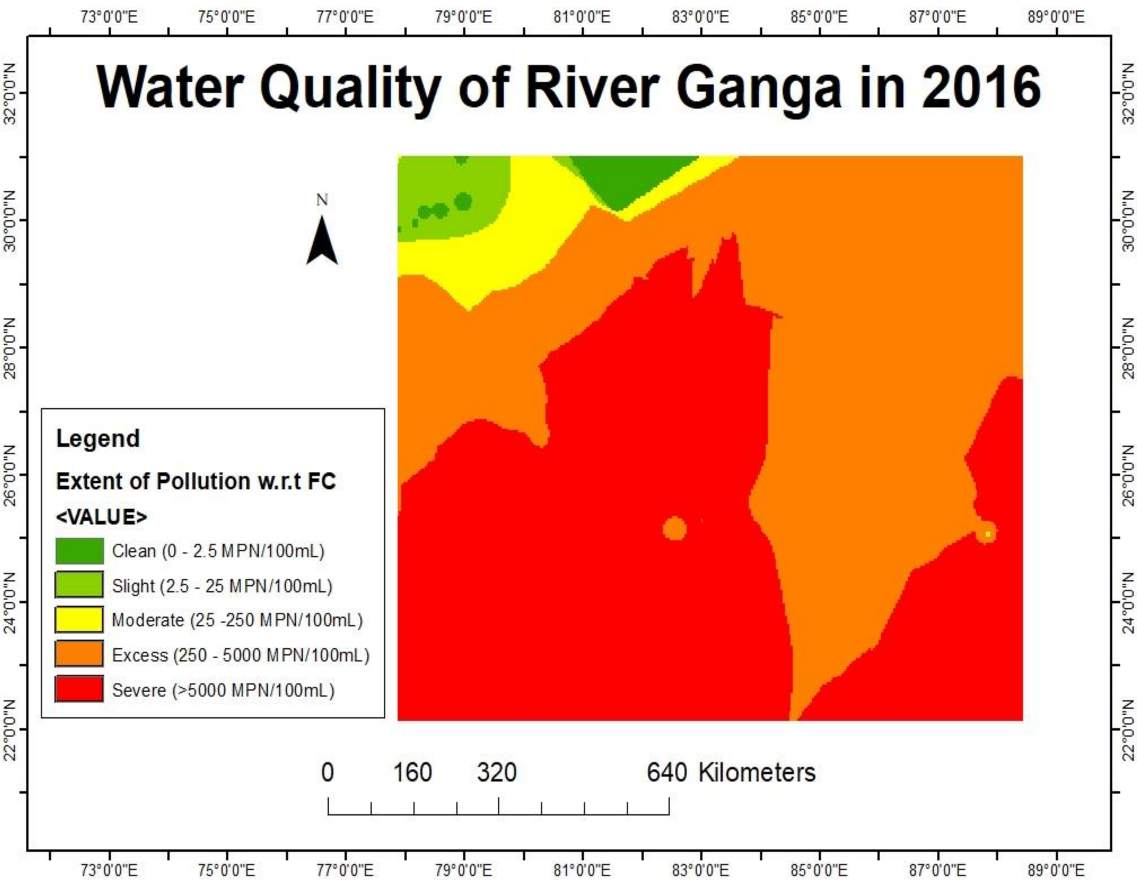

Figure 4.7 Water Quality of River Ganga w.r.t Faecal Coliform in 2016

4.1.8 Temperature

The River Ganga water can be classified into Cool, Cold and Warm. The river stretch from Gangotri to Devprayag is classified as cool water as its temperature varies from 0 to 15˚C in 2016. Rest part of River Ganga is classified as cold water as its temperature varies from 15 to 26.7˚C in 2016 except West Bengal and natural border of UP & Bihar made by River Ganga where it is classified as warm water with temperature varies from 32.2 to 43.3˚C in 2016. The average value of year 2000-2010 (11 years) was found as 15.93 ± 0.75 mg/l at Haridwar(Bhutiani *et al.*, 2016) which shows the river falls under cold water.

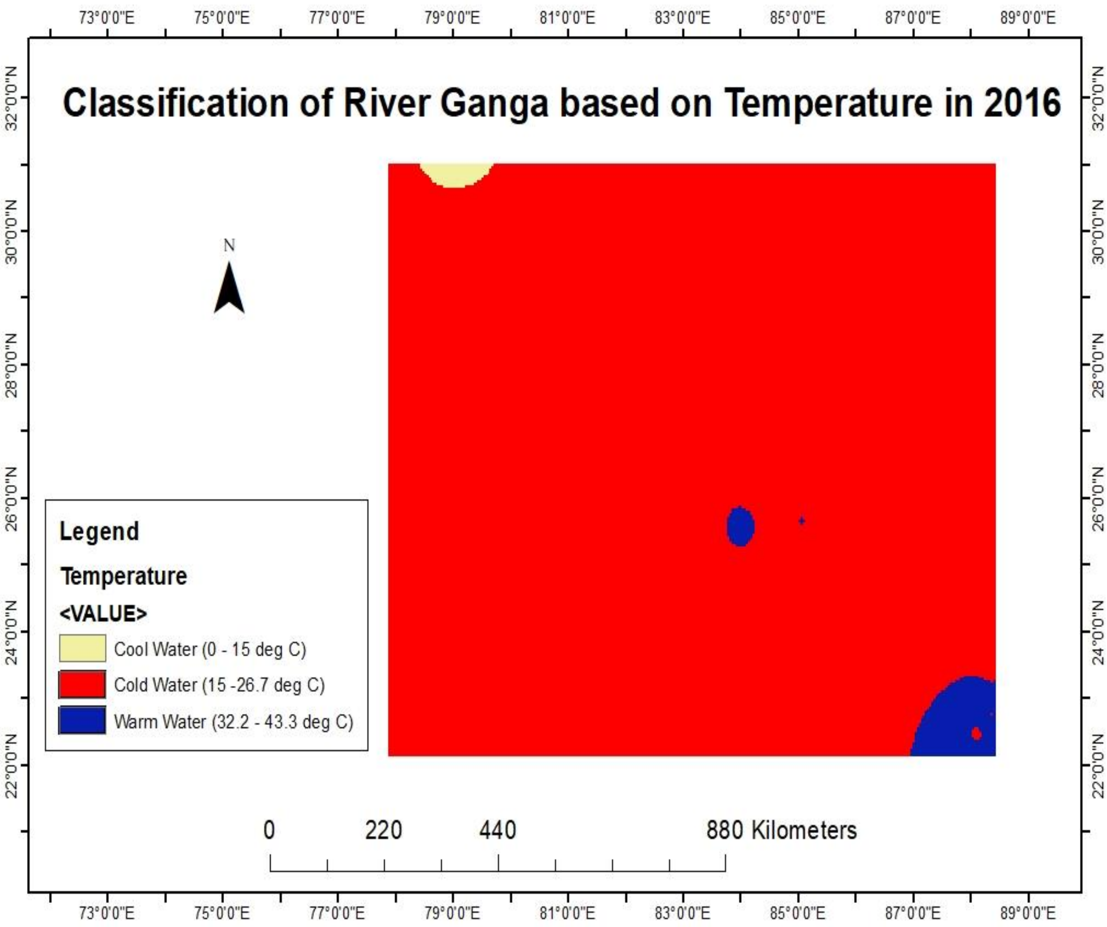

Figure 4.8 Classification of River Ganga based on Temperature in 2016

4.1.9 Water Quality of River Ganga

The Water Quality of River in Uttarakhand is having excellent quality of water as its Water Quality Index (WQI) is more than 90. In the Uttar Pradesh and Bihar stretch of River Ganga is having good quality of water except between the stretch of Prayagraj and Mirzapur. WQI of good quality of water ranges from 70 to 90. The water quality of West Bengal stretch and between Prayagraj and Mirzapur has medium quality of water and WQI ranges from 50 to 70.

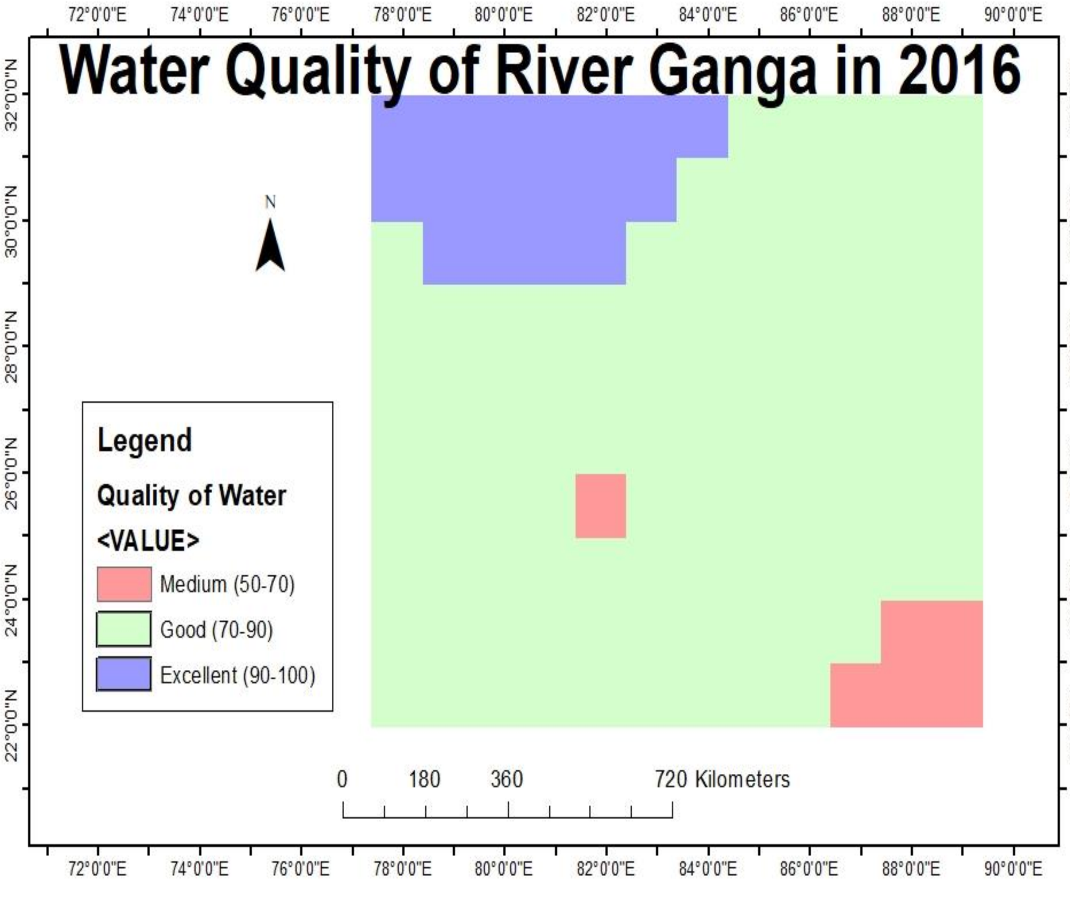

Figure 4.9 Water Quality of River Ganga in 2016

4.1.10 Particulate Matter

The Particulate Matter which is the predominant pollutant for air quality of India. It can be classified on the basis of aerodynamic size. The particles of aerodynamic diameter equal or less than 10 microns and equal or less than 2.5 microns are called PM_{10} and $PM_{2.5}$ respectively.

4.1.10.1 $PM_{2.5}$

It can be seen that the $PM_{2.5}$ concentration on whole stretch of River Ganga & nearby has value from 0 to 30 μg/m^3 and sub-index value between 0 to 50 shows good quality of air w.r.t $PM_{2.5}$.

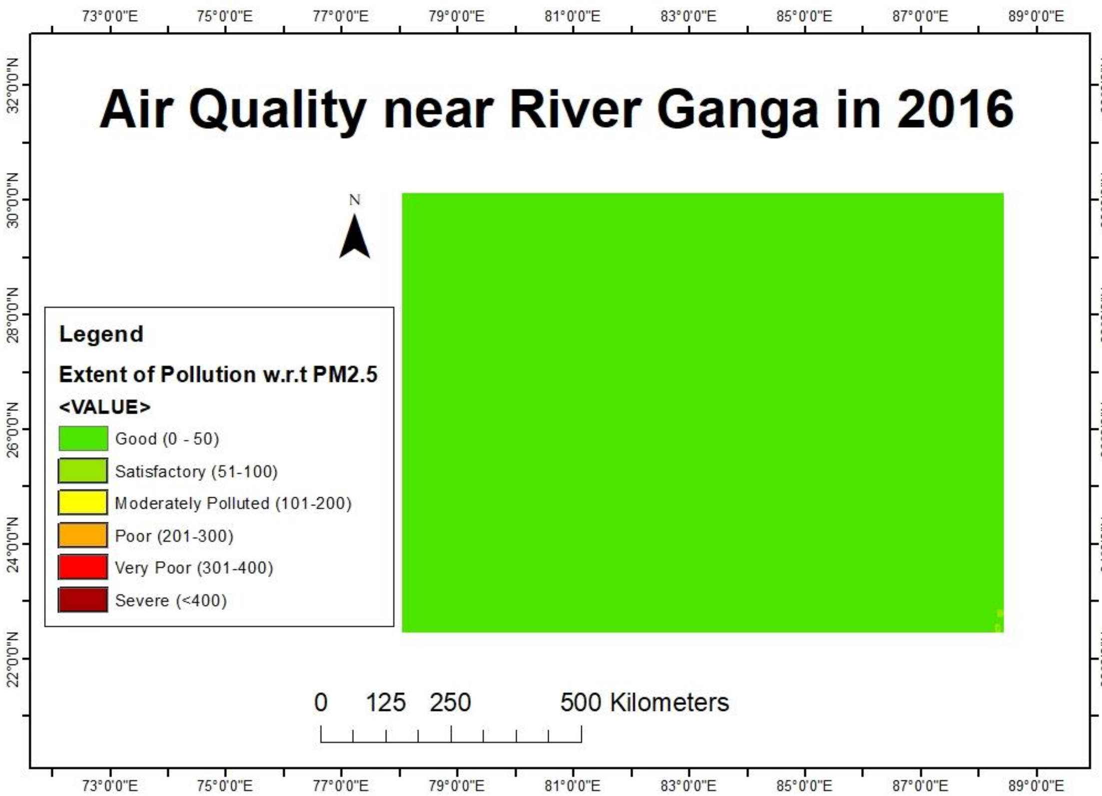

Figure 4.10 Air Quality near River Ganga w.r.t $PM_{2.5}$ in 2016

4.1.10.2 PM_{10}

The air quality w.r.t PM_{10} near River Ganga have mostly moderately polluted with values between 101 to 250 μg/m^3 and sub-index values between 101-200 except in Jharkhand where satisfactory air quality is observed. The mean concentration of PM_{10} in the central IGB at Patna in the state of Bihar is 192.0 ± 132.8 μg/m^3 during 2013 and 2014(Tiwari *et al.*, 2016) shows that the state of Bihar has moderately polluted air w.r.t PM_{10}.

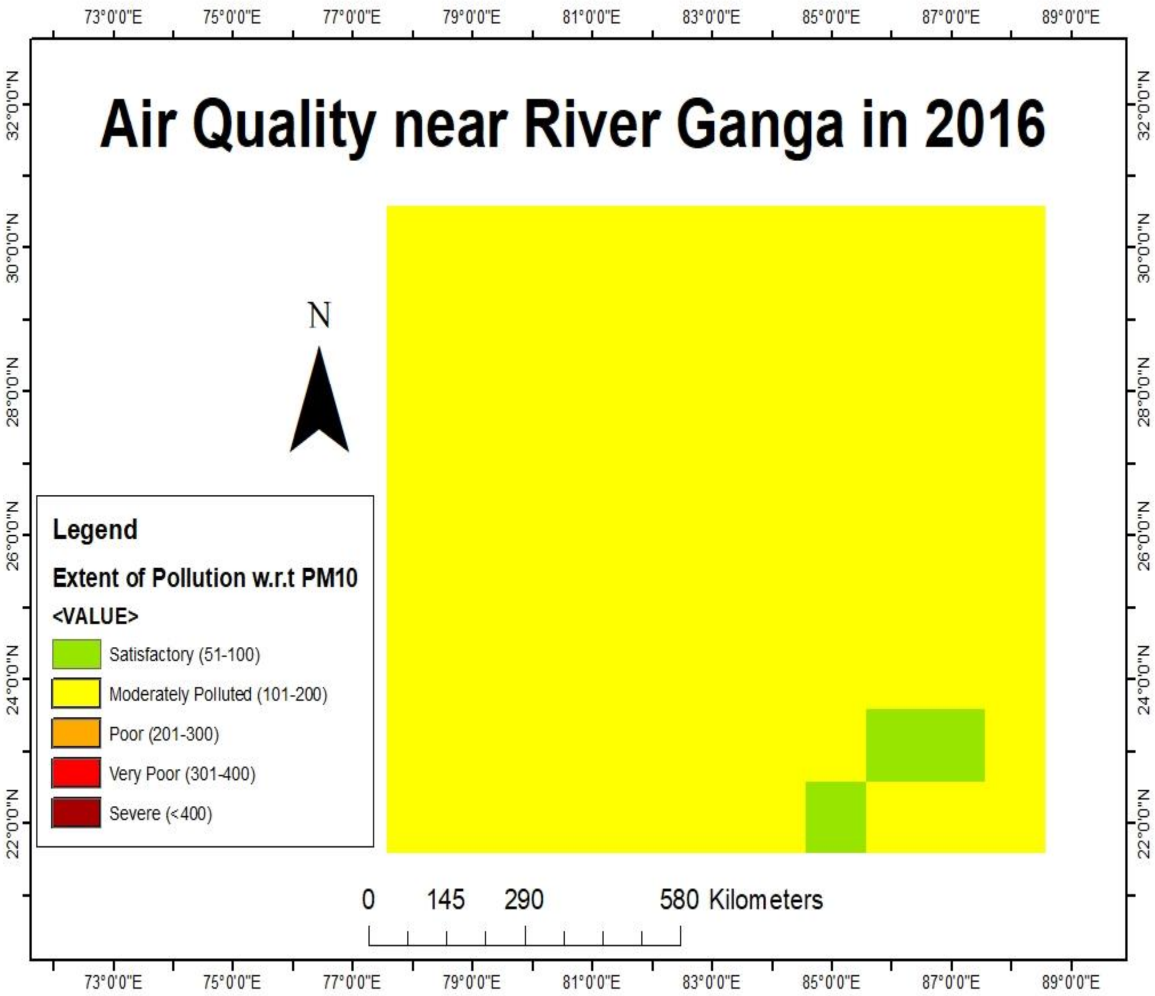

Figure 4.11 Air Quality near River Ganga w.r.t PM_{10} in 2016

4.1.11 Sulphur Dioxide (SO_2)

The sulphur dioxide concentration in the study area has a sub-index score of 0-50 which shows that the air quality w.r.t SO_2 falls under good quality. The concentration varies from 0 to 40 $\mu g/m^3$ in 2016 at study area. The mean concentration of SO_2 in the central IGB at Patna in the state of Bihar is 5.9 ± 4.8 $\mu g/m^3$ during 2013 and 2014(Tiwari *et al.*, 2016) shows that the state of Bihar has good air quality w.r.t SO_2.

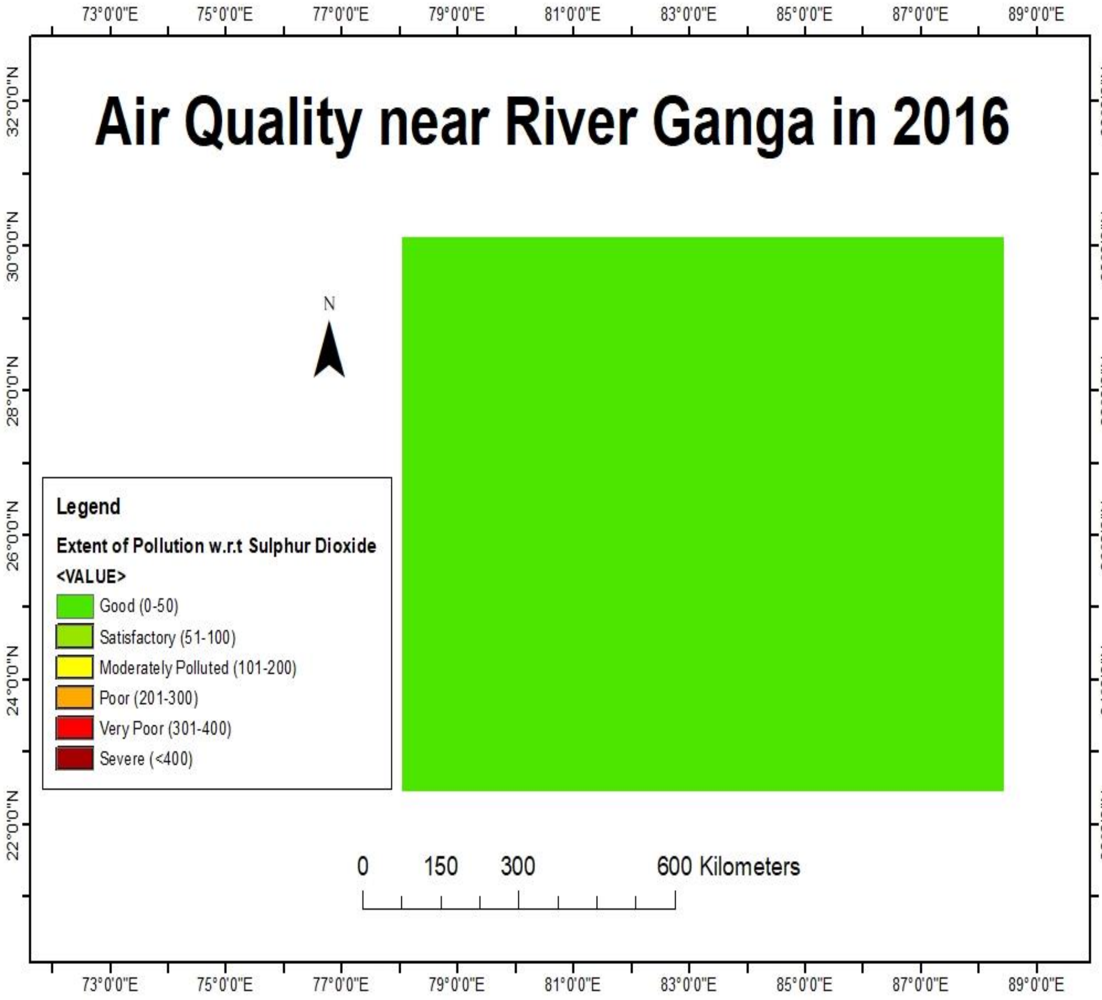

Figure 4.12 Air Quality near River Ganga w.r.t SO_2 in 2016

4.1.12 Nitrogen Dioxide (NO_2)

The nitrogen dioxide concentration in the study area has a sub-index score of 0-100 which shows that the air quality w.r.t NO_2 falls under good and satisfactory quality. The concentration varies from 0 to 80 µg/m^3 in 2016 at study area. The satisfactory air quality is observed in state of Jharkhand and West Bengal. In the remaining state good air quality is observed in 2016. The mean concentration of NO_2 in the central IGB at Patna in the state of Bihar is 20.6 ± 14.6 µg/m^3 during 2013 and 2014(Tiwari *et al.*, 2016) shows that the state of Bihar has good air quality w.r.t NO_2.

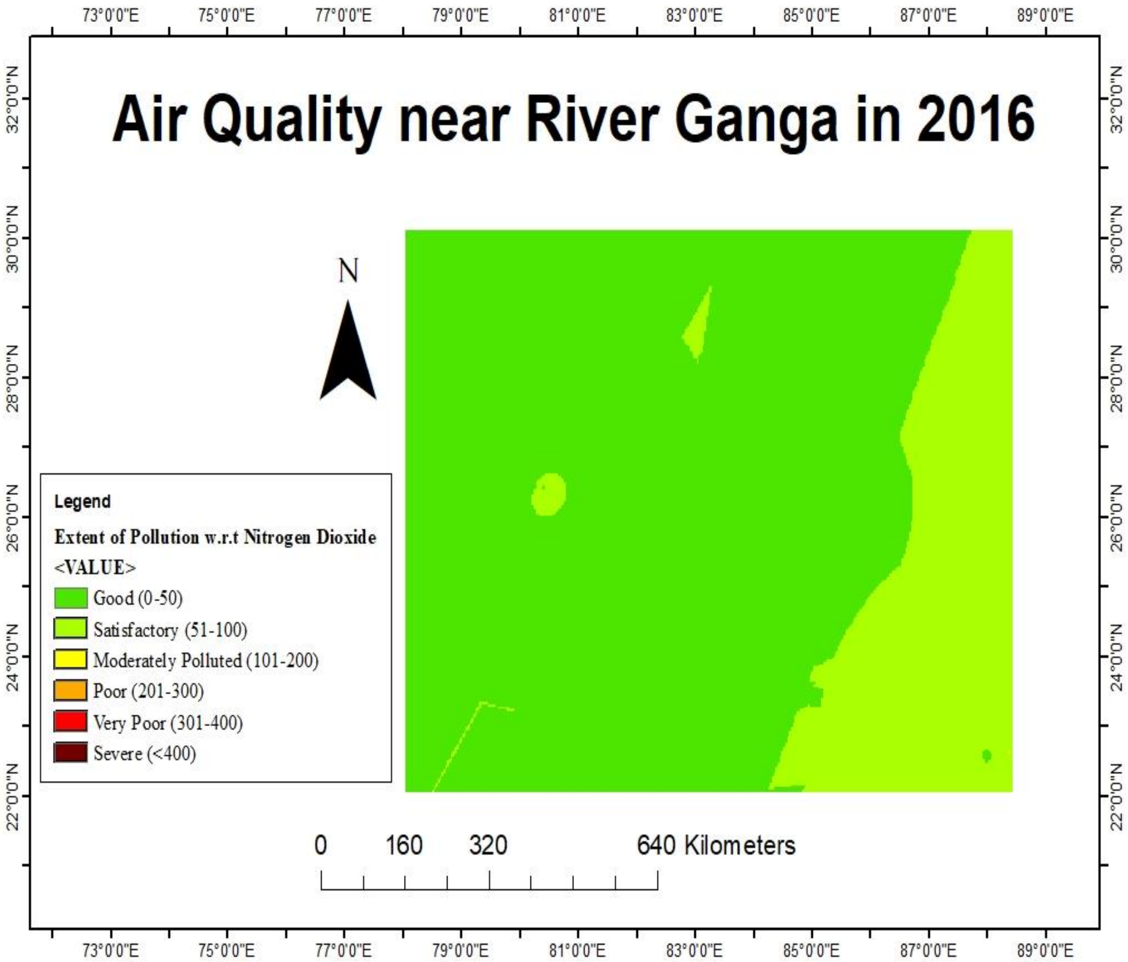

Figure 4.13 Air Quality near River Ganga w.r.t NO_2 in 2016

4.1.13 Air Quality near River Ganga

The air quality in Uttarakhand, some part of Bihar, Jharkhand and some part of West Bengal has moderately polluted air with Air Quality Index (AQI) score in the range of 101-200 in 2016 near River Ganga. The air quality near River Ganga in Uttar Pradesh and remaining part of Bihar is poor with AQI score in the range of 201-300 due to industrial emission and stubble burning. In the remaining part of West Bengal has satisfactory air quality with AQI score in the range of 51-100 due to dispersion of pollutants by winds near coastal areas.

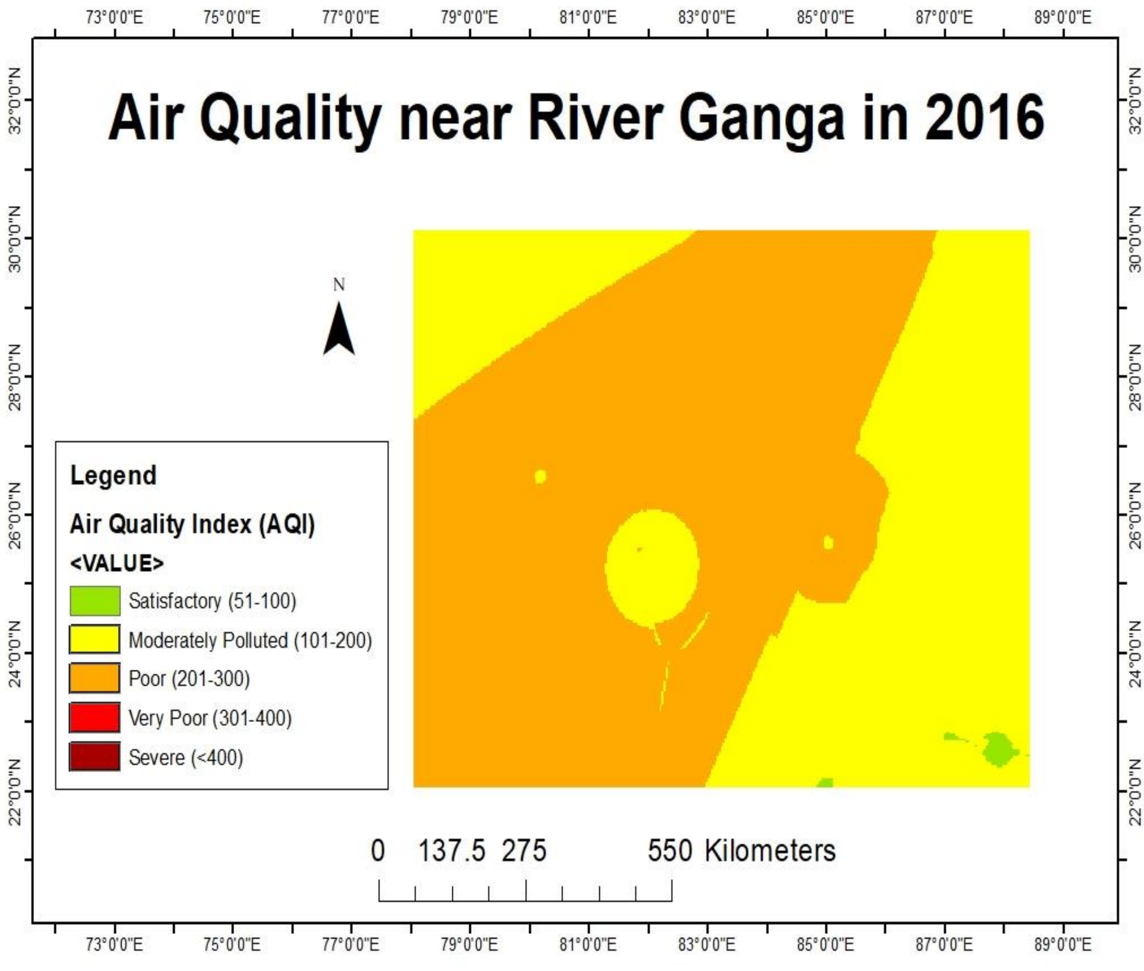

Figure 4.14 Air Quality near River Ganga in 2016

4.2 BASIC STATISTICAL ANALYSIS OF RIVER GANGA AND ITS NEARBY AREAS IN 2016

4.2.1 pH

The mean, standard deviation and variance of pH for water quality analysis of River Ganga in 2016 is 7.7484, 0.2534 and 0.0642 respectively. The Anderson-Darling Normality test gives the A-squared and P-value as 1.50 and less than 0.005 respectively. The pH doesn't follow the normal distribution as its P-value is less than significance level.

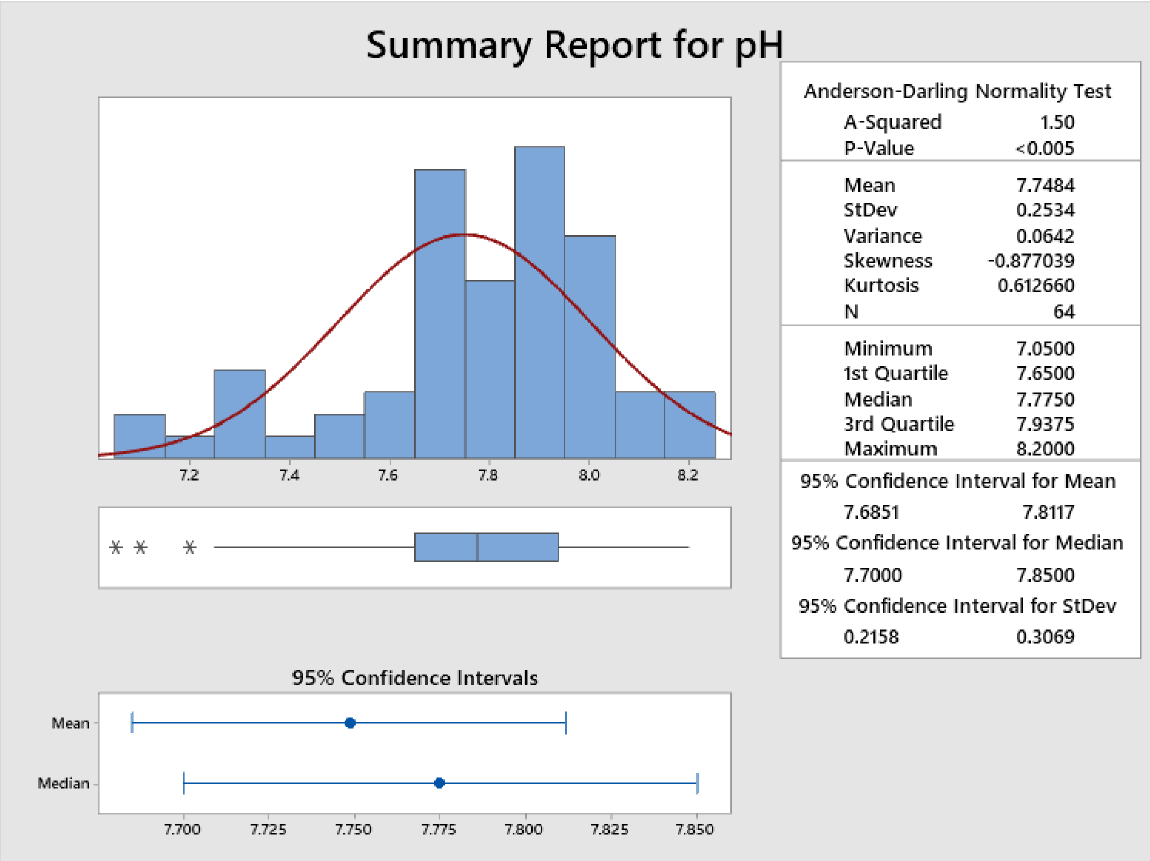

Figure 4.15 Graphical Representation of Basic Statistical Analysis for WQ w.r.t pH of River Ganga in 2016

4.2.2 Electrical Conductivity (EC)

The mean, standard deviation and variance of EC for water quality analysis of River Ganga in 2016 is 470.33, 881.66 and 777315.99 μmhos/cm respectively. The Anderson-Darling Normality test gives the A-squared and P-value as 15.72 and less than 0.005 respectively. The EC doesn't follow the normal distribution as its P-value is less than significance level.

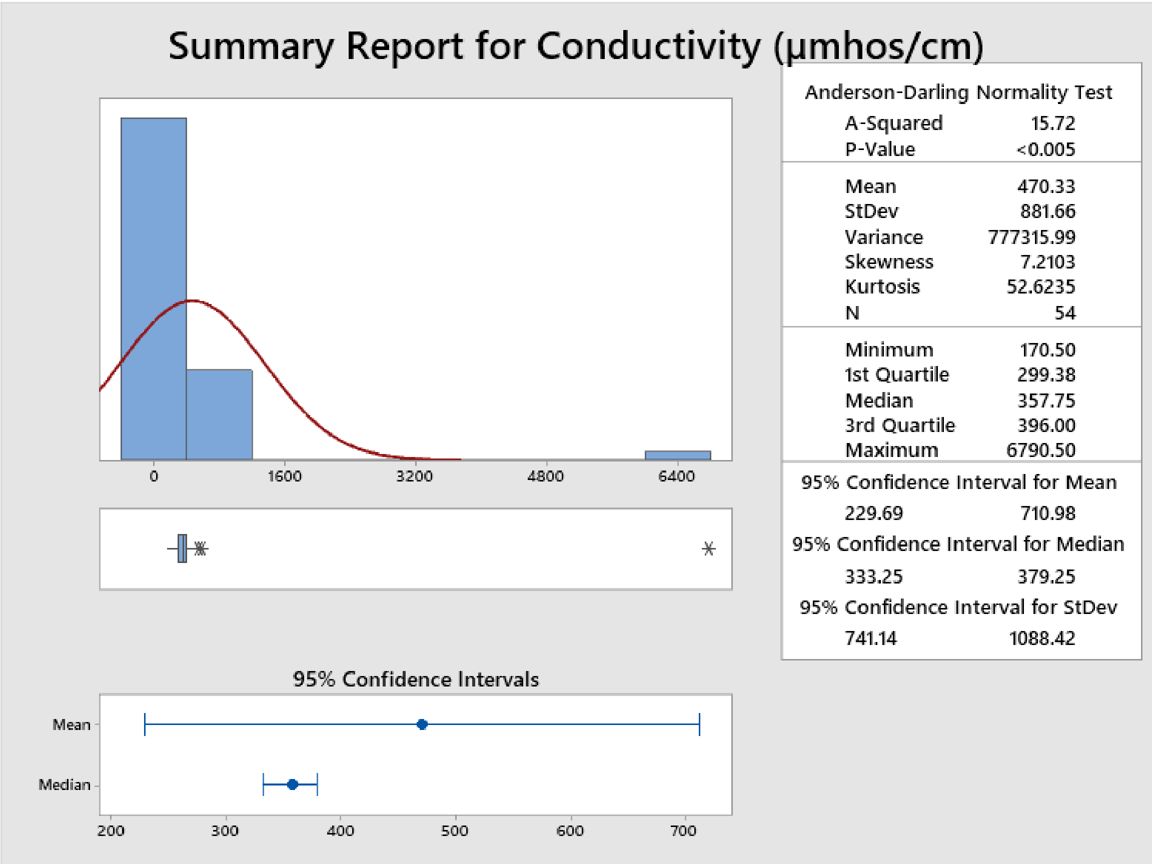

Figure 4.16 Graphical Representation of Basic Statistical Analysis for WQ w.r.t EC of River Ganga in 2016

4.2.3 Temperature

The mean, standard deviation and variance of temperature for water quality analysis of River Ganga in 2016 is 22.890, 3.996 and 15.966˚C respectively. The Anderson-Darling Normality test gives the A-squared and P-value as 0.92 and 0.018 respectively. The temperature doesn't follow the normal distribution as its P-value is less than significance level.

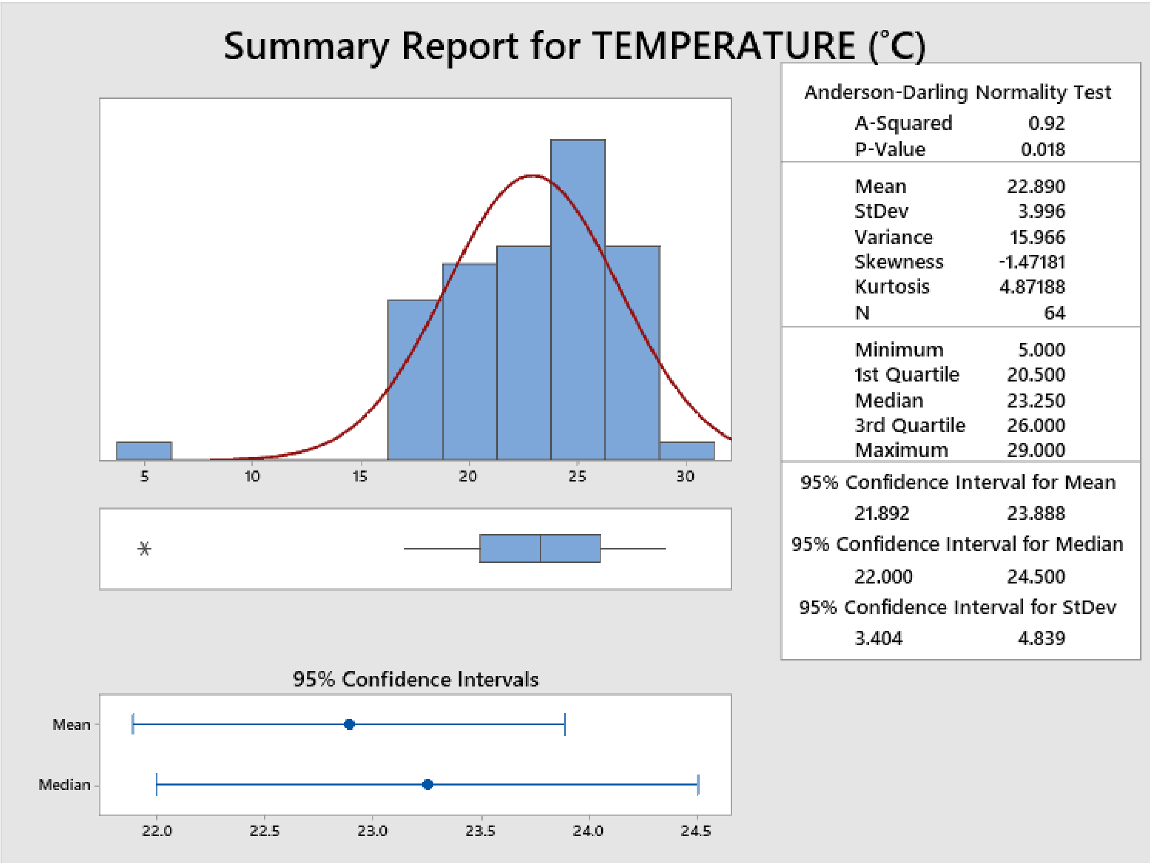

Figure 4.17 Graphical Representation of Basic Statistical Analysis for WQ w.r.t Temperature of River Ganga in 2016

4.2.4 Nitrate-N

The mean, standard deviation and variance of Nitrate-N for water quality analysis of River Ganga in 2016 is 0.22500, 0.34203 and 0.11698 mg/L respectively. The Anderson-Darling Normality test gives the A-squared and P-value as 7.41 and less than 0.005 respectively. The Nitrate-N doesn't follow the normal distribution as its P-value is less than significance level.

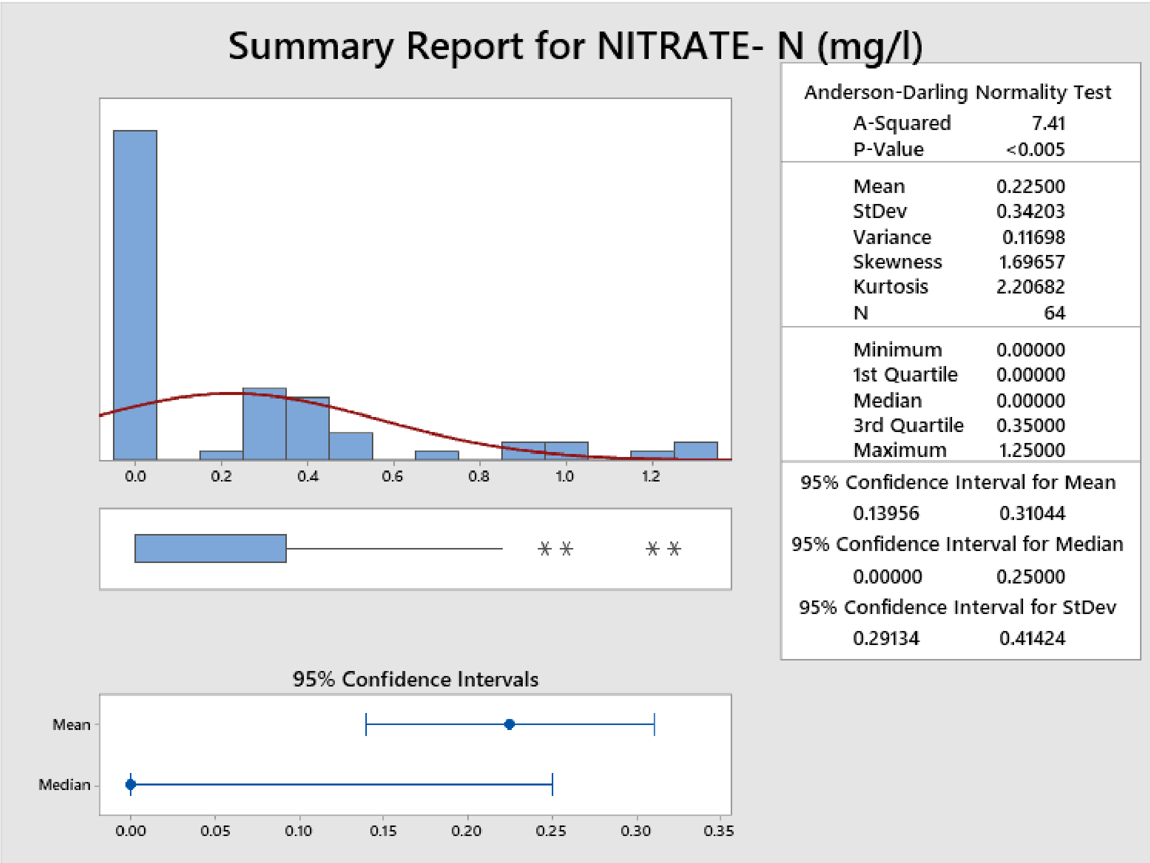

Figure 4.18 Graphical Representation of Basic Statistical Analysis for WQ w.r.t Nitrate-N of River Ganga in 2016

4.2.5 Dissolved Oxygen (DO)

The mean, standard deviation and variance of DO for water quality analysis of River Ganga in 2016 is 7.8801, 0.9809 and 0.9622 mg/L respectively. The Anderson-Darling Normality test gives the A-squared and P-value as 0.67 and 0.078 respectively. The DO follow the normal distribution as its P-value is more than significance level.

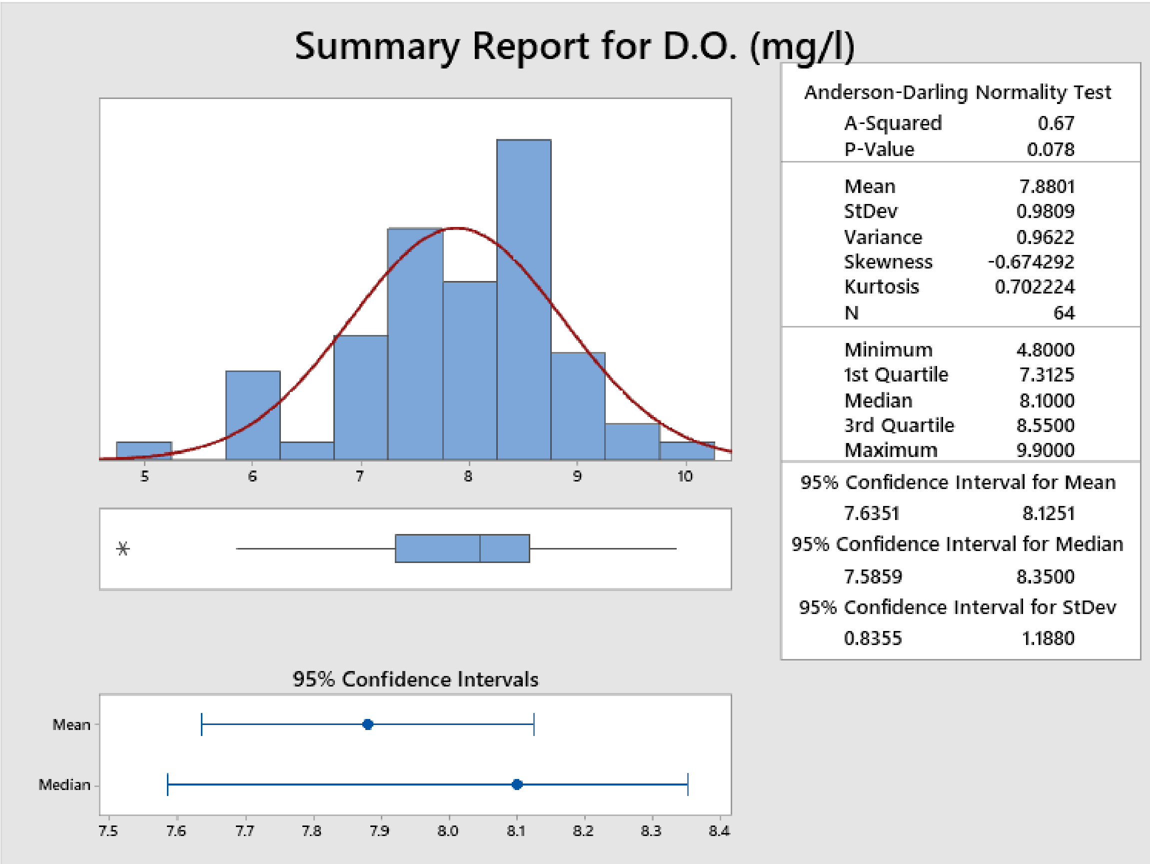

Figure 4.19 Graphical Representation of Basic Statistical Analysis for WQ w.r.t DO of River Ganga in 2016

4.2.6 Biochemical Oxygen Demand (BOD)

The mean, standard deviation and variance of BOD for water quality analysis of River Ganga in 2016 is 2.9476, 1.2951 and 1.6772 mg/L respectively. The Anderson-Darling Normality test gives the A-squared and P-value as 2.25 and less than 0.005 respectively. The BOD doesn't follow the normal distribution as its P-value is less than significance level.

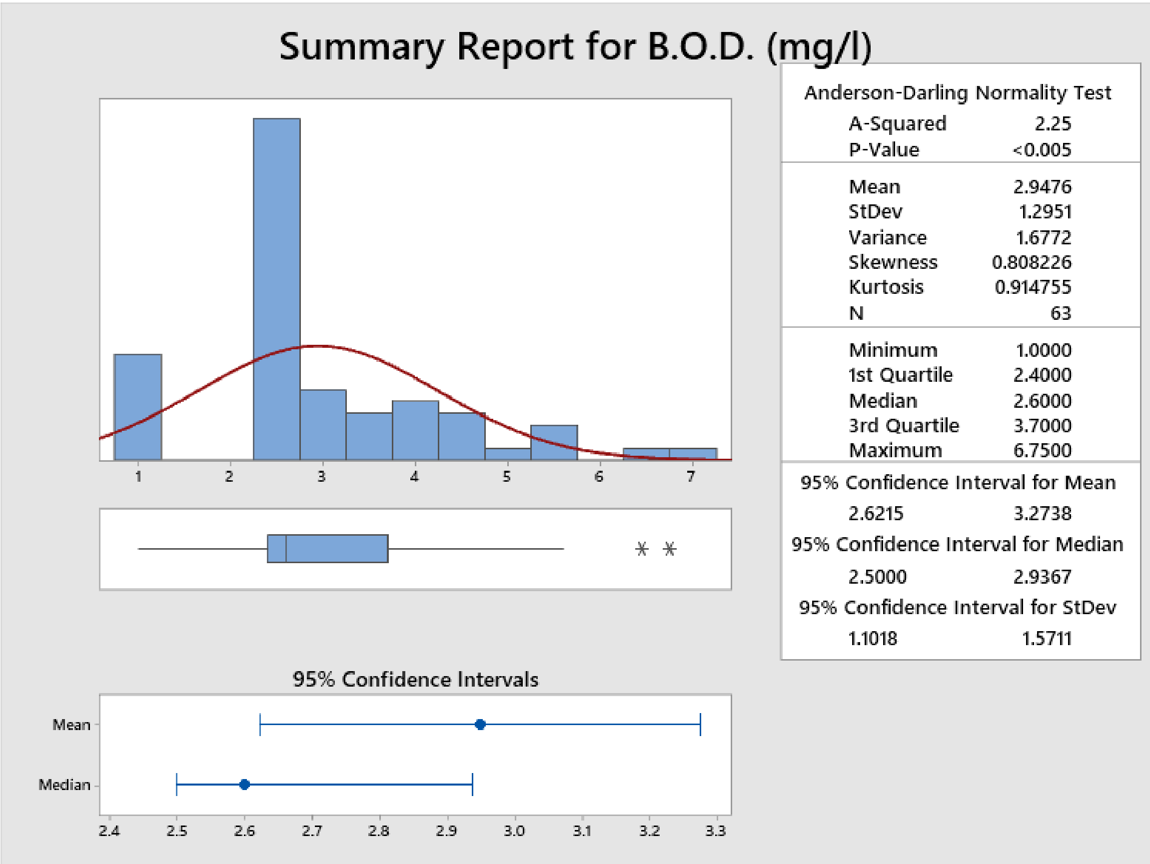

Figure 4.20 Graphical Representation of Basic Statistical Analysis for WQ w.r.t BOD of River Ganga in 2016

4.2.7 Faecal Coliform (FC)

The mean, standard deviation and variance of FC for water quality analysis of River Ganga in 2016 is 24442, 46207 and 2135068826 MPN/100 mL respectively. The Anderson-Darling Normality test gives the A-squared and P-value as 10.35 and less than 0.005 respectively. The FC doesn't follow the normal distribution as its P-value is less than significance level.

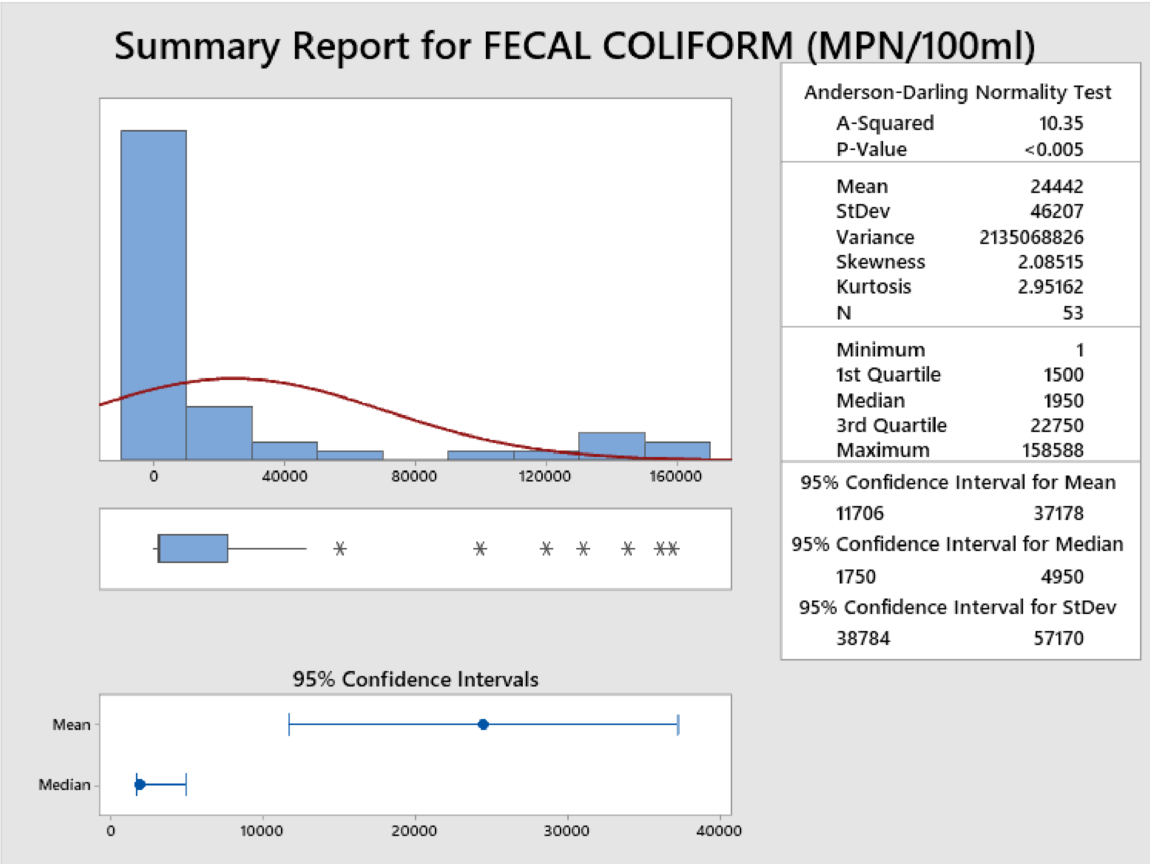

Figure 4.21 Graphical Representation of Basic Statistical Analysis for WQ w.r.t FC of River Ganga in 2016

4.2.8 Total Coliform (TC)

The mean, standard deviation and variance of TC for water quality analysis of River Ganga in 2016 is 38116, 69130 and 4778908180 MPN/100 mL respectively. The Anderson-Darling Normality test gives the A-squared and P-value as 9.87 and less than 0.005 respectively. The TC doesn't follow the normal distribution as its P-value is less than significance level.

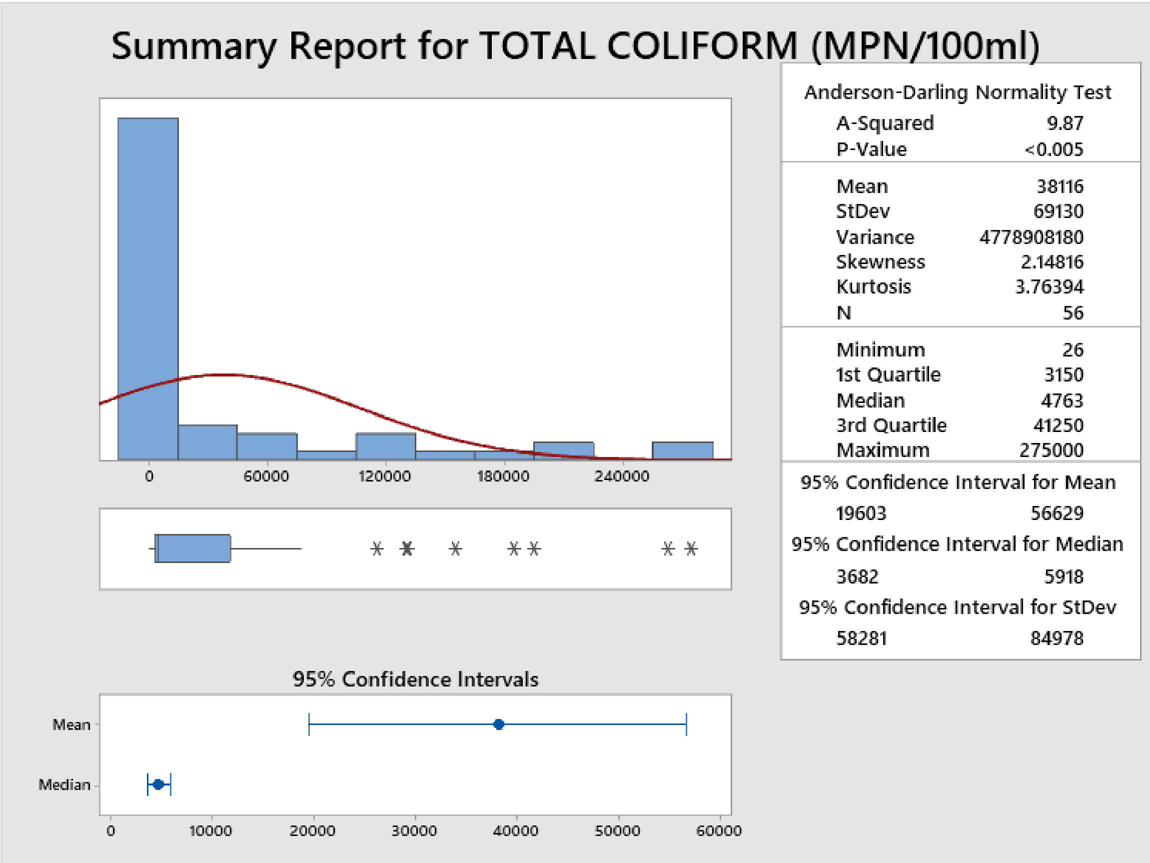

Figure 4.22 Graphical Representation of Basic Statistical Analysis for WQ w.r.t TC of River Ganga in 2016

4.2.9 Water Quality Index (WQI)

The mean, standard deviation and variance of WQI for water quality analysis of River Ganga in 2016 is 79.470, 11.288 and 127.418 respectively. The Anderson-Darling Normality test gives the A-squared and P-value as 2.94 and less than 0.005 respectively. The WQI doesn't follow the normal distribution as its P-value is less than significance level.

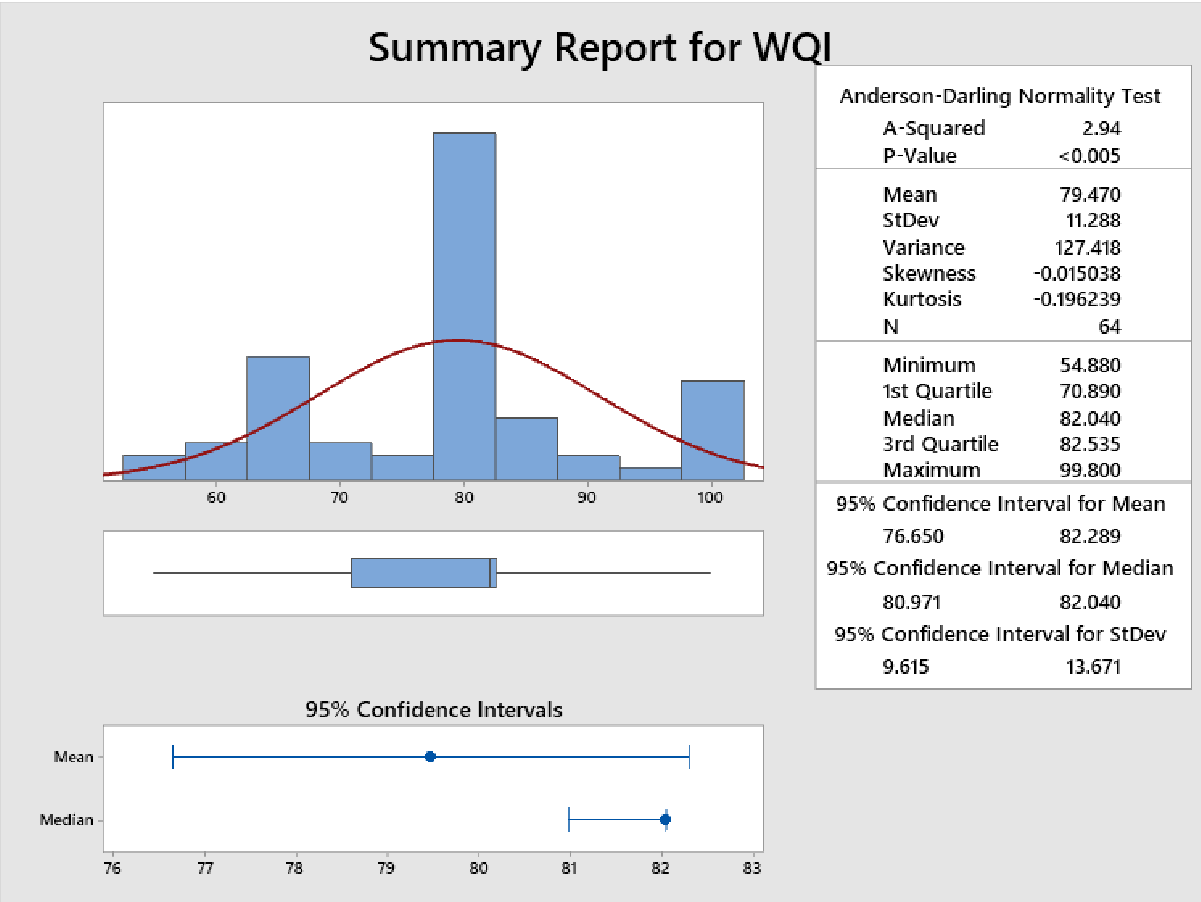

Figure 4.23 Graphical Representation of Basic Statistical Analysis for WQ w.r.t WQI of River Ganga in 2016

4.2.10 Sulphur Dioxide (SO_2)

The mean, standard deviation and variance of SO_2 for ambient air quality analysis near River Ganga in 2016 is 8.1000, 5.6013 and 31.3744 μg/m^3 respectively. The Anderson-Darling Normality test gives the A-squared and P-value as 3.31 and less than 0.005 respectively. The SO_2 doesn't follow the normal distribution as its P-value is less than significance level.

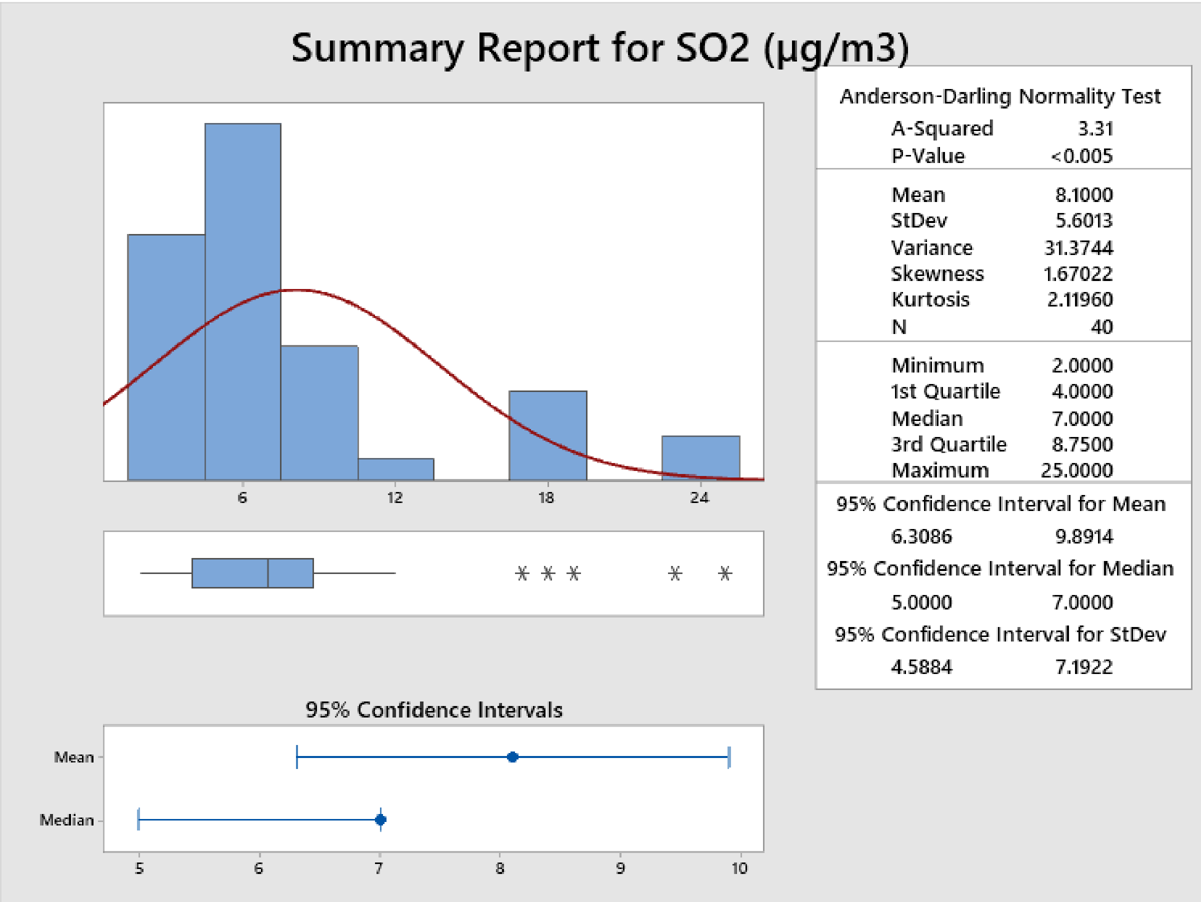

Figure 4.24 Graphical Representation of Basic Statistical Analysis for AQ w.r.t SO_2 near River Ganga in 2016

4.2.11 Nitrogen Dioxide (NO_2)

The mean, standard deviation and variance of NO_2 for ambient air quality analysis near River Ganga in 2016 is 43.350, 11.428 and 130.592 µg/m^3 respectively. The Anderson-Darling Normality test gives the A-squared and P-value as 0.94 and 0.015 respectively. The NO_2 doesn't follow the normal distribution as its P-value is less than significance level.

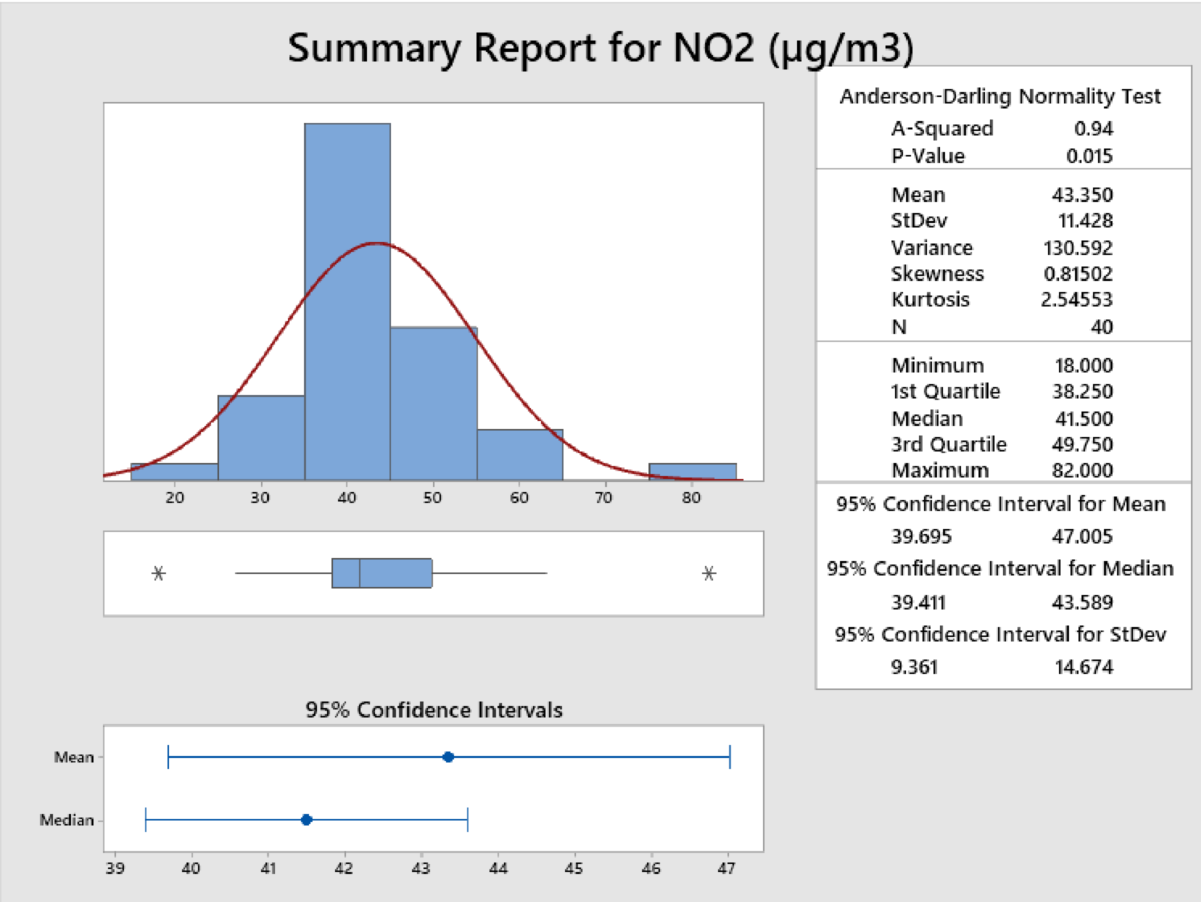

Figure 4.25 Graphical Representation of Basic Statistical Analysis for AQ w.r.t NO_2 near River Ganga in 2016

4.2.12 PM_{10}

The mean, standard deviation and variance of PM_{10} for ambient air quality analysis near River Ganga in 2016 is 146.18, 56.70 and 3214.92 µg/m^3 respectively. The Anderson-Darling Normality test gives the A-squared and P-value as 1.58 and less than 0.005 respectively. The PM_{10} doesn't follow the normal distribution as its P-value is less than significance level.

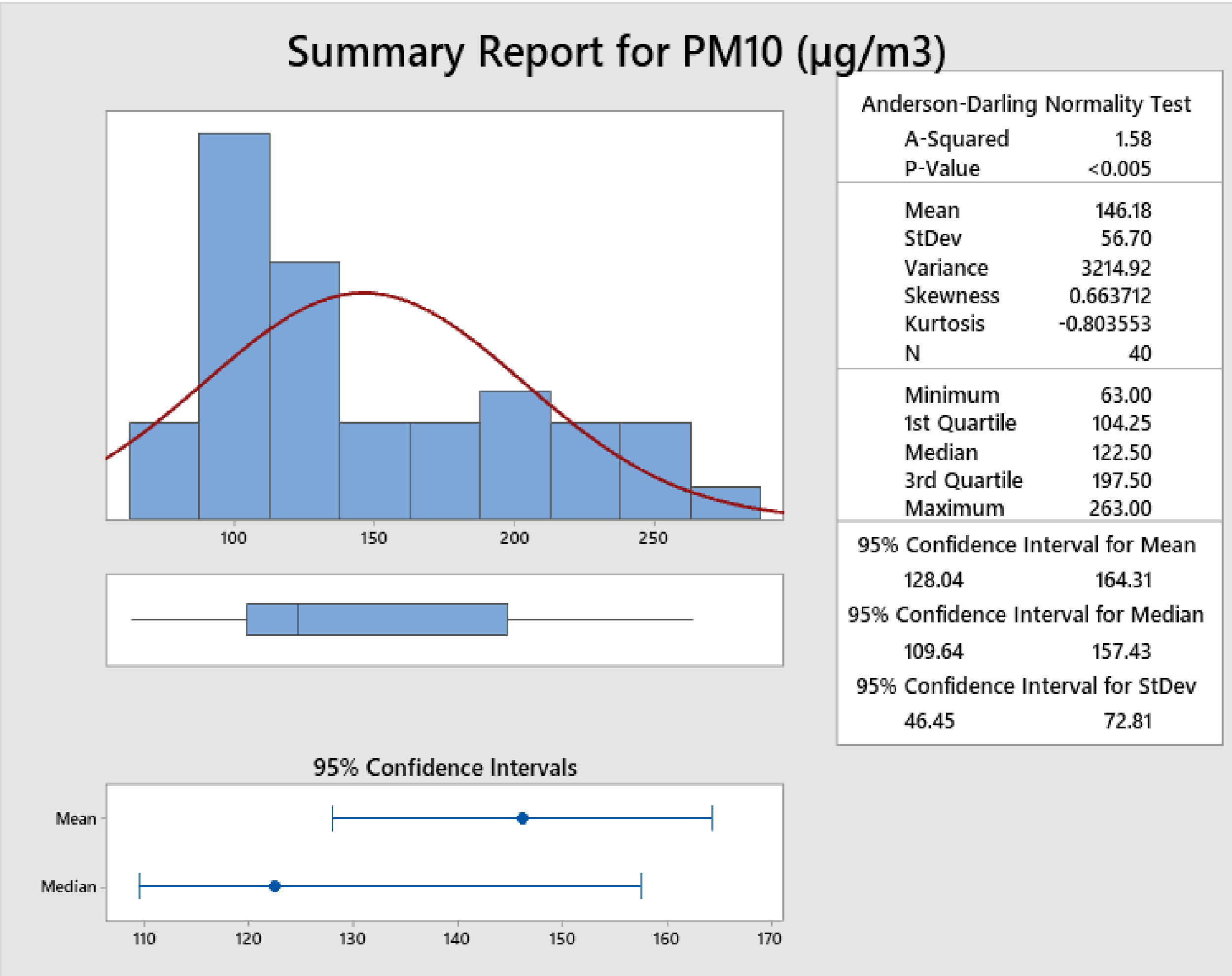

Figure 4.26 Graphical Representation of Basic Statistical Analysis for AQ w.r.t PM_{10} near River Ganga in 2016

4.2.13 $PM_{2.5}$

The mean, standard deviation and variance of $PM_{2.5}$ for ambient air quality analysis near River Ganga in 2016 is 63.714, 10.704, 114.571 µg/m^3 respectively. The Anderson-Darling Normality test gives the A-squared and P-value as 0.52 and 0.121 respectively. The $PM_{2.5}$ follow the normal distribution as its P-value is more than significance level.

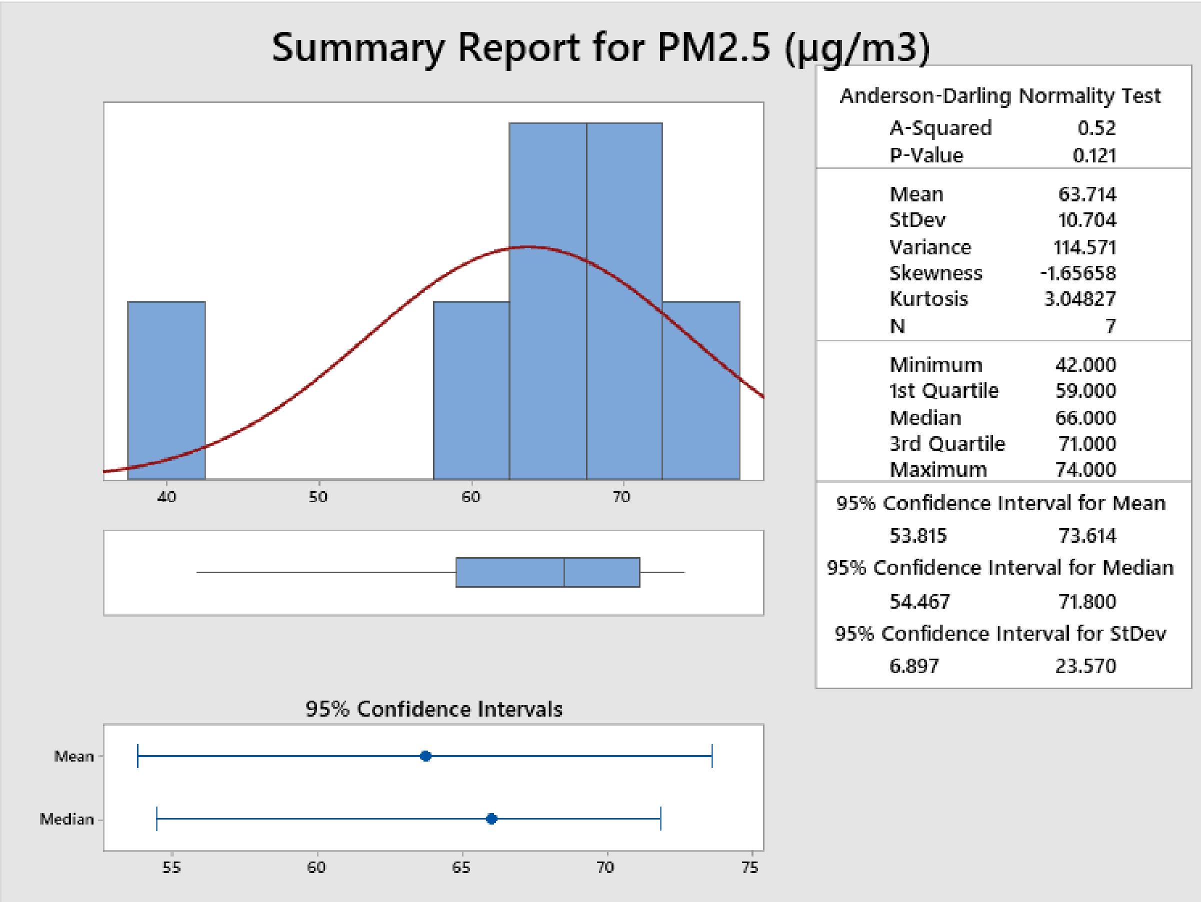

Figure 4.27 Graphical Representation of Basic Statistical Analysis for AQ w.r.t $PM_{2.5}$ near River Ganga in 2016

4.2.14 Ambient Air Quality Index (AQI)

The mean, standard deviation and variance of AQI for ambient air quality analysis near River Ganga in 2016 is 146.18, 56.70 and 3214.92 respectively. The Anderson-Darling Normality test gives the A-squared and P-value as 1.58 and less than 0.005 respectively. The AQI doesn't follow the normal distribution as its P-value is less than significance level.

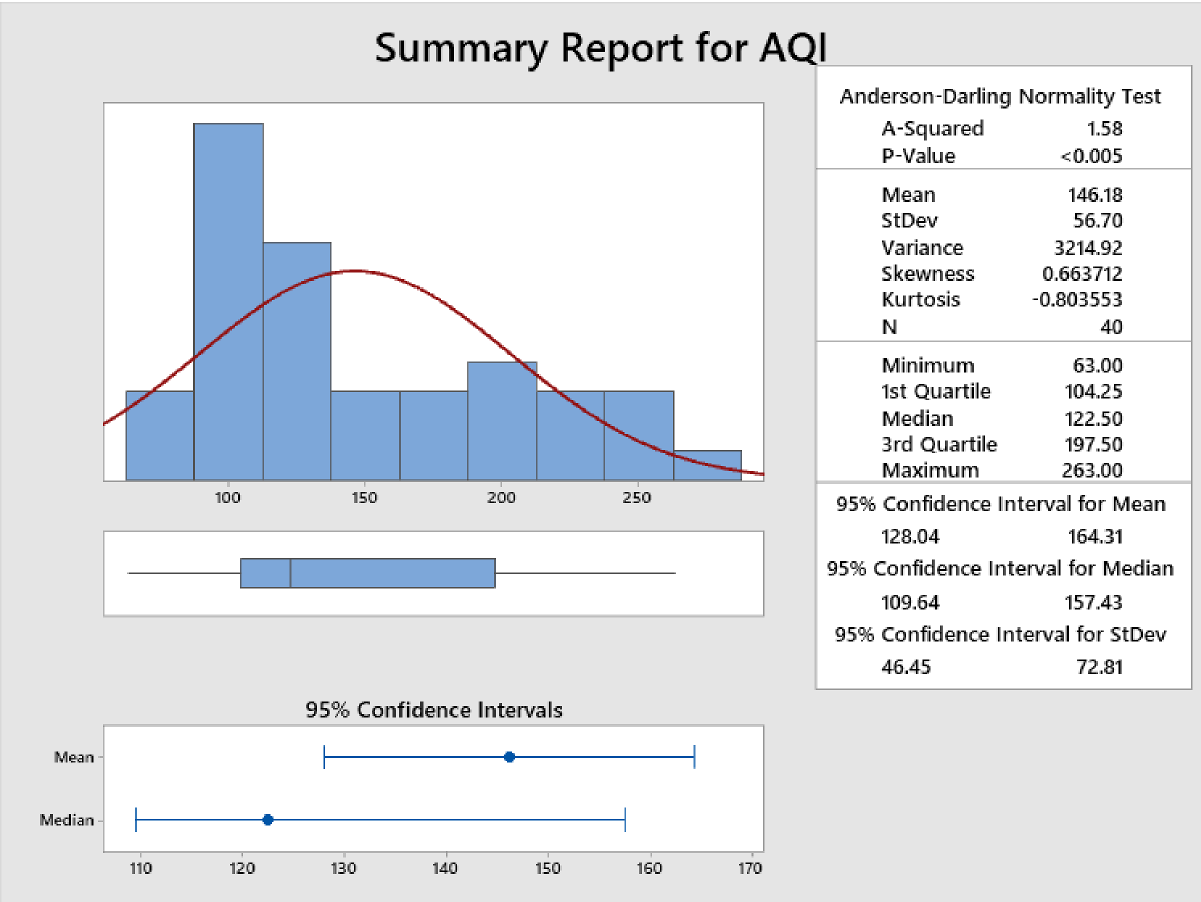

Figure 4.28 Graphical Representation of Basic Statistical Analysis for AQ w.r.t AQI near River Ganga in 2016

4.3 MULTIVARIATE STATISTICAL ANALYSIS OF RIVER GANGA AND ITS NEARBY AREAS IN 2016

4.3.1 Principal Component Analysis (PCA) for Water Quality (WQ) of River Ganga in 2016

The first principal component has the Eigen value of 3.6575 and accounts for 45.7% of total variance (shown in Table 4.1). The first principal component score is calculated and shown in Table 4.2 as PC1 = +0.376 Temperature -0.408 DO +0.187 pH +0.142 Conductivity +0.381 BOD +0.287 Nitrate-N +0.441 Faecal Coliform +0.463 Total Coliform. The interpretation of principal component is a subjective as the first principal component is representing an overall Temperature, pH, Conductivity, BOD, Nitrate-N, Faecal Coliform and Total Coliform because the coefficient of these parameters have positive sign and are not close to zero. The second principal component has variance 1.4118 and accounts for 17.6% of the data unevenness. The first two, three and four components together accounts for 63.4%, 75.8% and 87% respectively of the total data unevenness. Thus, most of the data structure can be encapsulated under two or three key elements and the remaining accounts for a little importance due to very small proportion of variability.

The components whose Eigen values greater than 1 are considered as Principal Component and are essential. The first component which contribute 45.7% data variability has a strong positive load on temperature, pH, Conductivity, BOD, Nitrate, Faecal Coliform and Total Coliform may be due to discharge of untreated sewage and defecating near and in River which leads to moderately pollution of stream. The second component which account for 17.6% data variance have a strong positive loading on Temperature, pH, Conductivity and BOD which may be due to disposal of organic waste into river. Both components have negative load on DO due to ecological balance of aquatic system. Nitrate-N, Faecal Coliform and Total Coliform could be considered as non-principal component as it has less importance in explaining the annual variance of data set.

Components 1 and 2 account for 57.8% and 13.8% of total variance of data set and have strong positive load on pH and DO, pH, TS, TSS and TDS respectively. The physico-chemical parameters like pH, TS, TSS and TDS are less importance in nature and could be consider as non-principal component (Kumar, Kaushal and Nigam, 2016).

Table 4.1 Eigen Analysis of the Correlation Matrix for WQ

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
Eigenvalue	3.6575	1.4118	0.9924	0.8980	0.3986	0.3291	0.2923	0.0203
Proportion	0.457	0.176	0.124	0.112	0.050	0.041	0.037	0.003
Cumulative	0.457	0.634	0.758	0.870	0.920	0.961	0.997	1.000

Table 4.2 Eigenvectors of the Correlation Matrix for WQ

Variable	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
TEMPERATURE (˚C)	0.376	0.131	0.450	-0.288	0.134	-0.709	-0.190	-0.004
D.O. (mg/l)	-0.408	-0.022	0.266	0.377	-0.272	-0.418	0.605	-0.082
pH	0.187	0.382	0.608	0.517	0.039	0.395	-0.155	0.022
Conductivity (µmhos/cm)	0.142	0.690	-0.257	-0.182	-0.630	-0.016	0.043	-0.071
B.O.D. (mg/l)	0.381	0.324	-0.300	0.121	0.556	-0.026	0.571	0.098
NITRATE- N (mg/l)	0.287	-0.149	-0.422	0.674	-0.131	-0.346	-0.352	-0.050
FAECAL COLIFORM (MPN/100ml)	0.441	-0.359	0.113	-0.036	-0.390	0.111	0.249	0.660
TOTAL COLIFORM (MPN/100ml)	0.463	-0.323	0.102	-0.070	-0.175	0.184	0.248	-0.735

4.3.2 Factor Analysis (FA) for Water Quality (WQ) of River Ganga in 2016

The first and second factor has a variance of 3.6575 and 1.4118 and accounts for 45.7% and 17.6% data variation respectively (shown in Table 4.3). Factor 1 has factor coefficient strongly positive load with the all water quality parameters except DO and Factor 2 has positive load with only water quality parameters like temperature, pH, Conductivity and BOD. The coefficient of Factor 1 has score equals to +0.917 Temperature, -0.213 DO, +0.098 pH, +0.074 Conductivity, +0.199 BOD, +0.150 Nitrate-N, +0.231 FC and +0.242 TC (shown in Table 4.4). Similar to the PCA the

FA also shows that parameters like Nitrate-N, TC and FC have less importance in the present water quality status.

Table 4.3 Unrotated Factor Loadings and Communalities for WQ

Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Factor 8	Communality
TEMPERATURE (˚C)	0.719	0.156	0.448	-0.273	0.084	-0.406	-0.103	-0.000	1.000
D.O. (mg/l)	-0.780	-0.026	0.265	0.357	-0.172	-0.240	0.327	-0.012	1.000
pH	0.358	0.454	0.606	0.490	0.025	0.227	-0.084	0.003	1.000
Conductivity (µmhos/cm)	0.271	0.820	-0.256	-0.173	-0.398	-0.009	0.024	-0.010	1.000
B.O.D. (mg/l)	0.728	0.385	-0.299	0.115	0.351	-0.015	0.308	0.014	1.000
NITRATE- N (mg/l)	0.549	-0.177	-0.420	0.639	-0.083	-0.199	-0.190	-0.007	1.000
FECAL COLIFORM (MPN/100ml)	0.844	-0.427	0.113	-0.034	-0.246	0.064	0.134	0.094	1.000
TOTAL COLIFORM (MPN/100ml)	0.886	-0.384	0.102	-0.067	-0.111	0.105	0.134	-0.105	1.000
Variance	3.6575	1.4118	0.9924	0.8980	0.3986	0.3291	0.2923	0.0203	8.0000
% Var	0.457	0.176	0.124	0.112	0.050	0.041	0.037	0.003	1.000

Table 4.4 Factor Score Coefficients for WQ

Variable	Factor1	Factor2	Factor3	Factor4	Factor5	Factor6	Factor7	Factor8
TEMPERATURE (˚C)	0.197	0.110	0.452	-0.304	0.212	-1.235	-0.352	-0.025
D.O. (mg/l)	-0.213	-0.019	0.267	0.398	-0.430	-0.728	1.118	-0.579
pH	0.098	0.322	0.610	0.545	0.062	0.689	-0.287	0.155
Conductivity (µmhos/cm)	0.074	0.581	-0.258	-0.193	-0.999	-0.028	0.080	-0.501
B.O.D. (mg/l)	0.199	0.272	-0.302	0.128	0.881	-0.046	1.055	0.688
NITRATE- N (mg/l)	0.150	-0.125	-0.423	0.711	-0.208	-0.604	-0.650	-0.355
FECAL COLIFORM (MPN/100ml)	0.231	-0.302	0.114	-0.038	-0.618	0.193	0.460	4.639
TOTAL COLIFORM (MPN/100ml)	0.242	-0.272	0.102	-0.074	-0.277	0.320	0.458	-5.162

4.3.3 Principal Component Analysis (PCA) for Ambient Air Quality (AQ) near River Ganga in 2016

The first principal component has the Eigen value of 2.6235 and accounts for 65.6% of total variance (shown in Table 4.5). The first principal component score is calculated and shown in Table 4.6 as PC1 = -0.544 SO_2, +0.233 NO_2, +0.522 PM_{10} and +0.614 $PM_{2.5}$. The interpretation of principal component is a subjective as the first principal component is representing an overall Nitrogen Dioxide and Particulate Matter of aerodynamic size of less than 10 microns i.e. PM_{10} and $PM_{2.5}$ because the coefficient of these parameters have positive sign and are not close to zero. The first two components together accounts for 89.7% of the total data unevenness. Thus, most of the data structure can be encapsulated under two key elements and the remaining accounts for a little importance due to very small proportion of variability.

The components whose Eigen values greater than 1 are considered as Principal Component and are essential. The first component which contribute 65.6% data variability has a strong positive load on $NO_{2,}$ PM_{10} and $PM_{2.5}$ may be due to vehicular pollution. $PM_{2.5}$ could be considered as non-principal component as it has less importance in explaining the annual variance of data set.

Table 4.5 Eigen Analysis of the Correlation Matrix for AQ

	PC1	**PC2**	**PC3**	**PC4**
Eigenvalue	2.6235	0.9646	0.3966	0.0153
Proportion	0.656	0.241	0.099	0.004
Cumulative	0.656	0.897	0.996	1.000

Table 4.6 Eigenvectors of the Correlation Matrix for AQ

Variable	**PC1**	**PC2**	**PC3**	**PC4**
SO_2 (µg/m^3)	-0.544	0.183	-0.688	0.444
NO_2 (µg/m^3)	0.233	0.941	-0.084	-0.231
PM_{10} (µg/m^3)	0.522	-0.282	-0.720	-0.359
$PM_{2.5}$ (µg/m^3)	0.614	0.045	0.035	0.787

4.3.4 Factor Analysis (FA) for Ambient Air Quality (AQ) near River Ganga in 2016

The first factor has a variance of 2.6235 and accounts for 65.6% data variation (shown in Table 4.7). Factor 1 has factor coefficient strongly positive load with the all ambient air quality parameters except SO_2. The coefficient of Factor 1 has score equals to -0.336 SO_2, +0.144 NO_2, +0.322 PM_{10} and +0.379 $PM_{2.5}$ (shown in Table 4.8). Similar to the PCA the FA also shows that $PM_{2.5}$ has less importance in the present ambient air quality status.

Table 4.7 Unrotated Factor Loadings and Communalities for AQ

Variable	Factor1	Factor2	Factor3	Factor4	Communality
SO_2 (µg/m^3)	-0.881	0.180	-0.433	0.055	1.000
NO_2 (µg/m^3)	0.378	0.924	-0.053	-0.029	1.000
PM_{10} (µg/m^3)	0.846	-0.277	-0.454	-0.044	1.000
$PM_{2.5}$ (µg/m^3)	0.994	0.044	0.022	0.097	1.000
Variance	2.6235	0.9646	0.3966	0.0153	4.0000
% Var	0.656	0.241	0.099	0.004	1.000

Table 4.8 Factor Score Coefficients for AQ

Variable	Factor1	Factor2	Factor3	Factor4
SO_2 (µg/m^3)	-0.336	0.186	-1.092	3.594
NO_2 (µg/m^3)	0.144	0.958	-0.133	-1.874
PM_{10} (µg/m^3)	0.322	-0.287	-1.143	-2.908
$PM_{2.5}$ (µg/m^3)	0.379	0.046	0.055	6.375

4.4 CORRELATION BETWEEN TEMPERATURE AND DISSOLVED OXYGEN FOR RIVER GANGA IN 2016

For the year 2016 dataset there is an inverse relationship between temperature and DO. As the temperature of the water increases there is a decrease in dissolved oxygen present in the water. At temperature 18˚C, DO available is 9 mg/L and DO present at 27˚C is 7.5 mg/L.

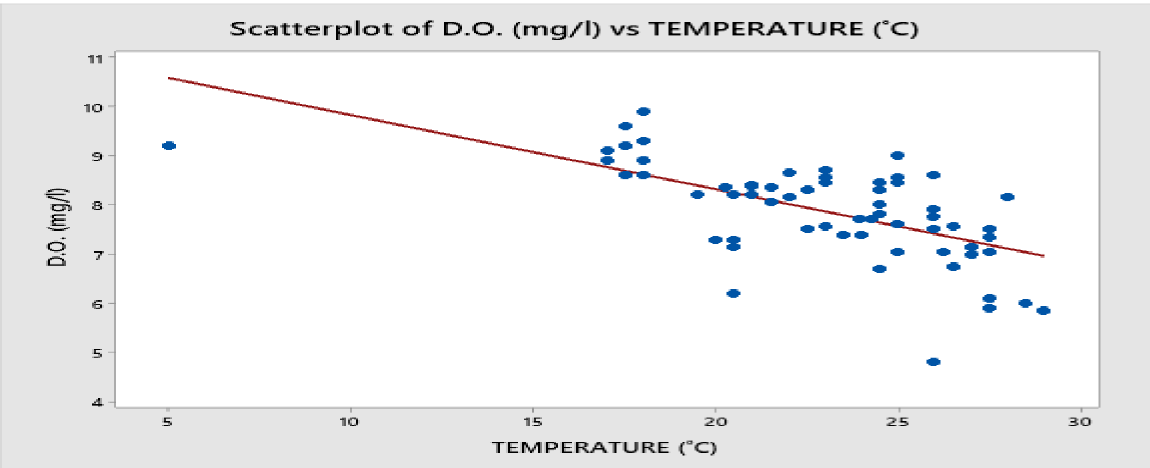

Figure 4.29 DO vs Temperature Plot

4.5 WATER QUALITY ASSESSMENT OF RIVER GANGA WITH TIME

4.5.1 Biochemical Oxygen Demand (BOD)

The water quality of River Ganga on comparative spatial analysis found that it get better day by day due to the inclusion of National Ganga River Basin Authority (NGRBA) for rejuvenation of River Ganga in 2009. It can be seen from figure 4.30 that at Varanasi the water quality changes from moderately polluted in 2007 to clean water in 2016. In the state of West Bengal the water quality slightly deteriorate from 2007 to 2016 which may have resulted due to discharge of untreated wastewater into River Ganga.

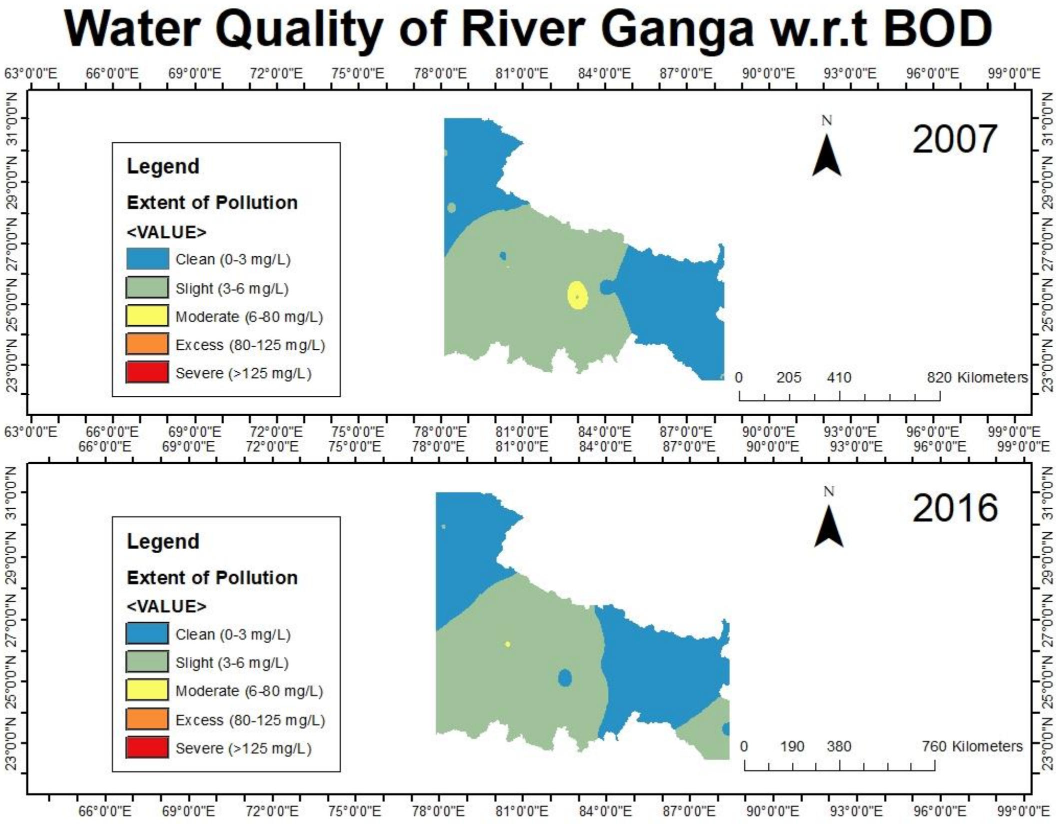

Figure 4.30 Water Quality of River Ganga w.r.t Biochemical Oxygen Demand in 2007 and 2016

4.5.2 Dissolved Oxygen (DO)

The water quality of River Ganga on comparative spatial analysis for year 2007 and 2016 found that at Kanpur the water quality changes from slightly polluted in 2007 to clean water in 2016 may be due to efforts of NGRBA for restoration of River Ganga water quality. In the state of West Bengal the water quality slightly deteriorate from 2007 to 2016 which may have resulted due to discharge of untreated wastewater into River Ganga.

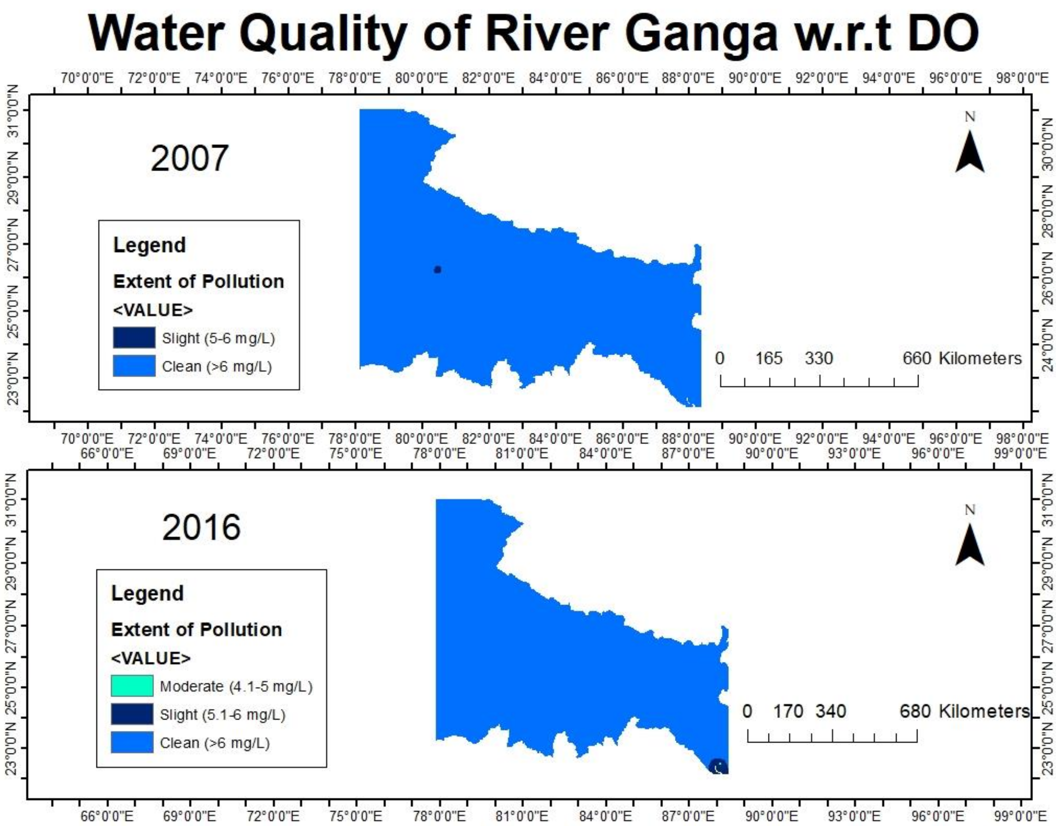

Figure 4.31 Water Quality of River Ganga w.r.t Dissolved Oxygen in 2007 and 2016

4.5.3 Electrical Conductivity (EC)

The water quality of River Ganga on comparative spatial analysis for year 2007 and 2016 found that in the state of Uttarakhand the water quality becoming better day by day while in the rest part of River Ganga Basin the water quality deteriorate may be due to increase in TDS content which may be result of floods in consecutive years.

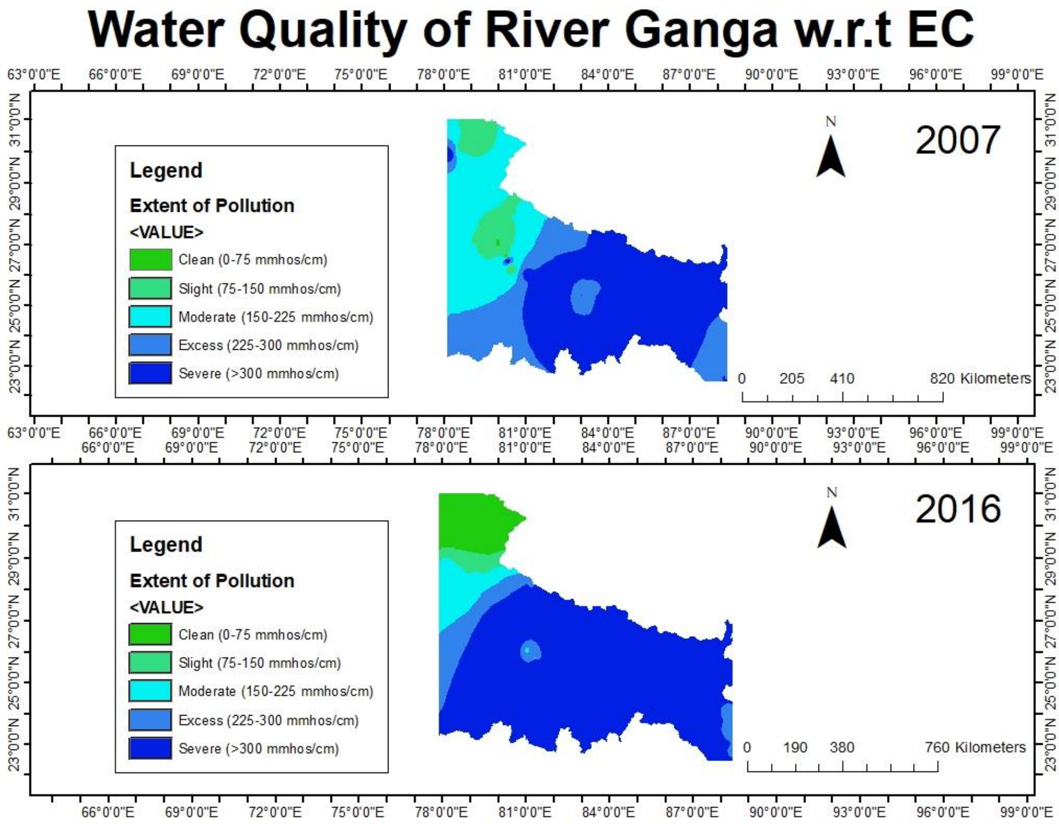

Figure 4.32 Water Quality of River Ganga w.r.t Electrical Conductivity in 2007 and 2016

4.5.4 Faecal Coliform (FC)

The water quality of River Ganga on comparative spatial analysis found that it get better day by day due to the inclusion of National Ganga River Basin Authority (NGRBA) for rejuvenation of River Ganga in 2009. It can be seen from figure 4.31 that at Bihar and Jharkhand the water quality changes from severely polluted in 2007 to excess polluted water in 2016. Also, in the state of Uttarakhand the water quality changes from excess polluted to moderately-slightly polluted.

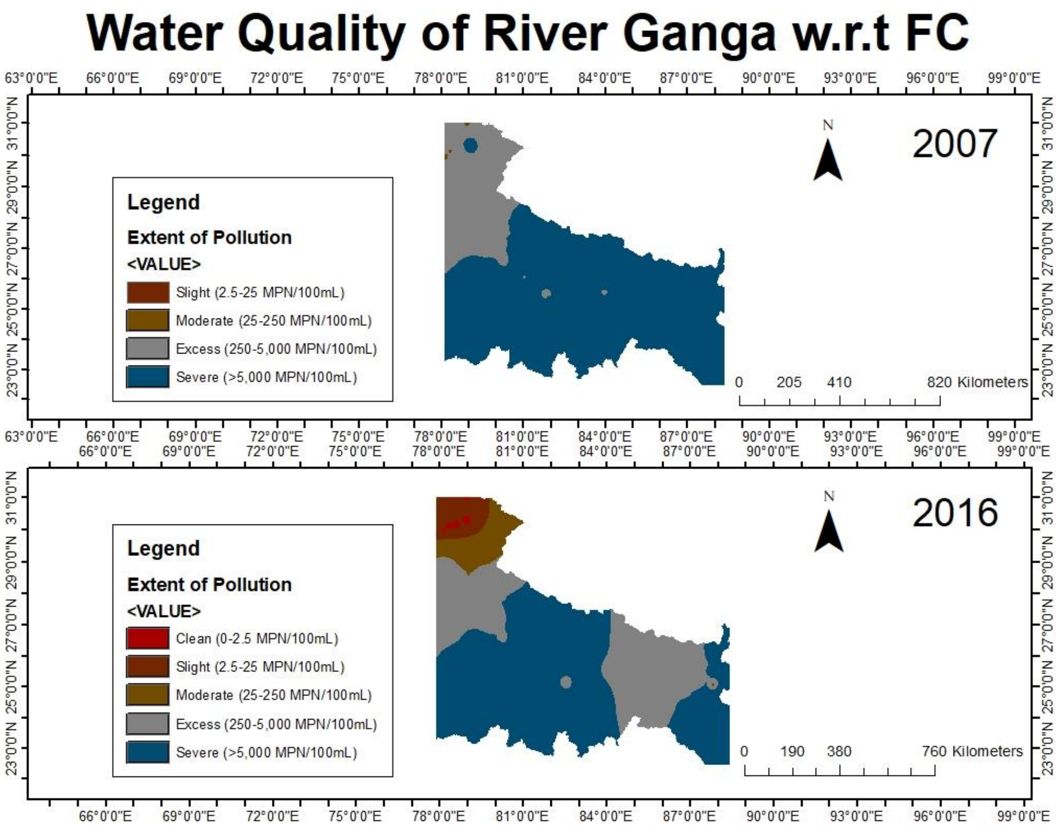

Figure 4.33 Water Quality of River Ganga w.r.t Faecal Coliform in 2007 and 2016

4.5.5 Nitrate-N and pH

It can be observed from the figure 4.34 and 4.35that the water quality of River Ganga w.r.t Nitrate-N and pH doesn't changes with time. It can be inferred that these parameters are non-principal parameters and have less impact on overall water quality of River Ganga.

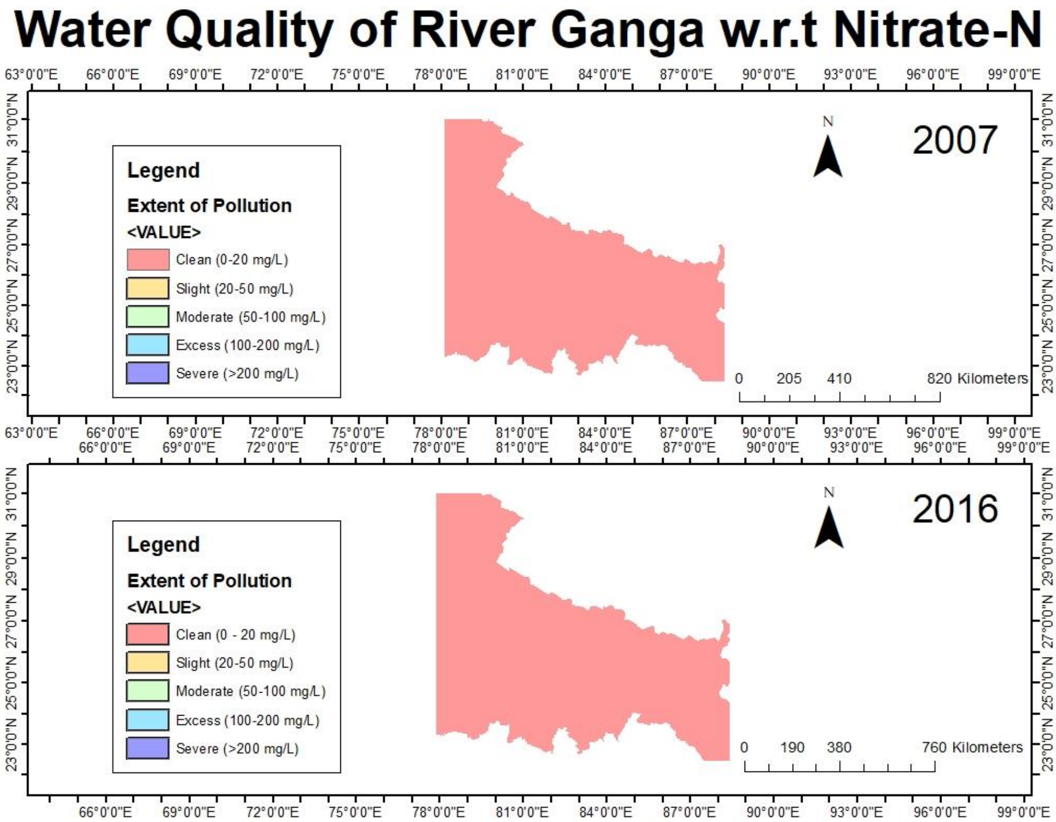

Figure 4.34 Water Quality of River Ganga w.r.t Nitrate-N in 2007 and 2016

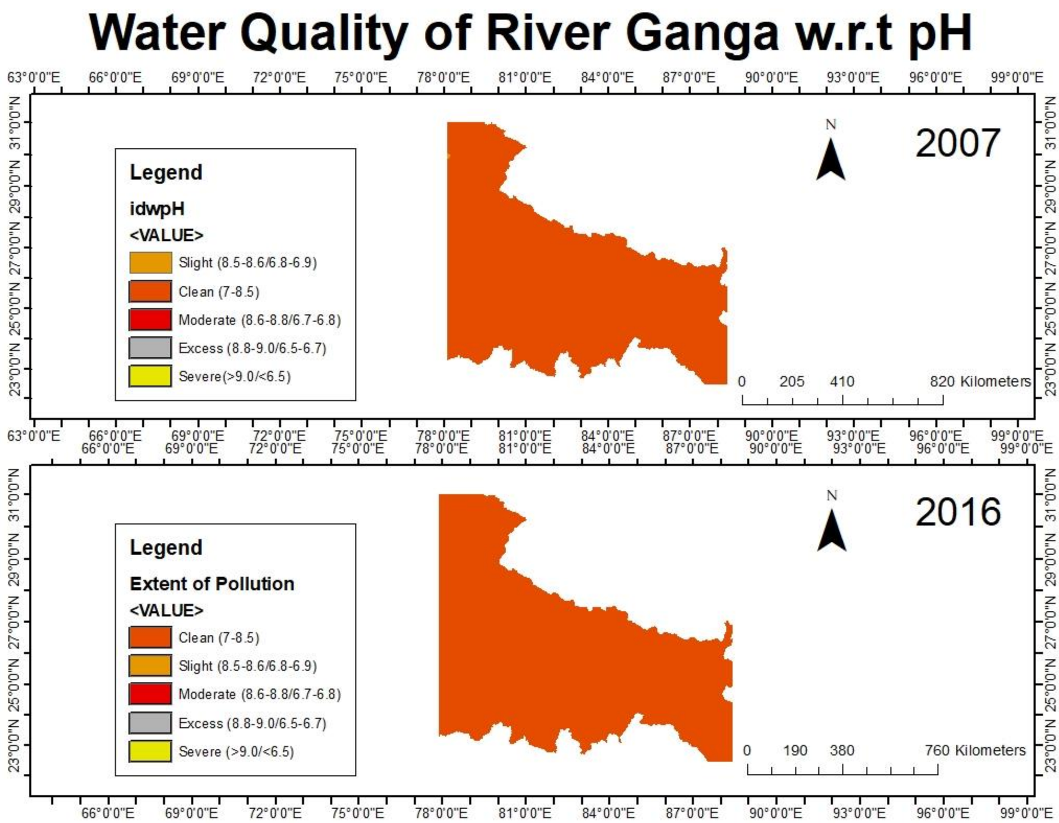

Figure 4.35 Water Quality of River Ganga w.r.t pH in 2007 and 2016

4.5.6 Total Coliform (TC)

The water quality of River Ganga on comparative spatial analysis found that it get better day by day due to the inclusion of National Ganga River Basin Authority (NGRBA) for rejuvenation of River Ganga in 2009. It can be seen from figure 4.36 that at Bihar and Jharkhand the water quality changes from severely polluted in 2007 to excess polluted water in 2016. Also, in the state of Uttarakhand the water quality changes from severely polluted to moderately polluted.

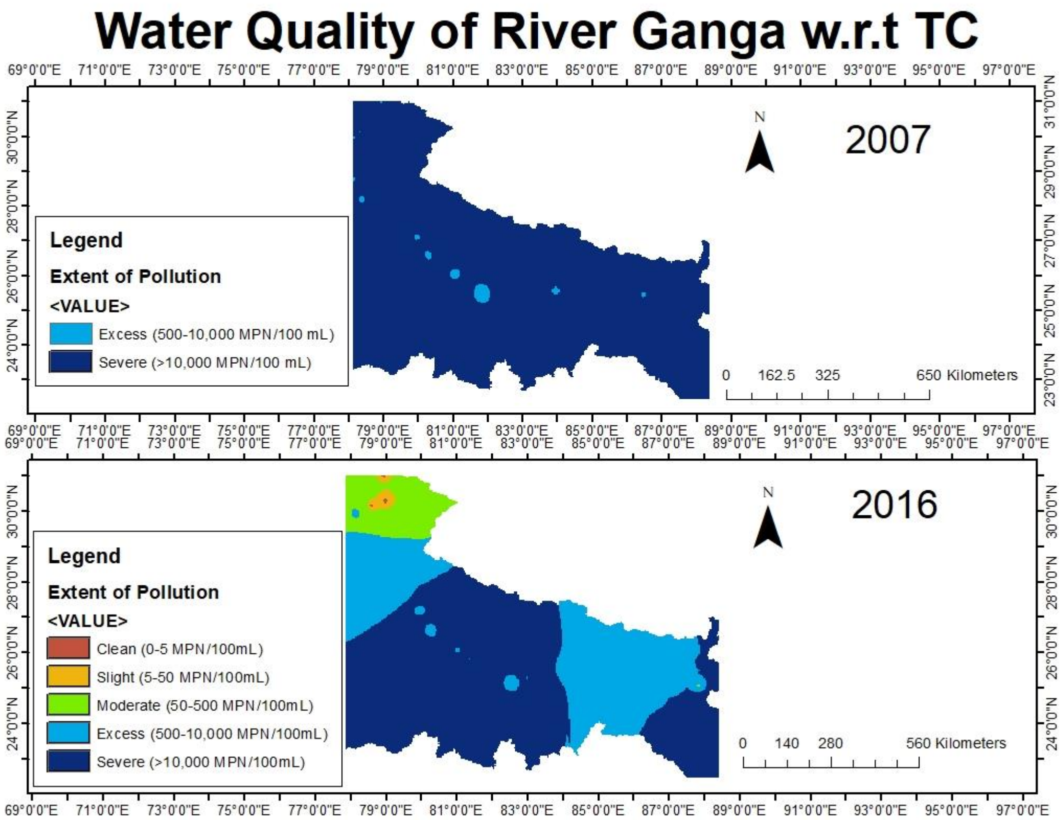

Figure 4.36 Water Quality of River Ganga w.r.t Total Coliform in 2007 and 2016

4.5.7 Quality of Water

The water quality of River Ganga on comparative spatial analysis found that it get better day by day due to the inclusion of National Ganga River Basin Authority (NGRBA) for rejuvenation of River Ganga in 2009. It can be seen from figure 4.37 that in Uttarakhand the water quality changes from good quality in 2007 to excellent quality in 2016. Also, at Varanasi of the water quality changes from medium to good.

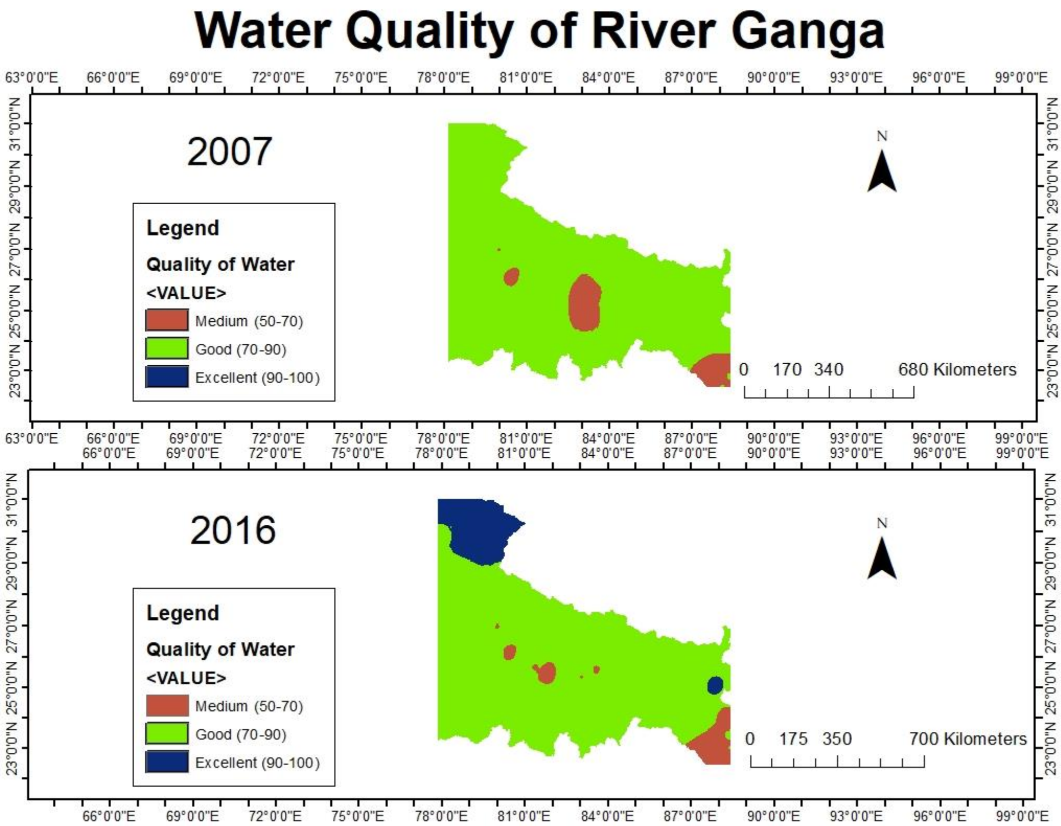

Figure 4.37 Water Quality of River Ganga in 2007 and 2016

4.5.8 Classification of Water based on Temperature

It can be observed from figure 4.37 the temperature of river water increases may be due to the effect of global warming. The temperature of atmosphere is increasing day by day because of warming of earth surface also results into increase of River Ganga temperature. At Varanasi the water classification changes from cold to warm water in year 2007 to 2016.

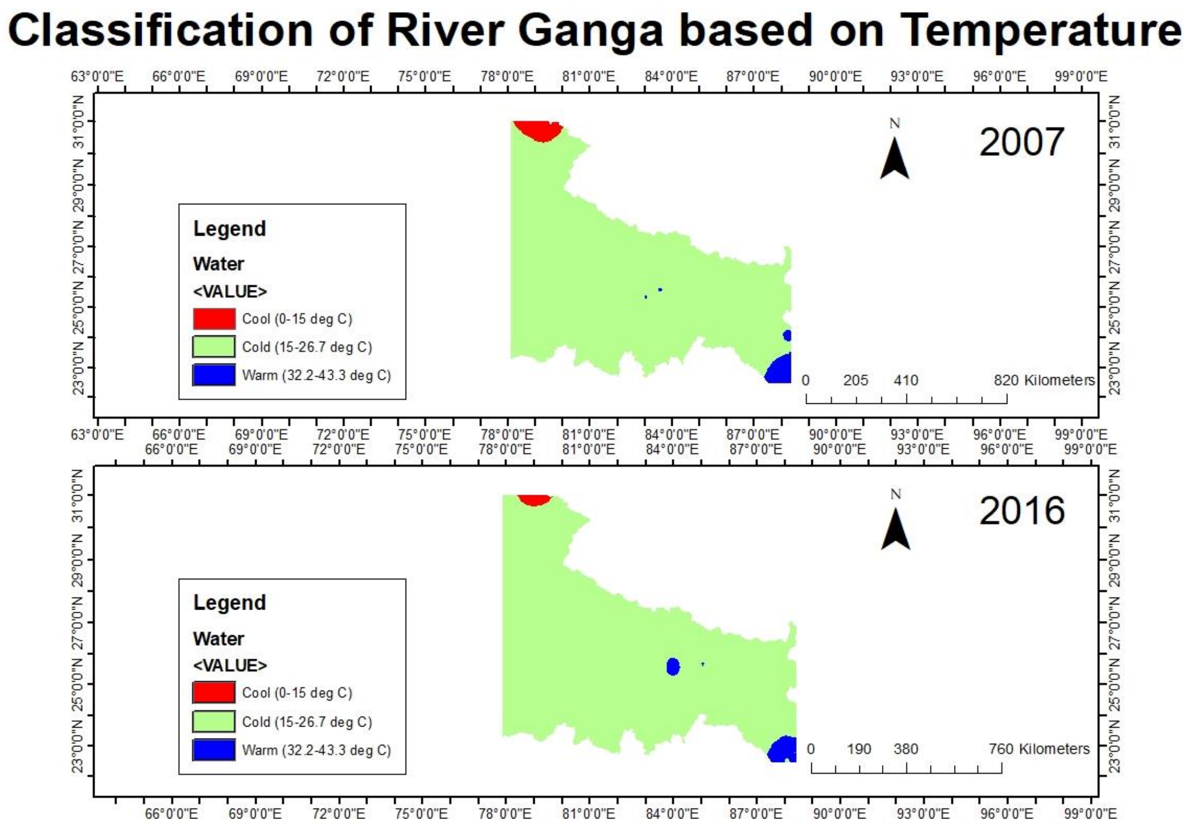

Figure 4.38 Classification of River Ganga based on Temperature in 2007 and 2016

4.6 ARTIFICIAL NEURAL NETWORK MODEL FOR PREDICTION OF WATER QUALITY OF RIVER GANGA

The Artificial Neural Network (ANN) model for River Ganga created in the present study using MATLAB R2015a (shown in Figure 4.39) having 8 inputs (water quality parameters including pH, EC, DO, Temperature, BOD, NO_3-N, TC, FC) to produce a single output (WQI). The training of the developed model is done using the data obtained from CPCB

ENVIS for 8 water quality parameters as input and calculated water quality index (WQI) as output of River Ganga for year 2007.

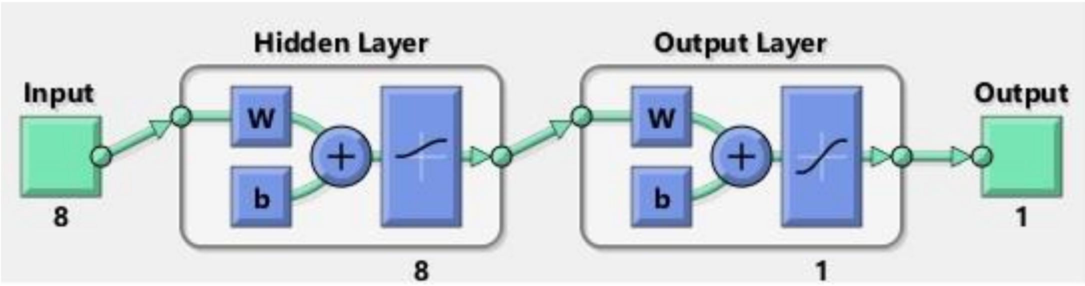

Figure 4.39 River Ganga Water Quality ANN Model

The algorithms used for training of the developed model are shown in Figure 4.40. The training is done for 1000 iterations and final trained model is obtained at 995 validation checks.

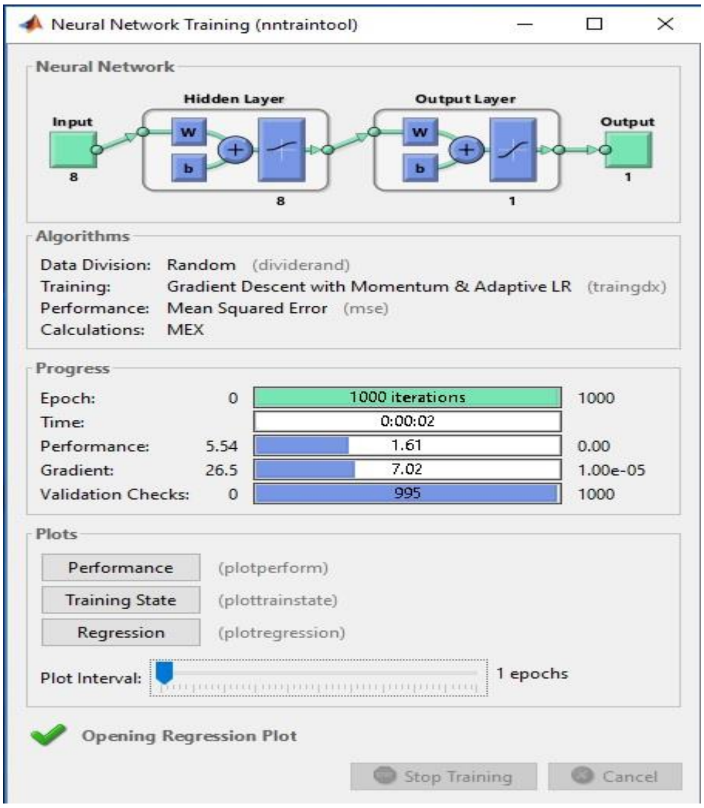

Figure 4.40 Training of River Ganga Water Quality ANN Model

The regression plot obtained for the ANN model developed for River Ganga water quality having R values for training, validation, test and overall equal to 0.94577, 0.95866, 0.94929 and 0.94761 respectively. The overall equation obtained for simulation of the water quality is given by Output ~= 0.9*Target +7.1. The best fit line lies almost on the line Y=T for all four scenario shown in Figure 4.41.

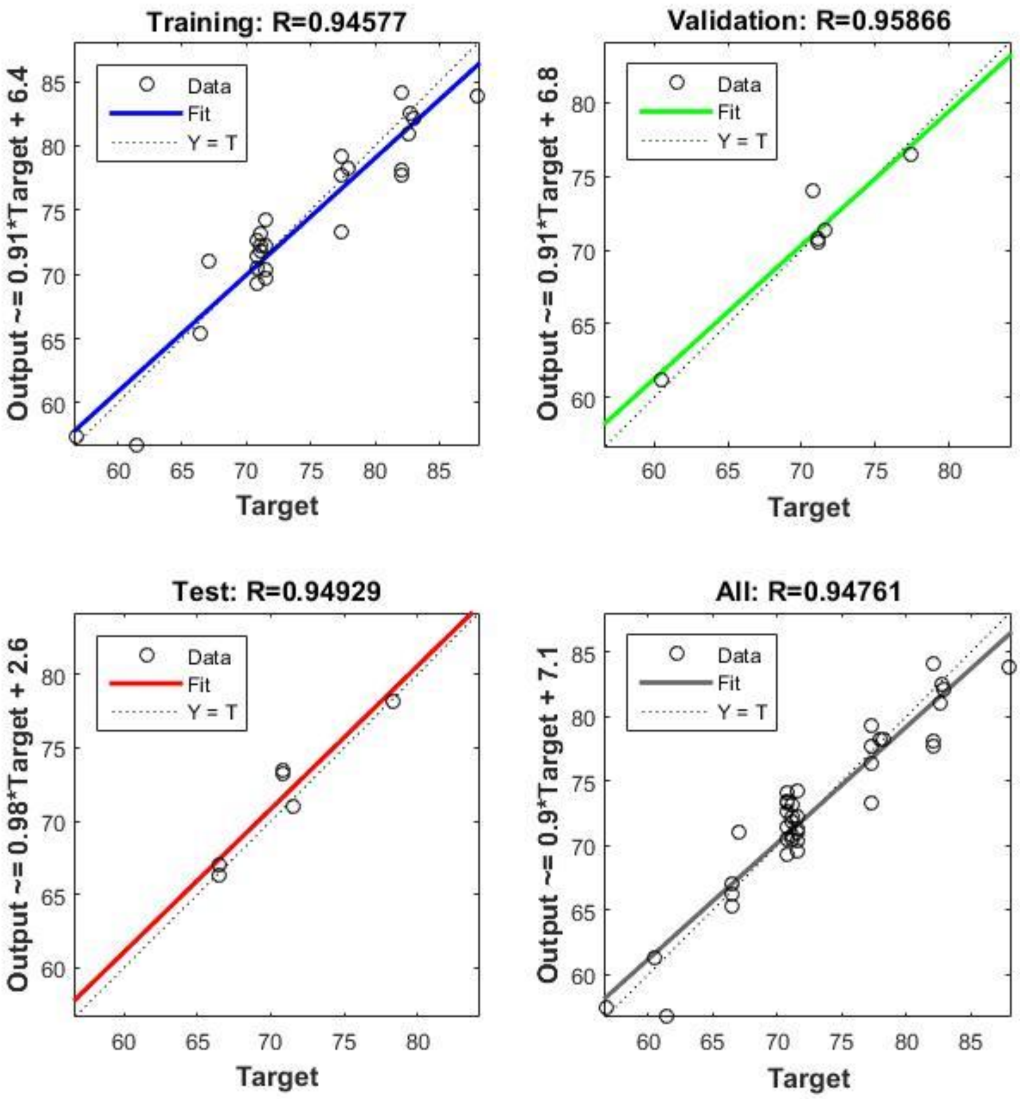

Figure 4.41 Regression Plot of River Ganga Water Quality ANN Model

The performance plot of the developed ANN model for River Ganga Water Quality (shown in Figure 4.42) shows that the mean square error (mse) decrease for train set with increase in epochs whereas it increase for validation and test set. The best validation performance is 2.1046 at epoch 0.

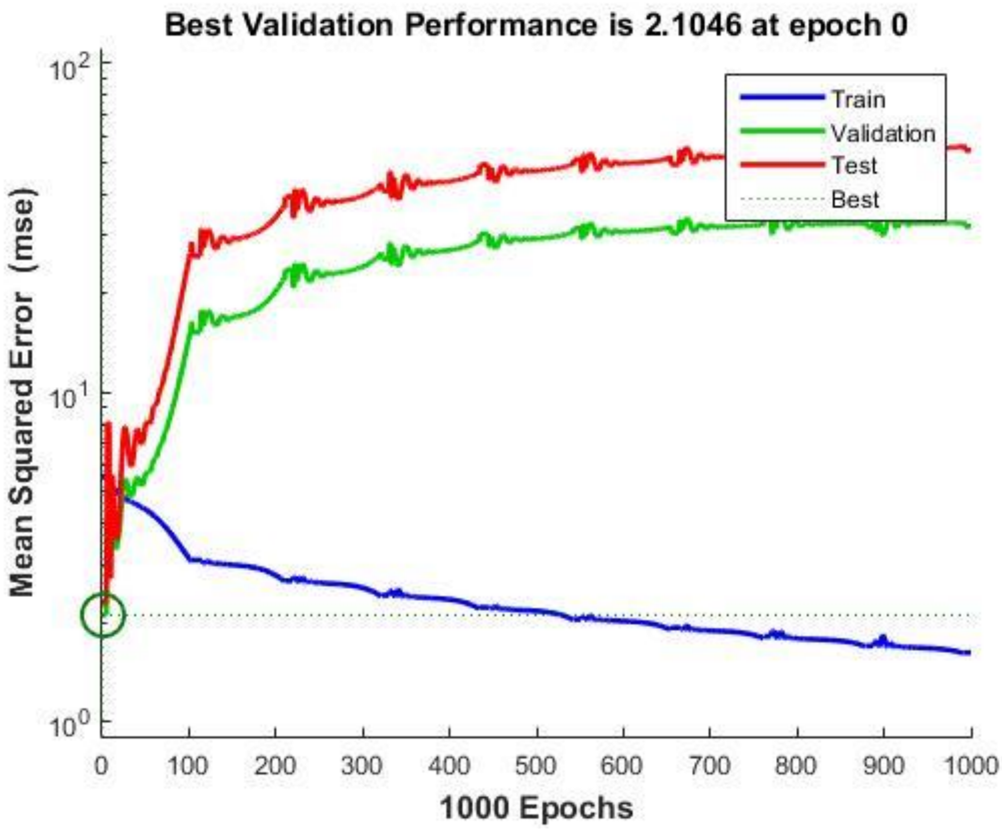

Figure 4.42 Performance Plot of River Ganga Water Quality ANN Model

The prediction is done using the ANN model for River Ganga water quality using the 2016 dataset of the 8 water quality parameters as input and the predicted values obtained from the model (shown in Table 4.9) is plotted against the theoretical values calculated. The plot of predicted vs theoretical (shown in Figure 4.43) follows a linear one degree polynomial model having equation f(x) = p1*x + p2, where x is normalized by mean 80.51 and standard deviation 13.8.

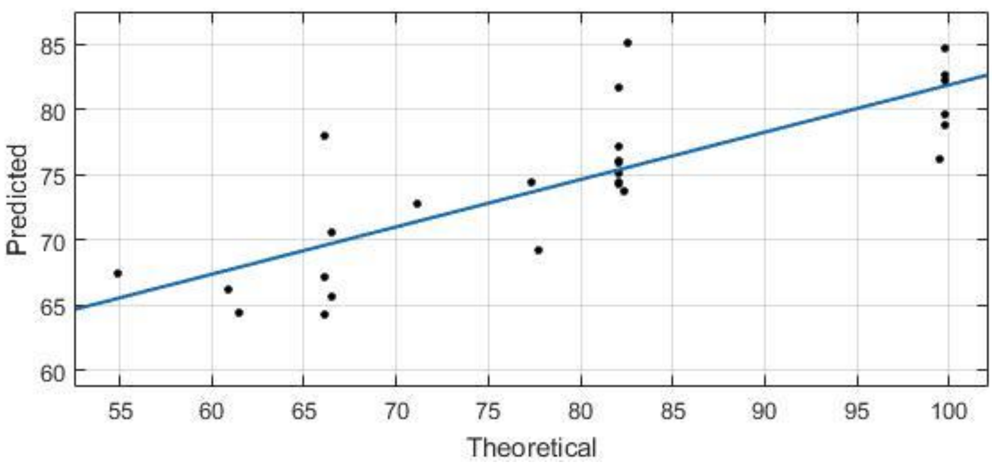

Figure 4.43 Predicted WQI vs Theoretical WQI Plot of River Ganga

The value of coefficients p1 and p2 with 95% confidence bounds are 5.013 (3.541, 6.484) and 74.84 (73.4, 76.29) respectively. The goodness of the fit for the plot of predicted vs theoretical WQI having SSE, R-square, adjusted R-square and RMSE values equal to 359.9, 0.6534, 0.6401 and 3.72 respectively.

The predicted WQI values almost follow the same trend as theoretical WQI for the River Ganga stretch starting from Gangotri in Uttarakhand to Diamond Harbour in West Bengal. The predicted WQI on an average approximately differ from theoretical WQI by 10 (shown in Figure 4.44).

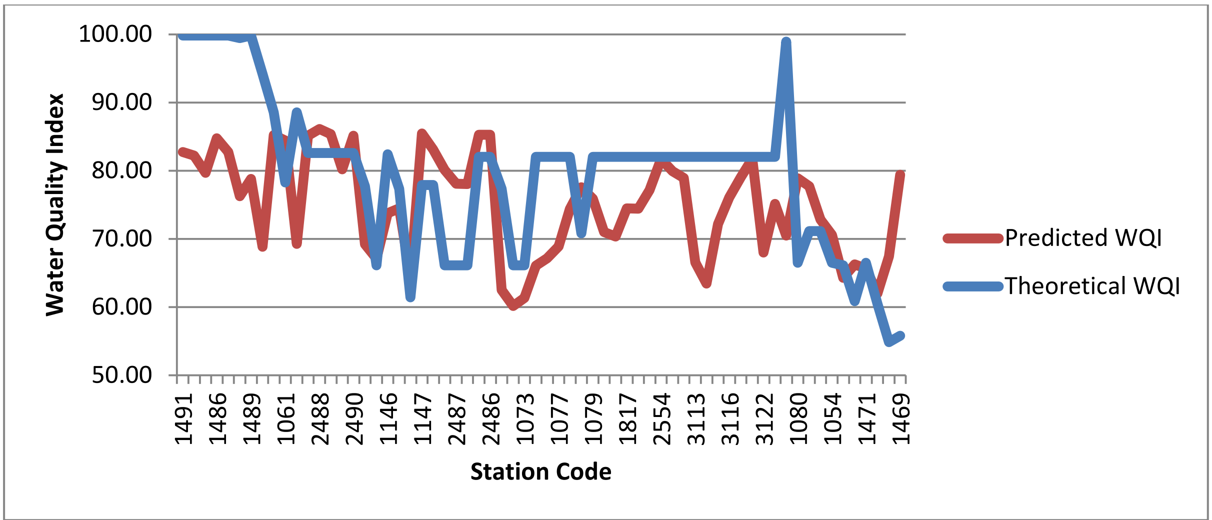

Figure 4.44 Variation of Predicted WQI and Theoretical WQI of River Ganga stretch

Table 4.9 Variation of Predicted WQI and Theoretical WQI of River Ganga stretch

Station Code	Location	State	Theoretical WQI	Predicted WQI
1491	Bhagirathi at Gangotri	Uttarakhand	99.80	82.72
1484	Alkananda B/C Mandakini at Rudra Prayag	Uttarakhand	99.80	82.21
1485	Mandakini B/C Alaknanda at Rudraprayag	Uttarakhand	99.80	79.70
1486	Alkananda A/C Mandakini at Rudraprayag	Uttarakhand	99.80	84.73
1487	Alaknanda B/C To Bhagirathi at Devprayag	Uttarakhand	99.80	82.72
1488	Bhagirathi B/C With Alaknanda at Devprayag	Uttarakhand	99.44	76.25
1489	Alkananda A/C With Bhagirathi at Devprayag	Uttarakhand	99.80	78.80
1060	Ganga at Rishikesh U/S	Uttarakhand	94.18	68.85
2725	Ganga River After Confluence Of River Song Near Satyanarayan Temple D/S	Uttarakhand	88.56	85.23

	Raiwala			
1061	Ganga D/S Haridwar	Uttarakhand	78.26	84.44
2727	Upper Ganga River D/S Roorkee	Uttarakhand	88.56	69.27
1062	Ganga at Garhmukteshwar, U.P	Uttar Pradesh	82.58	85.12
2488	Ganga U/S, Anoopshahar	Uttar Pradesh	82.58	86.10
2489	Ganga D/S, Anoopshahar	Uttar Pradesh	82.58	85.37
1145	Ganga at Narora (Bulandsahar), U.P.	Uttar Pradesh	82.58	80.20
2490	Ganga at Kachhla Ghat, Aligarh	Uttar Pradesh	82.58	85.13
1063	Ganga at Kannauj U/S (Rajghat), U.P	Uttar Pradesh	77.72	69.22
1066	Ganga at Kannauj D/S, U.P	Uttar Pradesh	66.12	67.12
1146	Ganga at Bithoor (Kanpur), U.P.	Uttar Pradesh	82.40	73.75
1067	Ganga at Kanpur U/S (Ranighat), U.P	Uttar Pradesh	77.36	74.48
1068	Ganga at Kanpur D/S (Jajmau Pumping Station), U.P	Uttar Pradesh	61.44	64.41
1147	Ganga at Dalmau (Rai Bareilly), U.P.	Uttar Pradesh	77.90	85.46
2498	Ganga at Kala Kankar, Raebareli	Uttar Pradesh	77.90	83.11
1046	Ganga at Allahabad (Rasoolabad), U.P.	Uttar Pradesh	66.12	80.09
2487	Ganga at Kadaghat, Allahabad	Uttar Pradesh	66.12	78.07
1049	Ganga at Allahabad D/S (Sangam), U.P.	Uttar Pradesh	66.12	78.04
2485	Ganga U/S, Vindhyachal, Mirzapur	Uttar Pradesh	82.04	85.24
2486	Ganga D/S, Mirzapur	Uttar Pradesh	82.04	85.28
1070	Ganga at Varanasi U/S (Assighat), U.P	Uttar Pradesh	77.36	62.49
1071	Ganga at Varanasi D/S (Malviya Bridge), U.P	Uttar Pradesh	66.12	60.18
1073	Ganga at Trighat (Ghazipur), U.P	Uttar Pradesh	66.12	61.32
1074	Ganga at Buxar,Bihar	Bihar	82.04	66.08
2551	Ganga at Buxar, Ramrekhaghat	Bihar	82.04	67.13
1077	Ganga at Khurji, Patna U/S, Bihar	Bihar	82.04	68.90
2564	Ganga at The Confluence Of Sone River Doriganj, Chapra	Bihar	82.04	74.37

2552	Ganga Darbhanga Ghat at Patna	Bihar	70.80	77.58
1079	Ganga at Patna D/S (Ganga Bridge), Bihar	Bihar	82.04	75.89
2555	Ganga at Punpun, Patna	Bihar	82.04	71.02
2553	Ganga at Fatuha	Bihar	82.04	70.33
1817	Ganga at Mokama (U/S)	Bihar	82.04	74.48
1815	Ganga at Mokama (D/S)	Bihar	82.04	74.45
1818	Ganga at Munger	Bihar	82.04	77.16
2554	Ganga at Sultanganj, Bhagalpur	Bihar	82.04	81.68
1819	Ganga at Bhagalpur	Bihar	82.04	79.90
1816	Ganga at Kahalgaon	Bihar	82.04	78.95
3113	Ganga at D/S Buxar Near Ganga Bridge	Bihar	82.04	66.56
3114	Ganga River Near Danapur (Near Pipapul)	Bihar	82.04	63.43
3115	Ganga River at Barh	Bihar	82.04	72.17
3116	Ganga At U/S Munger (Near Intake Well On Ganga)	Bihar	82.04	76.07
3117	Ganga at U/S Sultanganj	Bihar	82.04	79.05
3118	Ganga at U/S Bhagalpur	Bihar	82.04	81.73
3122	Ganga at Malsalami, Patna	Bihar	82.04	68.01
3123	Ganga River at Barahia	Bihar	82.04	75.11
1059	Ganga at Rajmahal	Jharkhand	98.90	70.47
1080	Ganga at Baharampore West Bengal	West Bengal	66.48	78.90
2511	Nabadip On Ganga,Ghoshpara Near Monipurghat	West Bengal	71.16	77.73
2506	Tribeni On Ganga, Near Burning Ghat	West Bengal	71.16	72.83
1054	Ganga at Palta, West Bengal	West Bengal	66.48	70.56
1472	Ganga at Serampore, West Bengal	West Bengal	66.12	64.28
1053	Ganga at Dakshmineswar, West Bengal	West Bengal	60.86	66.28
1471	Ganga at Howrah-Shivpur, West Bengal	West Bengal	66.48	65.64
1470	Ganga at Garden Reach, West Bengal	West Bengal	60.50	62.01
1052	Ganga at Uluberia, West Bengal	West Bengal	54.88	67.41
1469	Ganga at Diamond Harbour, West Bengal	West Bengal	55.82	79.41

CHAPTER 5

CONCLUSIONS and RECOMMENDATIONS

5.1 CONCLUSIONS

Based on the findings of the work using interpolation, statistical and neural network method of analysis for water quality the following concluding remakes can be inferred:

i. With respect to the water quality assessment parameters like EC, FC and TC the water quality varies from clean to severely polluted and thus is unfit for human consumption without treatment, which is a matter of concern given the holy status of Ganga due to which a large part of population actually uses the water for drinking.

ii. The water quality of River Ganga w.r.t DO and BOD varies from clean to moderately pollute which can be attributed to the large stretch travelled by the flowing water in varied terrains allowing proper diffusion of atmospheric oxygen.

iii. The overall pH and NO_3-N concentration in the locations being considered are found to be within the limit of being categorised as safe as per standard norms and hence do not pose very serious threat to human life or other life stock.

iv. The air quality around the river w.r.t $PM_{2.5}$ and SO_2 has good quality. The ambient air quality w.r.t PM_{10} has satisfactory to moderately polluted air quality and w.r.t SO_2 has satisfactory quality but needs improvement.

v. The pH, EC, Temperature, Nitrate-N, BOD, TC, FC, WQI, SO_2, NO_2, PM_{10} and AQI doesn’t follow the normal distribution based on Anderson-Darling Normality test while DO and $PM_{2.5}$ follow the normal distribution.

vi. Based on the principal component analysis it can be concluded that TC & FC dataset shows a lot of variation and may seems like a non-principal component but the variation may be attributed to seasonal human activities which is a very crucial factor when one focuses on pollution causes of River Ganga. Hence, a more extensive analysis of the water quality with larger time period is required to fully grasp the variation of TC and FC.

vii. The PCA analysis shows that water quality of River Ganga deteriorates due to discharge of untreated sewage and disposal of organic waste into River Ganga through drains. Similar analysis for air quality near River Ganga displays that area is majorly polluted due to vehicular emissions.

viii. The water quality of River Ganga improves with time on emergence of the effort made by National Ganga River Basin Authority (NGRBA).

ix. Further the ANN model developed for prediction of water quality of River Ganga also reported results in concurrence with the theoretical results obtained with small difference which may be attributed to the lack of data training to the model. It can be improved by better quality of training dataset provided to ANN model.

Hence, after careful consideration of all the above stated findings the water quality of River Ganga can be classified as good quality but unfit for human drinking. The ambient air quality around areas near River Ganga varies mostly from moderately polluted to poor.

5.2 RECOMMENDATIONS

As already established Ganga is a river of national importance not only because of its holy status but also because it directly affects the economy of five states it flows through, the number of human and animal lives that depend on it for their needs and the vegetation it supports. Therefore large amount of efforts are being made to restore the air and water quality of river stretch. With the emergence of the effort of NGRBA it has been observed that the water quality of River Ganga has improved considerably from 2007 to 2016. However some more remedial actions which can be taken to improve the quality of air and water:

i. 12% of the total pollution of river Ganga can be attributed to industrial effluent discharged in river or drains flowing into the river without treatment or improper treatment. So more stringent laws regarding the pre-treatment of effluent and better monitoring of the discharge being done in the river.

ii. The STPs and CETPs responsible for the treatment of effluent from the member units should be revaluated for the treatment capacity and the infrastructure should be available based on the records of effluent flow received during the last 2 years.

iii. Dumping of waste from religious ceremonies and cremation activities also contribute to a considerable amount of BOD and reduction in air quality along the river stretch. However, it cannot directly controlled by the government. So awareness among the local masses regarding the threat of pollution needs to be created. So campaigns for the same on both rural and urban levels should be organized.

iv. All the recreational spots made at the bank of river Ganga should be strictly monitored and public should be discouraged from throwing garbage and used plastics in the water bodies.

v. TC/FC of the river has been found to be alarmingly high and unsafe for use by human and animal stock. So the Municipal Corporations of the city should be made aware of the situation and directed to use measures such as bio-remediation before dumping their waste in the river.

vi. The entire stretch along the length of the River Ganga is very densely populated as it has been the major source of economic and social development, but because of the same there is largely contributed to pollution of air due to heavy vehicular emissions. So people must be encouraged to use public transport and the condition of roads should be properly maintained to reduce particulate matter pollution.

vii. Many municipal corporations still do not have proper disposal facilities for domestic plastic waste collected and they resort to uncontrolled open burning of the same. They can follow the example of Municipal Corporation, Gurugram which has come up with utilizing the plastic waste to make roads. This solves the problem of waste and also results in good quality of roads to reduce particulate matter pollution.

viii. Large shares of land along the river stretch in the states it flow are agricultural lands so that the river water can be used for irrigation. But after the harvest the residues are often burned which is a major source of air pollution. The government has been very active in the recent years to prevent it but more efforts in controlling it, creating awareness among masses and better monitoring of the same needs to be made.

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ANNEXURE

Table A1 NWMP Stations located in River Ganga

Station CODE	LOCATIONS	STATE
1491	BHAGIRATHI AT GANGOTRI	UTTARAKHAND
1484	ALKANANDA B/C MANDAKINI AT RUDRA PRAYAG	UTTARAKHAND
1485	MANDAKINI B/C ALAKNANDA AT RUDRAPRAYAG	UTTARAKHAND
1486	ALKANANDA A/C MANDAKINI AT RUDRAPRAYAG	UTTARAKHAND
1487	ALAKNANDA B/C TO BHAGIRATHI AT DEVPRAYAG	UTTARAKHAND
1488	BHAGIRATHI B/C WITH ALAKNANDA AT DEVPRAYAG	UTTARAKHAND
1489	ALKANANDA A/C WITH BHAGIRATHI AT DEVPRAYAG	UTTARAKHAND
1060	GANGA AT RISHIKESH U/S	UTTARAKHAND
2725	GANGA RIVER AFTER CONFLUENCE OF RIVER SONG NEAR SATYANARAYAN TEMPLE D/S RAIWALA	UTTARAKHAND
1061	GANGA D/S HARIDWAR	UTTARAKHAND
2727	UPPER GANGA RIVER D/S ROORKEE	UTTARAKHAND
1062	GANGA AT GARHMUKTESHWAR, U.P	UTTAR PRADESH
2488	GANGA U/S, ANOOPSHAHAR	UTTAR PRADESH
2489	GANGA D/S, ANOOPSHAHAR	UTTAR PRADESH
1145	GANGA AT NARORA (BULANDSAHAR), U.P.	UTTAR PRADESH
2490	GANGA AT KACHHLA GHAT, ALIGARH	UTTAR PRADESH
1063	GANGA AT KANNAUJ U/S (RAJGHAT), U.P	UTTAR PRADESH
1066	GANGA AT KANNAUJ D/S, U.P	UTTAR PRADESH

1146	GANGA AT BITHOOR (KANPUR), U.P.	UTTAR PRADESH
1067	GANGA AT KANPUR U/S (RANIGHAT), U.P	UTTAR PRADESH
1068	GANGA AT KANPUR D/S (JAJMAU PUMPING STATION), U.P	UTTAR PRADESH
1147	GANGA AT DALMAU (RAI BAREILLY), U.P.	UTTAR PRADESH
2498	GANGA AT KALA KANKAR, RAEBARELI	UTTAR PRADESH
1046	GANGA AT ALLAHABAD (RASOOLABAD), U.P.	UTTAR PRADESH
2487	GANGA AT KADAGHAT, ALLAHABAD	UTTAR PRADESH
1049	GANGA AT ALLAHABAD D/S (SANGAM), U.P.	UTTAR PRADESH
2485	GANGA U/S, VINDHYACHAL, MIRZAPUR	UTTAR PRADESH
2486	GANGA D/S, MIRZAPUR	UTTAR PRADESH
1070	GANGA AT VARANASI U/S (ASSIGHAT), U.P	UTTAR PRADESH
1071	GANGA AT VARANASI D/S (MALVIYA BRIDGE), U.P	UTTAR PRADESH
1073	GANGA AT TRIGHAT (GHAZIPUR), U.P	UTTAR PRADESH
1074	GANGA AT BUXAR,BIHAR	BIHAR
2551	GANGA AT BUXAR, RAMREKHAGHAT	BIHAR
1077	GANGA AT KHURJI, PATNA U/S, BIHAR	BIHAR
2564	GANGA AT THE CONFLUENCE OF SONE RIVER DORIGANJ, CHAPRA	BIHAR
2552	GANGA DARBHANGA GHAT AT PATNA	BIHAR
1079	GANGA AT PATNA D/S (GANGA BRIDGE), BIHAR	BIHAR
2555	GANGA AT PUNPUN, PATNA	BIHAR
2553	GANGA AT FATUHA	BIHAR
1817	GANGA AT MOKAMA (U/S)	BIHAR
1815	GANGA AT MOKAMA (D/S)	BIHAR
1818	GANGA AT MUNGER	BIHAR
2554	GANGA AT SULTANGANJ, BHAGALPUR	BIHAR
1819	GANGA AT BHAGALPUR	BIHAR

1816	GANGA AT KAHALGAON	BIHAR
3113	GANGA AT D/S BUXAR NEAR GANGA BRIDGE	BIHAR
3114	GANGA RIVER NEAR DANAPUR (NEAR PIPAPUL)	BIHAR
3115	GANGA RIVER AT BARH	BIHAR
3116	GANGA AT U/S MUNGER (NEAR INTAKE WELL ON GANGA)	BIHAR
3117	GANGA AT U/S SULTANGANJ	BIHAR
3118	GANGA AT U/S BHAGALPUR	BIHAR
3122	GANGA AT MALSALAMI, PATNA	BIHAR
3123	GANGA RIVER AT BARAHIA	BIHAR
1059	GANGA AT RAJMAHAL	JHARKHAND
1080	GANGA AT BAHARAMPORE WEST BENGAL	WEST BENGAL
2511	NABADIP ON GANGA,GHOSHPARA NEAR MONIPURGHAT	WEST BENGAL
2506	TRIBENI ON GANGA, NEAR BURNING GHAT	WEST BENGAL
1054	GANGA AT PALTA, WEST BENGAL	WEST BENGAL
1472	GANGA AT SERAMPORE, WEST BENGAL	WEST BENGAL
1053	GANGA AT DAKSHMINESWAR, WEST BENGAL	WEST BENGAL
1471	GANGA AT HOWRAH-SHIVPUR, WEST BENGAL	WEST BENGAL
1470	GANGA AT GARDEN REACH, WEST BENGAL	WEST BENGAL
1052	GANGA AT ULUBERIA, WEST BENGAL	WEST BENGAL
1469	GANGA AT DIAMOND HARBOUR, WEST BENGAL	WEST BENGAL

Table A2 NAMP Stations located near River Ganga

Location	City	State
Beltron Bhawan, Shastri Nagar	Patna	Bihar
Gandhi Maidan, Auto Exhaust Test Centre	Patna	Bihar
Square crossing circle of Laxmi Talkies	Prayagraj	Uttar Pradesh
Bharat Yantra Nigam Ltd	Prayagraj	Uttar Pradesh
Alopibagh/Sewage Pumping Stations	Prayagraj	Uttar Pradesh
Jhonstonganj/co-operative Bank	Prayagraj	Uttar Pradesh
Rambagh/Parag Dairy	Prayagraj	Uttar Pradesh
Forest & Training Centre, Kidwai Nagar	Kanpur	Uttar Pradesh
Chamber Of Commerce Darshanpurwa/ Deputy ka Parao	Kanpur	Uttar Pradesh
Associated Chem Pvt Ltd, Fazalganj, Panki, Site-5	Kanpur	Uttar Pradesh
Dabauli / Shastri NGR	Kanpur	Uttar Pradesh
Jajmau / Awas Vikas	Kanpur	Uttar Pradesh
I.I.T. Campus, Kanpur	Kanpur	Uttar Pradesh
Dada Nagar, Kanpur	Kanpur	Uttar Pradesh
Ramadevi, Kanpur	Kanpur	Uttar Pradesh
SIDCUL, Haridwar	Haridwar	Uttarakhand
Nagar Palika Parishad	Rishikesh	Uttarakhand
Barrackpore Municiaplity	Barrackpore	West Bengal
Dum Dum Telephone Exchange	Barrackpore	West Bengal
Khardah Municipality	Barrackpore	West Bengal
Bhabanipur, Milan Viyapith, Bhabanipur	Haldia	West Bengal
Bhunia Raichak, Driver's Hut , Bhunia	Haldia	West Bengal
Supermarket Building, Durgachak	Haldia	West Bengal
WBIIDC Ruchi Soya Ind. Durgachak	Haldia	West Bengal
Howrah Municipal Corporation Building	Howrah	West Bengal
CDS & Health Centre, Bator	Howrah	West Bengal
Howrah Municipality School, Bandhaghat	Howrah	West Bengal
Salt Lake, Rooftop of CK Market	Kolkata	West Bengal
Moulali, Rooftop of KMC office Building	Kolkata	West Bengal
Minto Park, Inside Park AJC Bose Road	Kolkata	West Bengal

Dunlop Bridge, National Sample Survey	Kolkata	West Bengal
Behala Chowrasta, Traffic Guard Building	Kolkata	West Bengal
Baishnabghata, Upanagari Sporting Club	Kolkata	West Bengal
Cossipore Police Station, B.T. Road	Kolkata	West Bengal
Dalhousie Square, Lal Bazzar Police Headqtr.	Kolkata	West Bengal
Kasba	Kolkata	West Bengal
Bharat Co-op Housing Society	Sankrail	West Bengal
Bagan Police Station, Bagan	Sankrail	West Bengal
Dhulagar Gram Pachayat	Sankrail	West Bengal
P Mukherjee's House, Near SBI Amta	Sankrail	West Bengal