Flow and Water Quality Trends in Ganga River in the State of Uttar Pradesh

By

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1. Introduction

1.1 Background

About 71% of the earth surface is covered with water in the form of fresh water and saline water. Fresh water is mainly available in the form of lakes, rivers, creeks, streams, ground water, etc. We, humans are dependent on fresh water systems. In fact, most of the civilizations have been established on the banks of various rivers. These rivers have become the part of our social, cultural, economic life and development since ages. For example, in India, the rivers, Indus, Ganga, Narmada, Brahmaputra, and others have their unique identity through Vedas, popular myths, and legends. Especially river Ganga occupies a distinctive place in the life of denizens of India. People of our country are emotionally attached to the river and pilgrimage centers on its banks since centuries.

Among the various river basins in India, Ganga basin is the largest river basin. It accounts for around 27 % of India's total geographical area, receives 35.5 % of annual average rainfall and supports almost 47% of our population. It extends over 11 states namely, Himachal Pradesh, Uttarakhand, Uttar Pradesh, Haryana, Delhi, Bihar, Jharkhand, West Bengal, Rajasthan, Madhya Pradesh, Chhattisgarh(*NRCD,* 2009). The mainstream, Ganga originates from the ice-caves at Gaumukh (30 55 N, 79 07 E), 4100 meters above sea-level. It travels a distance of ~ 2510 km before draining into the Bay of Bengal(*CPCB*, 2013).

The two most important parts of any river area flow which carries dissolved or suspended matter with it which ultimately affects the second part which is the river water quality. But nowadays rivers are treated as waste disposal sites due to urbanization, industrialization and the exponential increase in population. It carries a large amount of municipal, industrial wastewater along with the agricultural runoff; even most of the times the solid waste from domestic, commercial and industrial activities is also dumped into the river leading to deterioration in its water quality. Along with this, the various structures built along the river like dams and barrages for various purposes such as hydro power generation, irrigation, etc. affect the continuity of river flow. Hence by these activities river's integrity as an ecological entity is lost due to loss of Aviralta (connectivity) and Nirmalta (pollution) (IITC, 2015).

1.2 Problem Overview

Ganga river is a classic example of above mentioned anthropogenic interventions. It has attracted many national and international bodies to formulate various management plans for its conservation. This has led to the formation of Ganga Action Plan in 1985 with the objective

of restoration of River Ganga(*NRCD,* 2009).The work policies for GAP-I works were laid by the Central Ganga Authority established in 1985(*MoEF*, 1987). To prepare this program, Central Pollution Control Board(CPCB) had done an extensive study of the Ganga Basin in terms of identifying the pollution sources and factors affecting river flow(*NRCD,* 2009). Since then the river water quality and flow monitoring for river Ganga became crucial for other state pollution control boards, Central Water Commission of India and various local bodies like government and private institutes, etc. In 1995, GAP was expanded to the National River Conservation Plan so as to cover other rivers. A substantial amount of data has been gathered in the last thirty years by CPCB, NRCD ,and CWC. Proper analysis and interpretation of these data sets are equally important to understand the physiochemical and biological characteristics of the river, potential sources of pollution related to spatial and temporal variation. Out of these data sets, CPCB and NRCD data sets have been analyzed earlierto some extent while the data gathered by CWC, particularly on river water quality remains unexplored. This research was initiated to fill in this gap and compare the results with those derived from NRCD data.

1.3 Study Area

Three major rivers of India namely Indus, Ganga and Brahmaputra originates in the Himalayas(*NRCD,* 2009). River Ganga flows through 5 states of India, Uttrakhand, Uttar Pradesh, Bihar, Jharkhand and West Bengal. Along the complete course of around 2525 km, many large and small tributaries meet Ganga. Its main tributaries are Yamuna, Ramganga, Gomati, Ghagara, Gandak, Damodar, Kosi and Kali. Due to such large stretch and large variation in altitude, climate, land use pattern, development projects, etc., river Ganga is generally divided into three stretches, namely as Upper Ganga (Devprayag to Haridwar), Middle Ganga (Haridwar to Varanasi) and Lower Ganga(Varanasi to GangaSagar)(*CPCB,* 2013). These three stretches along with study area are shown in Figures 1.1.

The CWC data used in this thesis is from Garhmukteshwar (point A in the insert of Figure 1.1) to Buxar (point B in the insert of Figure 1.1), that is mainly for the Middle Ganga stretch. Stations from Garhmukteshwar to Varanasi are in Uttar Pradesh while Buxar is on the boundary of Uttar Pradesh and Bihar but it's in Bihar state. Between these stations river mainly covers a distance of ~950km.

In the Middle Ganga stretch, the river enters into plains as the elevation is below 300 m from sea level and the majority of river bed consists of fine sand. The river bed is almost flat and wide with an approximate slope of 1:5000. In this stretch,the river undergoes a lot of meandering causing bifurcation into many small channels at several places. From Garhmukteshwar to Narora Barrage is an area for the active site of Ganges Dolphins. There are active breeding sites for turtles, crocodiles, ghariyalsetc(IITC, 2010).

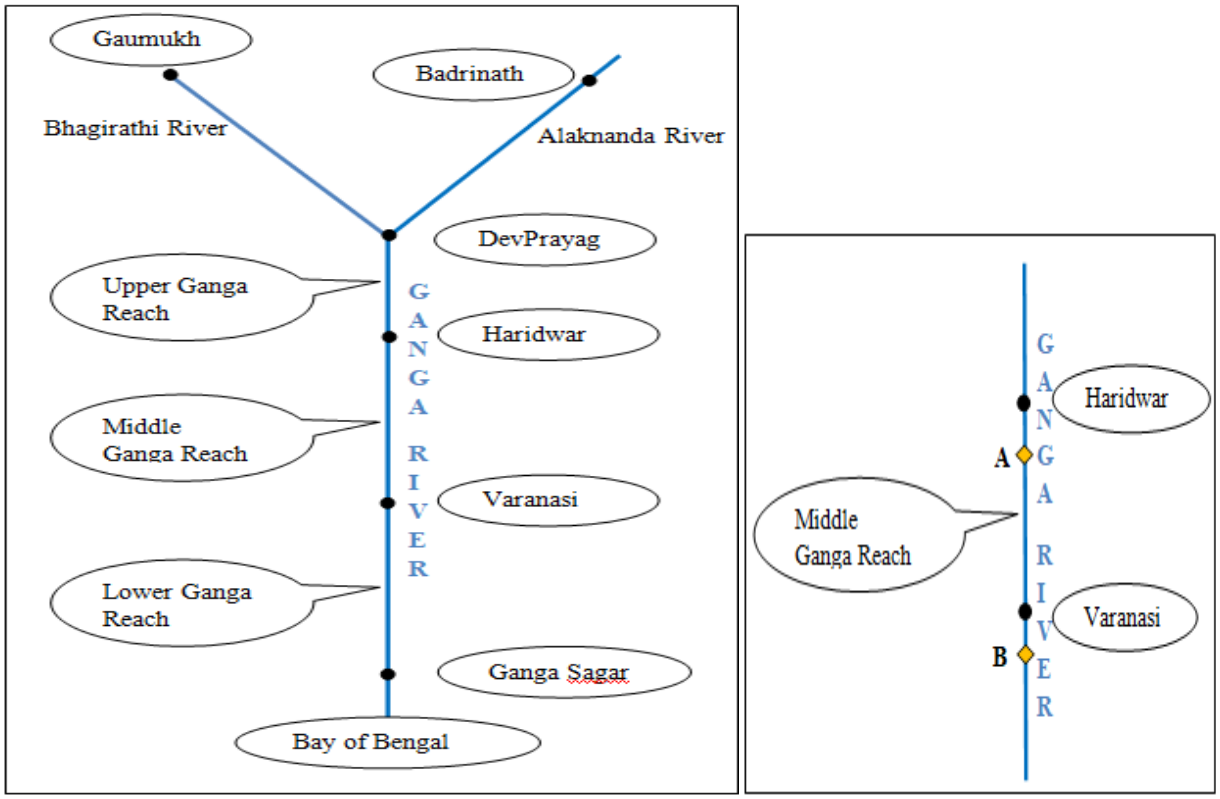

Figure Error! No text of specified style in document**..1: Three Stretches of River Ganga**

The important sources of water in river Ganga are snow melt, subsurface flow,and rainfall. Out of these, in this area, rainfall and subsurface flow are main. In this stretch, the annual rainfall is around 800 to 1200 mm(CIFRI, 2008). Here majority of rainfall is in monsoon season from June to September while the south-west monsoon also brings few showers in the winter season. But the summers are very dry and flow is mainly base flow. But in recent years, due to a drastic increase in groundwater abstraction lean flow has reduced significantly(Trivedi, 2010).

Even the majority of river flow is diverted into canals for irrigation purposes. In middle Ganga stretch, there are three canals namely Upper Ganga Canal, Middle Ganga Canal and Lower Ganga Canal-Parallel Lower Ganga Canal(*CPCB,* 2013). Lower Ganga Canal- parallel Lower Ganga Canalfall under the present study area. Lower Ganga Canal is downstream of Garhmukteshwar at NaroraBarraga. It is commissioned in 1878.The parallel lower Ganga canal system was put in operation during1980s(IWRD, 2018).This has led to a reduction in the flow after Garhmukteshwar. There are mainly two barrages in this stretch one at Narona and other at Kanpur. But the river flow is augmented by various tributaries. Ramganga meeting at Kusumkher which is between Fatehgarh and Ankinghat, Kali meeting at Kannauj which is just

downstream(~12 km) of Kusumkher,Yamuna meeting at Allahabad and other tributaries after Allahabad contribute to great extent in increasing the river flow(*CPCB*, 2013).

These tributaries also bring a large amount of domestic and industrial pollution load. Ramganga and Kali are one of those(*CPCB,* 2013). There are several industrial (e.g. Kanpur, Allahabad, and Varanasi) and cultural (e.g. Allahabad andVaranasi) centers along the main course of river Ganga which further enhance the pollution. Pollution load is also augmented by very high population density. As per 2001 census, the average population density in Ganga basin is almost 160% higher than the entire country(*NRCD,* 2009). The complete study area (except Buxar) is in Uttar Pradesh which has the highest population than other states from which the main course of river flows. These conditions lead to a drastic increase in point or non-point sources of pollution like riverbed farming, disposing of untreated wastewater, agricultural runoff into the river, washing clothes, animals on river banks, dumping solid waste like floral offerings, throwing un-brunt or partially burnt dead bodies into the river. All such activities harm the aquatic life, water quality,and aesthetics.

The CWC stations in the study area along the river Ganga are shown in Figure 1.2. The CWC stations with the tributaries meeting the river Ganga along with majorcanals are shown in Figure 1.3. Tributaries meeting on left are shown on the left side and those meeting on right are shown on right side.

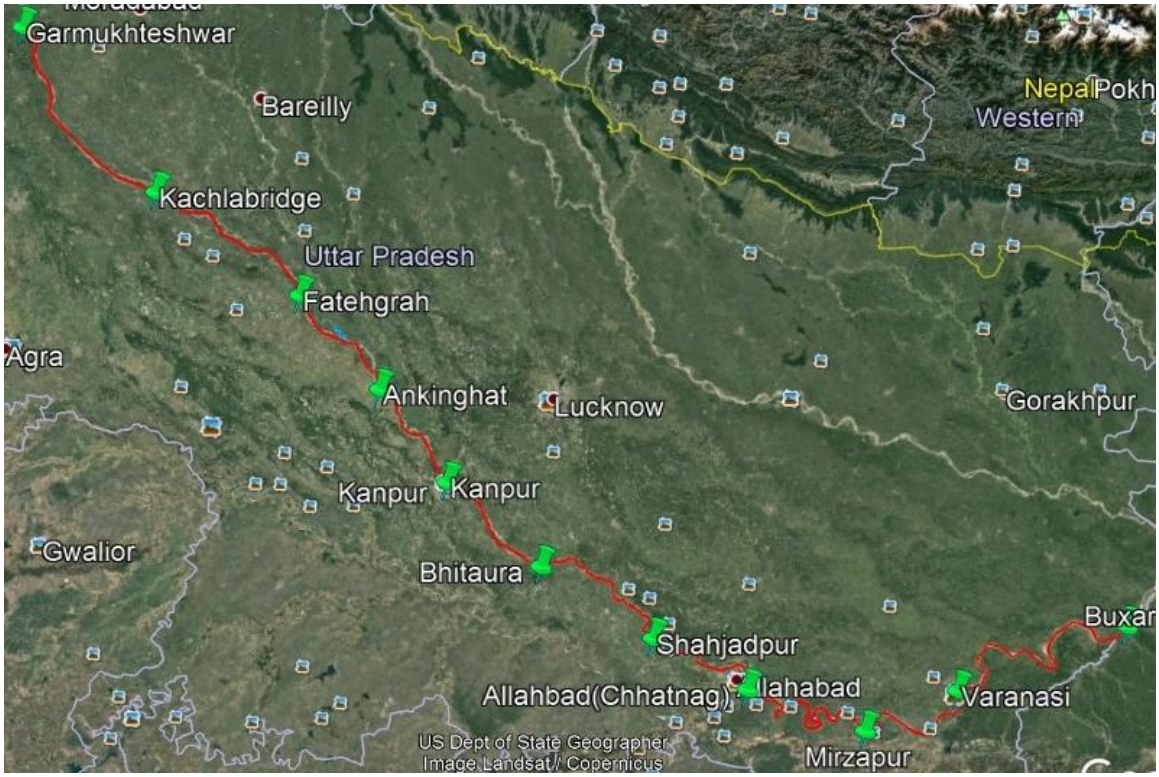

Figure Error! No text of specified style in document..**2: Representation of CWC Stations along River Ganga in the Middle Stretch**

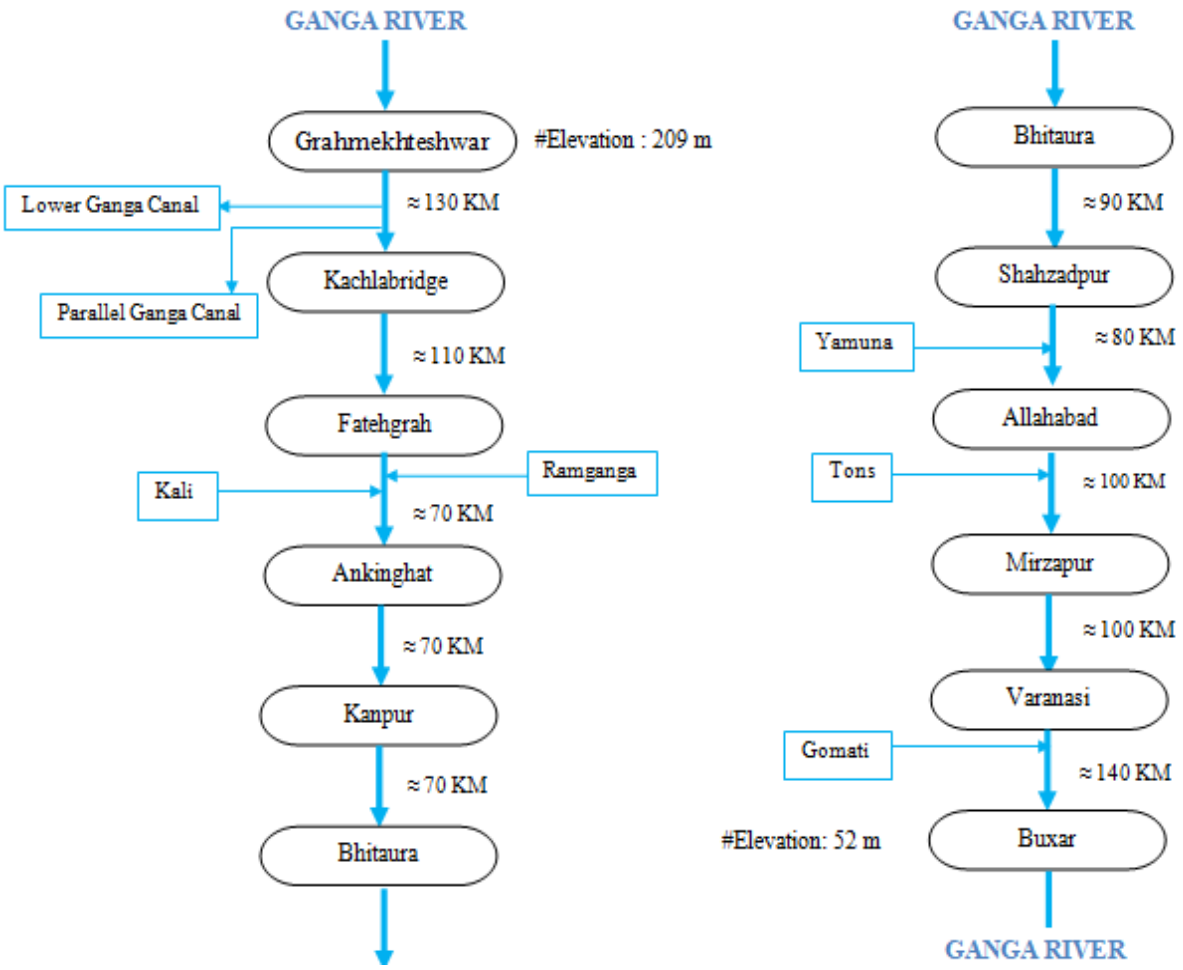

Figure Error! No text of specified style in document..**3: CWC Stations in Study Area along with Tributaries and Canals**

1.4 Data Acquisition

1.4.1 Central Water Commission

Central Water Commission is a premier Technical Organization of India in the field of Water Resources and is presently functioning as an attached office of the Ministry of Water Resources, River Development and Ganga Rejuvenation, Government of India.One of its mandate is to collect, analyse and disseminate information on various aspects of Indian Rivers.

It works in consultation with state government bodies for conservation, control,and utilization of water resources in respective states from point of view of flood management, drinking water supply, irrigation, water quality monitoring and hydro-power generation(CWC, 2013).

Water Quality Monitoring:

CWC has set up 371 stations in all major river basins in India for water quality monitoring. These monitoring stations are of three types as presented in Table 1.1.

Table Error! No text of specified style in document.**.1: Classification of CWC Stations**

Name	Sampling Frequency	Description
Base Station	Once in Two Month	Very less influence of human activities
Trend Station	Once in Month	The considerable influence of human activities
Flux Station	Trice in Month	Influence of human activities, geological feature and industrial pollution

The samples are collected from mid-stream for base and trend stations while for flux stations, the samples are collected from ¼, ½, and ¾ of the river width.Samples are collected in DOSampler or weighted Bottle and preserved and transported to laboratories for further analysisof various water quality parameters.

There are three types of laboratories where the analysis of water quality parameters is done. There are 258 Level-1 laboratories where physical parameters are analyzed. 24 Level-2 laboratories where physical, physico-chemical, biological and bacteriological parameters are analyzed. 4 Level-3 laboratories where along with all the above parameters toxic elements and pesticides are also analyzed(CWC, 2011). After Analysis, simple validation checks like ion balance, TDS-EC ratios etc. are carried on data and it is reported in well-prescribed format.

Discharge Measurements:

Discharge of river is measured thrice daily (8.00 am, 1.00pm, and 6.00pm) during the non-monsoon season and hourly in monsoon season (1st June to 31st October) by various methods. Discharge monitoring is done by either Direct methods like Area-Velocity Method using Current Meter, Float Method or indirect methods like Slope-Area method, Stage-Discharge Relation, etc. (*CWC,* 2017). Discharge data is being maintained in standard formats and then sent to sub-divisional and divisional offices.

The CWC data was obtained by IIT Kanpur under the project for preparation of Ganga River Basin Management Plan (GRBMP) from sub-divisional and divisional offices of CWC. The data is classified. Out of total available CWC data, a specific set of data is used in this analysis.

Data Used:

In this thesis, the water quality and flow data are used mainly from Garhmukteshwar (28.76N, 78.14E), Uttar-Pradesh to Buxar (25.58N, 83.97E), Bihar for past 40-42 years.

Table Error! No text of specified style in document.**.2:CWC Data Format**

Parameter	Monitoring Frequency	Duration
Discharge	Daily	1972-2014
Water Quality	Monthly	1972-2014

National River Conservation Directorate

As stated earlier, the river conservation programs started in India with Ganga Action Plan and then further extended to other rivers by National River Conservation Plan(NRCP) in 1995. Since 1995, GAP is also merged with NRCP. The Financial assistance and work policies under the NRCP are provided by NRCD to state government bodies so as to reduce river pollution(NRCD, 2018).

To assess the organic and microbial pollution in river Ganga selected parameters namely Dissolved Oxygen, Biochemical Oxygen Demand, Total and FecalColiform were analyzed by NRCD. The complete course of River Ganga has been divided into many segments and the water quality monitoring was done by various institutes or organizations for past 25 years (1986-2010) under the instructions of NRCD. Total 70 sampling Locations were considered on the entire course of Ganga River(*IITC*, 2012). Sampling was done on monthly basis and at some critical locations twice a month. Samples are collected from mid-stream and at some critical locations at 1/4, 1/2, 3/4, of river width. IIT Kanpur was one of the institutes handling one segment of river mainly from Fatehgarh Upstream to Kanpur downstream. Data for rest stations were obtained from the NRCD website.

Data Used:

In this thesis, the water quality data is used mainly from Garhmukteshwar (28.81N, 78.14E), Uttar-Pradesh to Buxar (25.58N, 83.99E), Bihar for past 25 years.

Table Error! No text of specified style in document.**.3: NRCD Data**

Parameter	Monitoring Frequency	Duration
Water Quality	Monthly	1986-2010

2. LITERATURE REVIEW

2.1 Past Study

River water monitoring is important for maintaining the wholesomeness of the river. Consortium of 7 IITs has included following four aspects to determine the wholesomeness of rivers: (i) Continuity of flow of water, sediment, and nutrients; (ii) Flow to be unpolluted; (iii) Recognition as a geological entity, and (iv) Functioning as an ecological entity (IITC, 2015). River flow monitoring helps in understanding the river flow pattern and also in predicting the flood and drought conditions. The unpolluted flow can be achieved by knowing the current or changing water quality of the river. River water quality monitoring programs help in knowing this and provide the base for planning water pollution abatement strategies. Considering these perspectives, river flow and water quality monitoring programs have been started in India by government bodies during the 1970s.

River Flow Analysis

According to Status Paper on River Ganga (NRCD, 2009; Trivedi, 2010) and a report published on river Ganga(CSE, 2014), the flow of water in river Ganga is predominantly due to rainfall, subsurface flows,and snow melts.In the study area,the river flows through the plains. Yamuna, Son, Kosi and Ghagra are the major tributaries which contribute to half of the flow in river Ganga. But all these tributaries meet Ganga after Allahabad. In the selected stretch, water from the river is abstracted for irrigation and drinking purpose while a large amount of wastewater is added into the river. December to May is a period of low flow due to very less precipitation. All these conditions lead to a negligible flow in this stretch during winter and summer seasons. The mean seasonal flows are presented in these reports which show a wide seasonal variation.

Being an international river, observed flow data of river Ganga is considered classified information hence many researchers have used SWAT(Soil Water Assessment Tool) to simulate flow over a defined timescale and for selected stretch of river mainly for studying the river hydrology and E-flows(Tare *et al.*, 2003;Parua, 2010;Webster, *etal*, 2010, Dubey *et al.*, 2015). Apart from short stretches, many researchers have even considered the complete Ganga river basin for river flow analysis. Jin *et al.*, (2015) have divided complete river basin into 70 stretches

out of which 21 stretches are on mainstream of river Ganga. In this study, the current flows and future flood or drought conditions up to 2090 have beenanalyzed by the INCA model. Model is calibrated by observed flows at Garhmukteshwar, Kachla bridge, Ankin ghat, Kanpur and Harding Bridge during 1981-2000. Flow at these five stations is controlled by the monsoon.

Researchers likeKhan *et al.*, (2018), have even used CWC flow data for river Ganga from source to Farraka but for a shorter time span of 1994-2008. They have analyzed flow-duration curves to understand the magnitude of flood, variability of yearly discharge and INCA model calibration for sediment dynamics. Flow reduction in a stretch of Garhmukteshwar to Buxar during lean seasons is also reported in this paper.

River Water Quality Analysis

Many researchers have studied the water quality of river Ganga since 1960-70s along various stretches of rivers or near particular cities. For example, Saxena *etal.*, (1966) havestudied river water quality at Kanpur; Bhargava, (1977) has monitored Ganga water quality from Rishikesh to Varanasi and has reported the Kannauj to Kanpur stretch and Varanasi city as critically polluted. All the industrial and cultural centers along the river tend to increase its pollution. In order to abate it, Ganga Action Plan was conceptualized but river water quality has hardly been found to improve (Gupta,2002, Yadav,2002,Jain, 2003). Hence till present date, many researchers have an interest in monitoring Ganga river water quality, understanding its pollution sources by statistical methods and finally suggesting some pollution prevention measures.

Government agencies like NRCD, CPCB have published many reports on water quality of river Ganga over these years. Status Report on River Ganga(NRCD, 2009) has analyzed river water quality before and after GAP for parameters DO, BOD, COD and Total Coliform at 39 monitoring stations from Rishikesh to Diamond Harbour. For the pre-GAP period (1980 to 1985) and post-GAP period(1986-2008), DO levels have always been found to be more than 4 mg/L but BOD and Total Coliform have always exceeded the limits. BOD and Total Coliform levels have reduced in the post-GAP period than a pre-GAP period (CPCB, 2013). CPCBhas assessed river water quality for the duration of 10 years from 2002-2011 on 57 monitoring stations set up by CPCB along complete river stretch. Ranges of these parameters along with spatio-temporal trends for last 5 years are presented in the report. As per this report, BOD and Coliform have found to exceed the limits. In Ganga river water quality report (IITC, 2012), water quality trends have beenanalyzed for historical data of last 25 years (1986-2010), monitored by various agencies and institutes or universities under NRCD on 70 monitoring stations along the river. The water quality trends are shown for a complete year as well as dry and wet seasons for 25

years. Only Coliform concentrations have shown positive trends over these years which infer that river action plans have not been completely successful in restoring river water quality.

Along with these, many researchers have done an analysis of water quality for short durations in the selected stretch of the study area at particular sites. Seasonal and temporal variation of DO, pH, Nitrates, Phosphates and Bacterial population (Coliform, E.Coli, Bacterial Density) at 6 ghats in Varanasi during 2005-06 has been studied byMishra *et al.*(2009). Namrata(2010) has studied various river water quality parameters at 6 sampling sites for 2 years (2006-2008) on monthly basis to find the most polluted ghats along the river Ganga in Varanasi. It has shown a very high loading of feacal population and correlation between physico-chemical parameters and bacterial density has also been studied.Allahabad and Varanasi being important cultural centers, many researchers have studied the change in water quality during Kumbh. Srivastava *et al.*, (1996), have studied the change in river water quality before and after Mahakumbh in 1989 which has shown elevated levels of BOD, COD and FC after Mahakumbh.

Apart from cultural centers, many industrial cities like Kanpur are located along the river Ganga in a selected stretch where Khatoon *et al.*, (2013)have analyzed river water quality from 6ghats during 2010-11. Pearson correlation analysis is also carried between water quality parameters which showed a significant positive correlation between BOD-Temperature, EC-Cl etc. Trivedi *et al.*, (2009) has carried seasonal water quality sampling in 2008 and analyzed correlation.

Many experts have even observed the water quality variation over some distance. Timescale changes in river water quality have been studied for a stretch of 250 km from Kanpur to Allahabad during 2011-12 in 3 seasons(Tiwari *et al.,* 2016). Water quality trends analyzed from Narora to Kannauj for a stretch of approximately 350 km during 1987-90 have shown very less change in water quality in the complete stretch(Khan *et al.*, 1994). Effect of industrial waste and sewageon river water quality has also been studied from Kanpur to Varanasi from 1993-95 by(Singh *et al.*, 1999). It has reported the effect of point sources to be localized and that over some distance river water quality regains its original characteristics. A stretch of river Ganga from Haridwar to Varanasi has been studied for one year period(Kumar *et al.*, 2016). Multivariate statistical techniques have been used to identify pollution sources in this course of the river.

As inferred from above, long term temporal and spatial variation in river water quality has hardly been analyzed by researchers in India unlike researchers all over the world. Halliday *et al.*, (2012)have studied long-term water quality trends and seasonality dynamics in Upper Hafren Catchment, Plynlimon, Wales. Weekly data used in the analysis has been collected from the Centre of Ecology and Hydrology over 20 years (1990-2010).Chang, (2008)have studied

water quality trends over 18 sites in Han river basin for a period of 1993-2002 for data collected from the Korea Ministry of Environment. Seasonal Mann-Kendall trend test has been used for trend analysis. Many researchers have studied long term water quality trends for understanding temporal and spatial variation(Ngwenya, 2006, LI *et al.*, 2009, Barakat *et al.*, 2016).

2.2 Summary

The literature on long term river water quality and flow analysis of rivers in the Ganga Basin is very scanty. A large amount of data collected by CPCB, CWC,and NRCD is available for past 30-40 years. But apart from basic temporal and spatial variation, statistical methods are rarely used by these agencies. Eventhese secondary data sets have rarely been used by researchers. Hence it is necessary to analyze these data sets to understand the river's hydro-chemical dynamics.

3. OBJECTIVES

As explained earlier, the two most important factors that affect the river health and its ecological and hydrological status are flow and water quality. Hence the current study is focused on variation in these two factors. Primary Objectives of the study are as follows:

3.1 Temporal and Spatial Variation in River Flow

River flow is a combined result of various climatological and geographical factors interacting within the drainage basin. Its assessment helps in the management of various water resources, river ecological health, construction of water structures, developing hydro-power potential, etc. The historical record of observed flow data assists in identifying, quantifying and interpreting hydrological trend and to form coping mechanisms for future flood or drought conditions.

3.2 Temporal and Spatial Variation in River Water Quality

There are basic two reasons for studying the variation in river water quality, first is the intrinsic interest in water quality changes due to various factors and for this large amount of public and private money is invested in water quality monitoring and improvement and this lead to interest in evaluating this expenditure. The second reason is large amount water quality data sets are available due to a consistent collection, monitoring and analysis of water quality at various water quality stations along rivers(Hirsch*et al.*, 1982). These datasets will help in detecting actual or potential water quality problems and then find its causes and remedial

techniques for it. It will also help in restating some pre-defined water quality standards or formulating some new standards(Antonopoulos*et al*., 2001).

3.3 Comparison between CWC and NRCD Data Sets

CWC and NRCD, these two agencies are collecting water quality data along river Ganga for almost 30 years. But both the agencies have different objectives in collecting and analyzing the river water quality. CWC'sprimary focus ison river water quality based on its usage for irrigation and agricultural needs while NRCD focuses onriver water pollution. Comparison between these two data sets will help in understanding the river water quality from two different perspectives.

3.4 Analysis of DO-BOD and Coliform Variation in River Ganga

A status report on River Ganga(MOEF, 2009) and Pollution Assessment of River Ganga (CPCB,2013)show that the tolerance limits for BOD and Coliform defined under surface water quality standards are mostly exceeded along entireGanga river stretch. But these reports also describe that DO levels are within the tolerance limit. This objective mainly aims to analyze this DO and BOD levels discrepancy and detect possible sources of high Coli Form Levels in river Ganga.

4. Methodology

4.1 Data Processing

The water quality and flow data have been collected from CWC and NRCD. The flow data collected from CWC is a daily flow data and water quality data collected from both the agencies is monthly data. One identical format has been decided and flow and water quality data for all stations are converted into that format in Microsoft-Excel and with help of MATLAB software. The flow and water quality data has been divided into five seasons for temporal and spatial analysis. The five seasons are decided based on prominent weather conditions in corresponding months. The seasons considered are as given in Table 4.1.

Table Error! No text of specified style in document.**.4: Seasons Considered in Analysis**

Winter	PostWinter	PreMonsoon	Monsoon	PostMonsoon
December-January	February-March	April-May	July-August	October-November

4.2 Removal of Outliers

Outliers are the unusually small or large values when compared with the rest of the data sets. These outliers can be due to incorrect data entry, errors in measurement techniques or instruments. These outliers have deleterious effects on statistical analysis such as increase error variance, reduce the power of statistical tests, violate assumptions of statistical tests, estimations can become biased(Osborne and Overbay, 2004). Standard Deviation and Box Plots are common methods for outlier detection(Seo, 2006). Out of these, Box plots method is used in this study. This method was developed by Tukey, (1977). It does not consider any distribution. By these plots, data distribution can be visualized by five number summary – minimum, first quartile (Q1), median, third quartile (Q2) and Maximum. Tukey, (1977) has defined outliers as strong and weak outliers. Strong outliers are values above or below 3x interquartile range [3(Q3-Q1)] whereas weak outliers are values above or below 1.5 x inter quartile range. In this study, only strong outliers are considered.Such Box plots are plotted for all water quality parameters season wise and outliers removed. In the case of flow, outliers are removed by manual observation only. But box plots are drawn for seasonal flow data to identify extreme flow conditions in respective seasons.

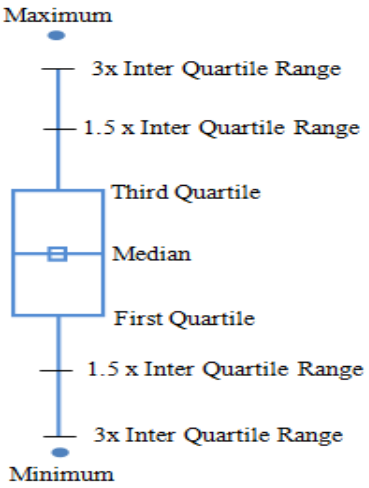

Figure Error! No text of specified style in document.**.2: Schematic Representationof Box Plots**

4.3 Temporal and Spatial Variation Plots for Flow and Water Quality

In case of Flow analysis, temporal and spatial variation is plotted season wise. Seasonal averages are considered for the plotting. For Water Quality analysis, initially temporal and spatial variation is plotted season-wise for all water quality parameters at all stations. A sample Dissolved Oxygen variation is shown in Figure 4.2for data gathered at Garhmukhteshwar.

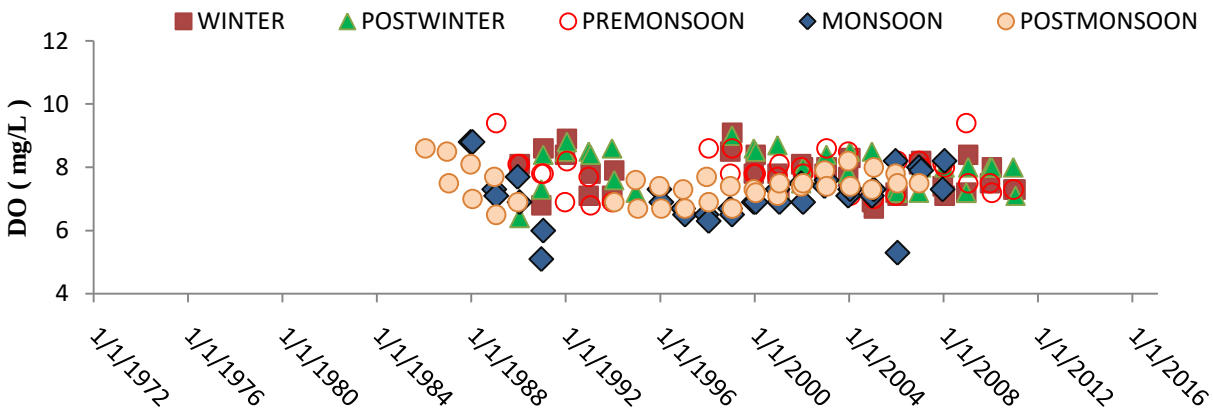

Figure Error! No text of specified style in document.**.3: Seasonal Variation in DO at Garhmukhteshwar**

It can be observed that seasonal variation in DO at Garhmukhteshwar is much less. Many water quality parameters showed very less seasonal variation between all five seasons but a good variation between lean seasons and monsoon seasons. Out of total 5 seasons, 4 seasons represent non-monsoon condition. Hence temporal and spatial plots are modified as Non-Monsoon and Monsoon seasonal plots. Non-Monsoon and Monsoon seasonal water quality plots are drawn by dividing the timeline into 4 decades from 1976 to 2015. Water quality data for these 10 years is plotted as median, minimum and maximum values. A sample plot is shown in Figure 4.3.

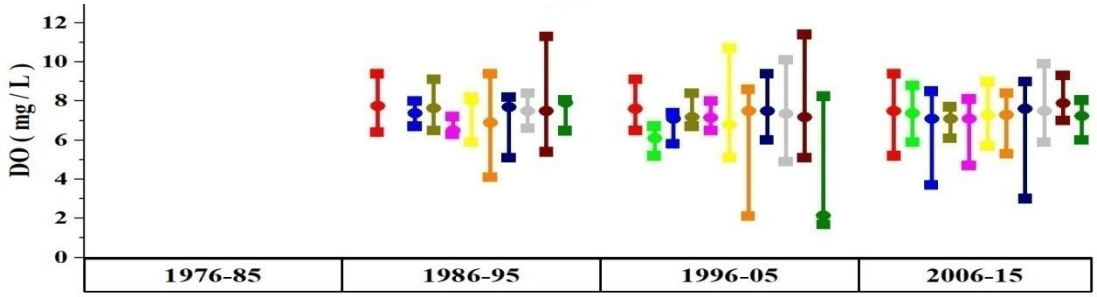

Figure Error! No text of specified style in document.**.4: DO Variation in Non-Monsoon season**

4.4 Seasonal Mean Variation

Seasonal mean variation is compared between five seasons as defined earlier. Two statistical tests are performed to check seasonal mean difference- one-way ANOVA and Paired-t-Test.

One-Way ANOVA

One-way Analysis of Variance (ANOVA) is used to determine the statistical significant mean difference between three or more independent data sets. Here the five seasonal datasets are considered as independent groups for analysis. F-distribution is used in One-Way ANOVA. The null hypothesis is stated as-

$H_o: \mu_1=\mu_2=\mu_3=\ldots=\mu_n$ $H_A: \mu_1\neq\mu_2\neq\mu_3=\ldots=\mu_n$

Where μ = group mean and n = number of groups. The Calculated F value compared with critical F value at 95 % confidence interval. If calculated F value is more than critical F value along with p-value less than set confidence level (95%) then a significant variation exists between the seasonal means. Here the One-Way ANOVA test is performed using Microsoft-Excel. A sample output of the test is presented in Table 4.2.

Table Error! No text of specified style in document.**.5: Sample Output for One-Way ANOVA Test**

ANOVA – Total Alkalinity at Garhmukhteshwar						
Source of Variation	**SS**	**df**	**MS**	**F**	**P-value**	**F Critical**
Between Groups	20115	4	5029	6.528	0.000	2.413
Within Groups	167951	218	770			
Total	188067	222				

In Table 4.2, SS = Sum of Squares, MS = Mean of Squares, df = degrees of freedom and FCritical= critical F value. F is the ratio of MS between Groups and MS within groups. Here we can see that F >FCritical for a p-value less than 0.05, hence the significant mean difference exists between seasonal means. But from One-Way ANOVA, one cannot understand which two specific groups differ in their means. To know this, those water quality parameters showing the significant seasonal mean difference in One-Way ANOVA are further analyzed by Paired-t-test.

Paired-t-Test

The paired t-test is used to determine whether the means of two seasonal datasets are the same or different. Here the Null Hypothesis is defined as – H_o: μ_d= 0 and H_A:$\mu\neq$ 0 in case of a two-tailed test. First, the differences between the data points are calculated then its mean and standard deviation is taken and corresponding test statistics are calculated. If calculated t value is more than critical t value fora p-value less than set confidence level(95%) then a significant

mean variation exist between the seasons of the parameter. Here the Paired-t-test is performed using SPSS software. A sample output is shown in Table 4.3

Table Error! No text of specified style in document.**.6: Sample Output for Paired-t-Test**

Total Alkalinity at Garhmukhteshwar		Paired Differences			t	df	Sig. (2-tailed)
		Mean	Standard Deviation	Std. Error Mean			
Pair 1	Winter – PostWinter	-3.28	23.68	3.61	-.908	42	.369
Pair 2	PostWinter-PreMonsoon	-10.07	21.29	3.25	-3.101	42	.003
Pair 3	PreMonsoon-Monsoon	26.05	47.076	7.35	3.543	40	.001
Pair 4	Monsoon-PostMonsoon	-10.72	22.22	3.39	-3.164	42	.003
Pair 5	PostMonsoon-Winter	-0.707	24.16	3.77	-.187	40	.852

From Table 4.13, we can infer that significant seasonal mean variation is observed for seasonal pairs like Post Winter- Pre Monsoon, Pre Monsoon- Monsoon and Monsoon-Post Monsoon as two-tailed p values are less than 0.05.

4.5 Trend Analysis

An association between concentration and time or spatial location is a trend. Purpose of trend analysis is to know whether the collected data over a frequent time interval is increasing, decreasing or almost constant. So that the corresponding causes can be analyzed and the overall condition of any water body can be understood. Trends in data can be statistically analyzed by parametric tests, non-parametric tests,and mixed tests. The parametric test includes simple linear regression while non-parametric test includes the Mann Kendall Test, etc. In the real world, the data will be mostly non-normal and trends may not be always linear hence the non-parametric tests will give better results than parametric tests.

Mann-Kendall Trend Test

Non-parametric trend test has many advantages over parametric test as a normal distribution of data and homogeneity in variance is not assumed; the test is not affected by outliers; the test can be applied to a dataset having values below detectable limits(Arora *et al.*, 2017).World Meteorological organization has recommended the Mann Kendall Test for detecting monotonic trends in hydrological data(Bera, 2017).Null Hypothesis (H_o) is defined as no trend whereas the alternative hypothesis (H_A) is for significant increasing or decreasing trend. Mann Kendall test statistics (S) is calculated for this. It is calculated through pair-wise comparison of each data point with all preceding data points and determining the number of increases, decreases,andties.S is calculated as follows-.

$$s = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} signum(Pj - Pi) \qquad Var(s) = \frac{[\{n(n-1)(2n+5)\} - \{\sum_{i=1}^{T}(ti(ti-1)(2ti+5))\}]}{18}$$

$$signum(Pj - Pi) = \begin{cases} 1 \ldots\ldots if\ (Pj - Pi) > 0 \\ 0 \ldots\ldots if\ (Pj - Pi) = 0 \\ -1 \ldots\ldots if\ (Pj - Pi) < 0 \end{cases} \qquad Z(s) = \begin{cases} \frac{s-1}{\sqrt[2]{Var(s)}} \ldots\ldots if\ s > 0 \\ 0 \ldots\ldots\ldots\ldots\ldots if\ s = 0 \\ \frac{s+1}{\sqrt[2]{Var(s)}} \ldots\ldots if\ s < 0 \end{cases}$$

Where p_i and p_j are successive data points in a given time series.Then Mann Kendall Z statistics is calculated with zero mean and varianceof S. It is compared with standard Z for checking the significance of the test.Here n is a total number of data points and t_i is a number of ties in data series. Positive values of S or Z give increasing trend whereas negative value gives a decreasing trend.

Theil - Sen Slope Estimator

Along with detecting the trend, its slope is also important. The slope of the trend (change per timeline i.e. yearly, monthly) is calculated by the Theil-Sen slope estimator. The slope of the trend was developed by Theil, (1950) then discussed by Sen, (1968) and explained in Statistics Methods for Environmental Pollution Monitoring by Gilbert, (1987). In this method, total n(n-1)/2 slope estimates (Q) are calculated. Then the median of these slope estimates is considered as Thiel-Sen slope (β) for the trend. β is calculated as follows.

$$\beta = Median[\frac{Pj - Pi}{j - i}]$$

where Pi and Pj are successive data points in given time series and i and j are indices of data points. Trend test and slope estimate is carried by Microsoft-Excel VBA code considering all 5 seasons for flow and water quality. A sample output of Trend Analysis is presented in Table 4.4.

Table Error! No text of specified style in document.**.7: Trend Analysis for Alkalinity in Winter Season**

Station	MK Statistic	p-value (at 95%)	Slope Code	Slope (change/unit)
Garhmukhteshwar	-65	0.51		-0.11
Kachlabridge	126	0.17		0.55
Fatehgarh	-246	0.07		-0.48
Ankinghat	-99	0.47		-0.26

Kanpur	340	0.00	+	1.43
Bhitaura	88	0.25		0.76
Shahzadpur	-740	0.00	-	-1.16
Allahabad	-993	0.00	-	-0.68
Mirzapur	-742	0.00	-	-0.85
Varanasi	-231	0.35		-0.29
Buxar	-2	0.50		-6.33

In Table 4.4, MK statistics is S values. From Slope code, it can be inferred that alkalinity significantly increases at Kanpur with a slope of 1.43 mg/L as $CaCO_3$ per year while at stations Shahzadpur, Allahabad and Mirzapur its trend is significantly decreasing.

4.6 Correlation Analysis

Correlation is a measure of how things are associated with each other. Correlation is categorized as positive correlation, negative correlation and no correlation based on the correlation coefficient. It helps in understanding the physical, chemical and biological nature of the river and to validate the long-term data collected by various agencies.Most commonly used correlation in statistics is Pearson's Correlation. It gives the linear relationship between two variables. Pearson's Correlation coefficient is denoted as r. Its value ranges from -1 to 1 where r = -1 means strong negative correlation, r = 1 means strong positive correlation and r = 0 means no correlation.Then the significant test is performed to know any evidence about the linear relationship in populations. The Null hypothesis is H_0: population coefficient (ρ) = 0 and Alternative hypothesis H_A: population coefficient (ρ)≠ 0. The significance level (p-value) of correlation is calculated by calculating t value and comparing it with critical t value at (n-2) degrees of freedom. The correlation coefficient and t value are calculated as follows-

$$r = \frac{\sum(x - mx)(y - my)}{\sqrt[2]{(\sum(x - mx)^2)(\sum(y - my)^2)}} \qquad t = \frac{r\sqrt[2]{n-2}}{\sqrt{1 - r^2}}$$

Where x and y are two vectors of length n; mx and my are means of x and y respectively.Here the confidence level is considered as 95%. If the p-value is less than 0.05 then significant correlation exists between x and y. Correlation analysis is performed for all water quality parameters by considering two seasons Monsoon and Non-Monsoon in software R-studio.Correlation analysis is carried out as per following groups is given in Table 4.5.

Table Error! No text of specified style in document.**.8: Correlation Analysis Water Quality Groups**

Sr. No.	Water Quality Parameters
Group 1 1	EC, TDS, Ca, Mg, Na, K

Group 2	TDS, F, Cl, SiO2, SO4
Group 3	HCO_3, CO_3, Total Alkalinity, pH, PO_4
Group 4	Total Hardness, Ca, Mg, Total Alkalinity
Group 5	NH_3-N, NO_3, PO_4, DO, Temperature
Group 6	BOD, COD, TC, FC, DO

A sample software output of correlation analysis is shown in Figure 4.4.

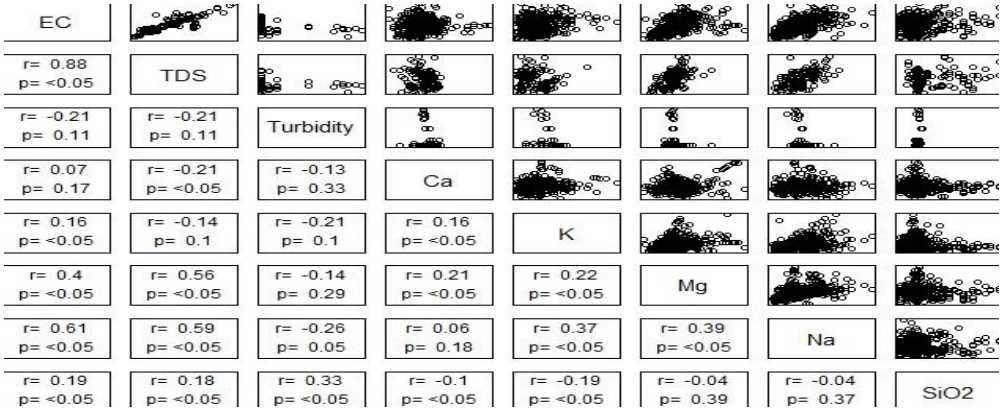

Figure Error! No text of specified style in document.**.5: Correlation analysis for EC, TDS, Turbidity,and Cations at Allahabad in Non-Monsoon Season**

From Figure 4.4, significant p-values is denoted as p = < 0.05. EC-TDS, TDS-Ca, Mg, Na, SiO_2, show the significant positive correlation among them.

5. Results and Discussion

5.1 Temporal and Spatial Variation in River Flow

As explained earlier, to study the variation in the flow of river Ganga in the selected stretch, seasonal averages are plotted for 11 CWC stations for past 4 decades from 1972 to 2015.The 11 CWC stations are divided into 3 groups based on the canals and tributaries meeting the river Ganga, Garhmukhteshwar to Fatehgarh as Group 1, Ankinghat to Shahzadpur as Group 2 and Allahabad to Buxar as Group 3. Figures 5.1 to 5.3 show flow variation in lean seasons namely Winter, Post-Winter and Pre-Monsoon.

For Group 1, it is observed that the flow substantially reduces after Garhmukhteshwar. It is mainly due to the Lower Ganga Canal and Parallel-Lower Ganga Canal. A large amount of flow is diverted into these canals for irrigation purposes. Flow increases from Ankin ghat and becomes almost comparable with the flow at Garhmukhteshwar is due to the two tributaries, Ramganga

at Kusumkher and Kali at Kannauj meeting the river Ganga. As per the status report of River Ganga if flow in main-stream and its tributaries considered as 100 % then Ramganga river contributes almost 3-4% of total flow. It can be observed that for stations in Group 2 (Ankinghat, Bhitaura, Kanpur and Shahzadpur) the flow is almost same for all the three lean seasons.

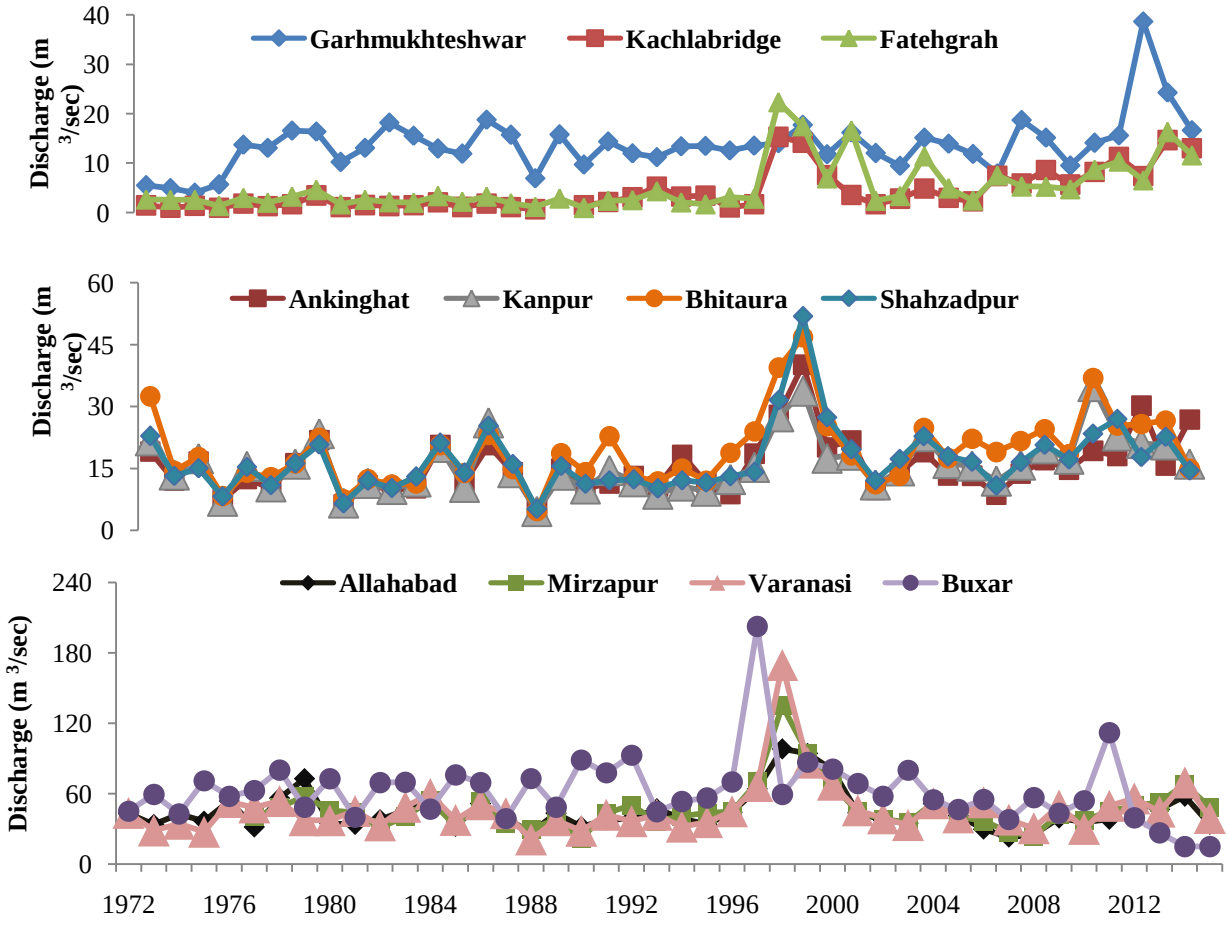

Figure Error! No text of specified style in document.**.6: Temporal and Spatial Flow Variation in Winter Season**

For Group 3, in all 3 seasons flow increases to around 2-3 times that of earlier flow due to the confluence of a major tributary of river Ganga, the Yamuna just before Allahabad. River Yamuna along with Chambal contributes almost 25% of total flow, according to a status report of River Ganga. From Allahabad to Buxar, tons and Gomati along with other small tributaries join the main stream hence flow increases further.

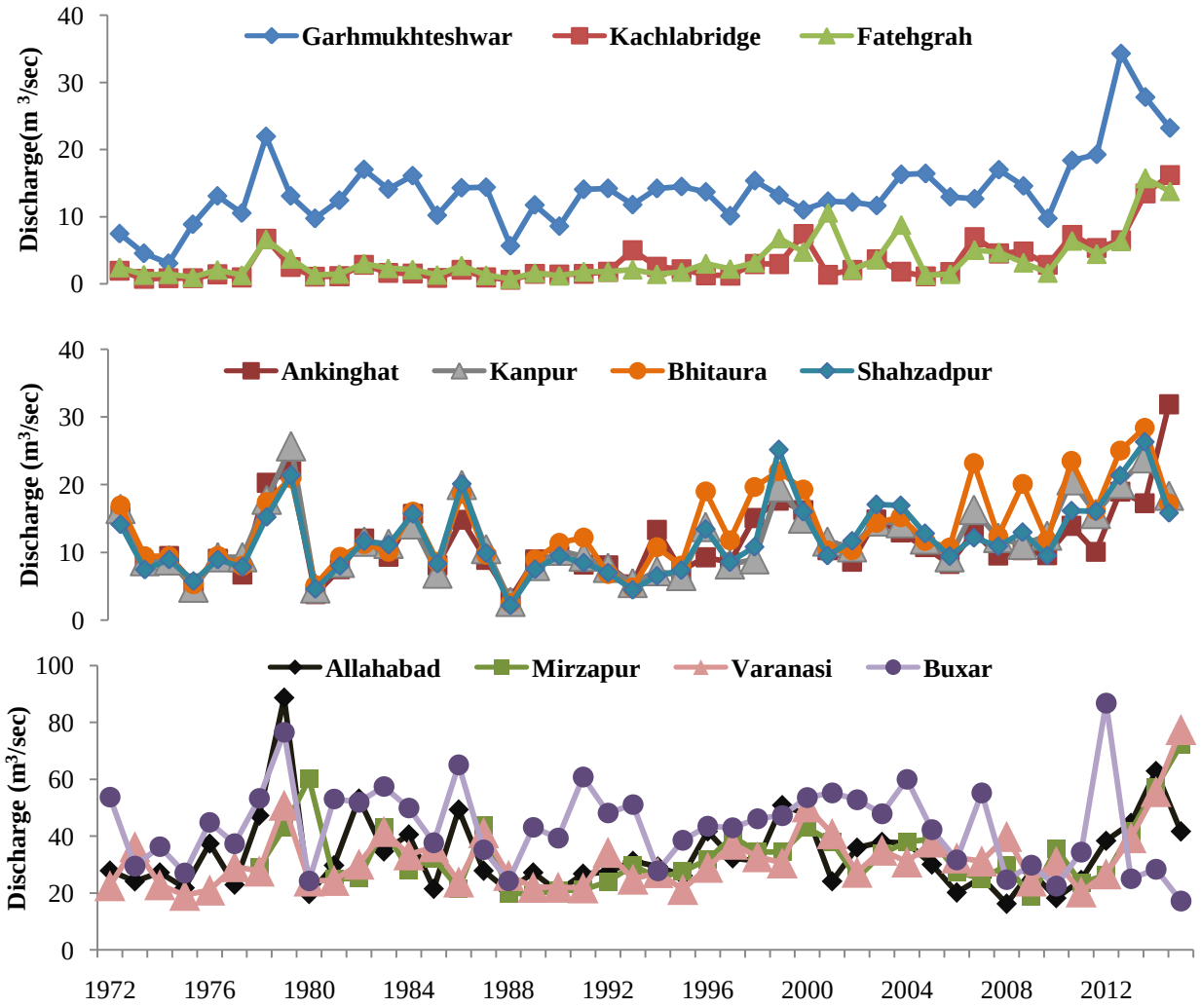

Figure Error! No text of specified style in document.**..7: Temporal and Spatial Flow Variation in Post-Winter Season**

In the stretch from Garhmukhteshwar to Buxar, highest flow is at Buxar and lowest at Fatehgarh. In all 3 seasons, over these years some sudden peaks in the flow are observed like for Winter in 1997-1999,Post-Winter in 1977-1979 and Pre-Monsoon in 1977-1979 and 1982-1984. All these peaks could be related to high rainfall observed in these years compared to other years(Indian Water Portal metadata).

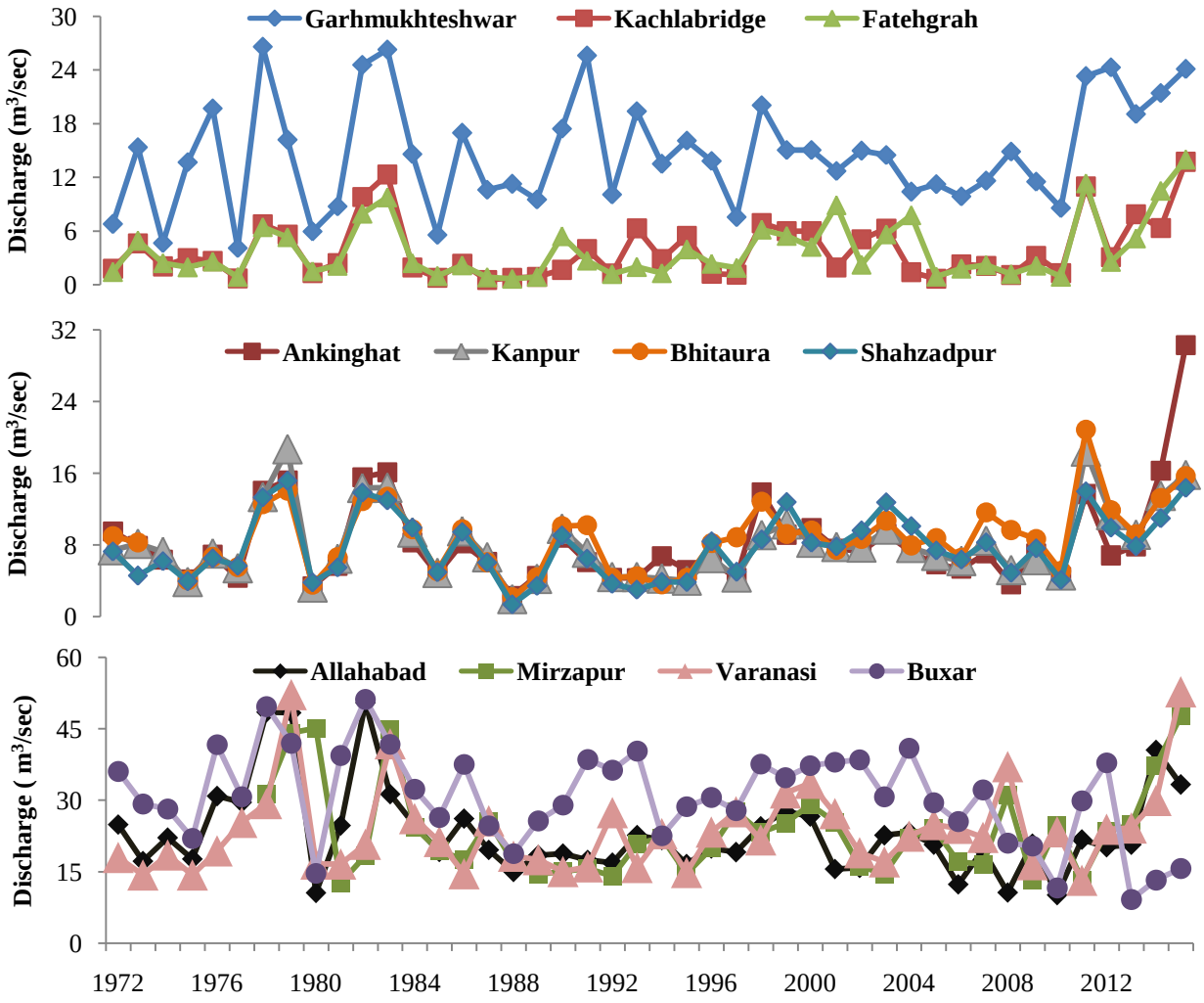

Figure Error! No text of specified style in document.**.8: Temporal and Spatial Flow Variation in Pre-Monsoon Season**

The monsoons and post-monsoon flow variation are shown in Figures 5.4 and 5.5. During monsoon and post-monsoon season; flows in Group1 for all three stations are comparable. This is due to the insignificant abstraction for irrigation purposes compared to surface runoff from the catchment. Though the precipitation is not same in monsoon and post-monsoon seasons as the magnitude of flow in post-monsoon is very less than that of monsoon but the trend is same. This is perhaps due to the after-effects of monsoon. As in case of earlier seasons flows after Allahabad are almost 3-4 times higher than at stations before it.

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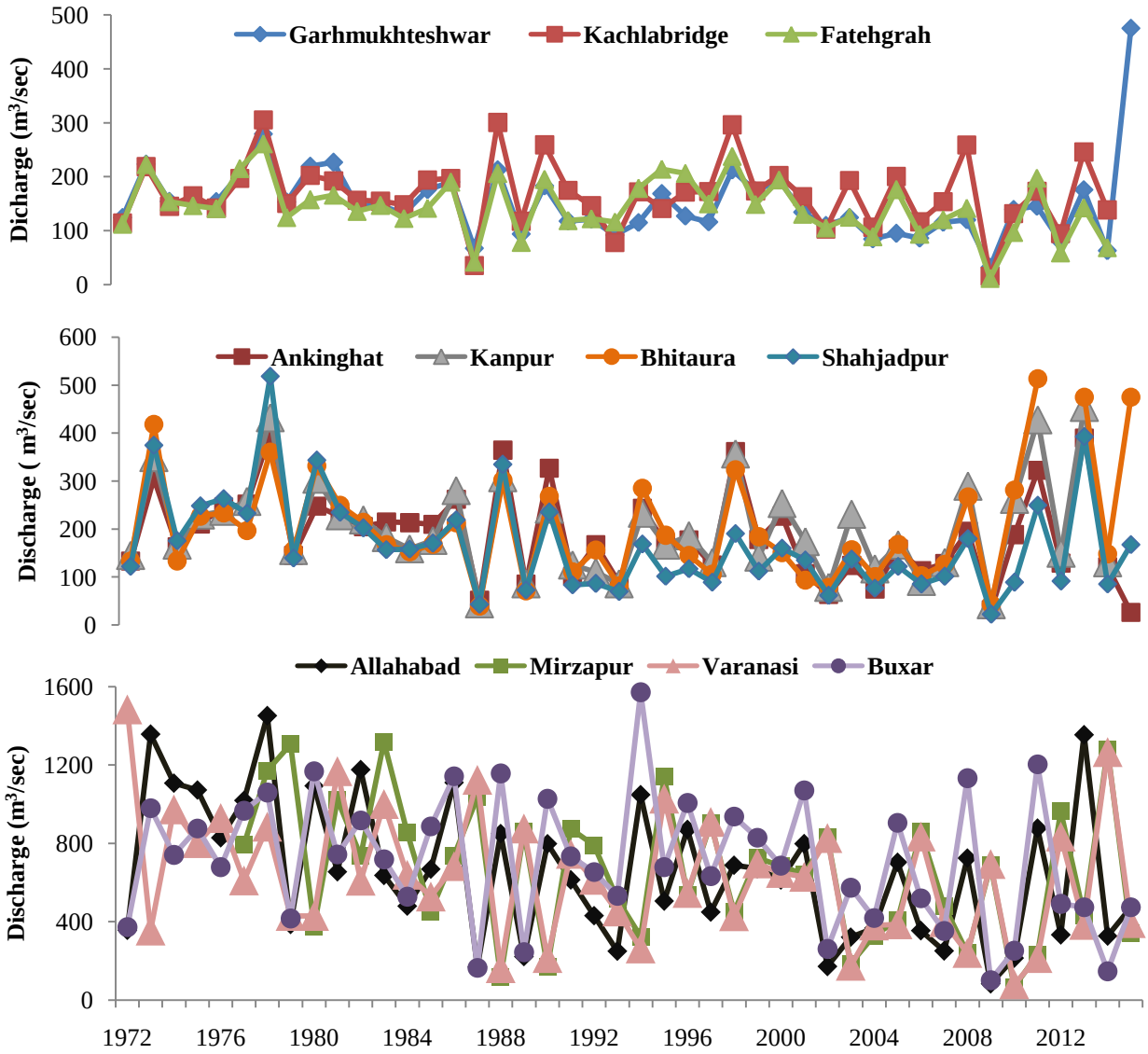


Figure Error! No text of specified style in document..**9: Temporal and Spatial Variation in Monsoon Season**

As observed in other seasons, extreme flows are not observed in monsoon. In Post-Monsoon, peaks are observed in 1985-87, 1997-99. Again these could be related to the rainfall data and these peaks are attributed to increase in precipitation.

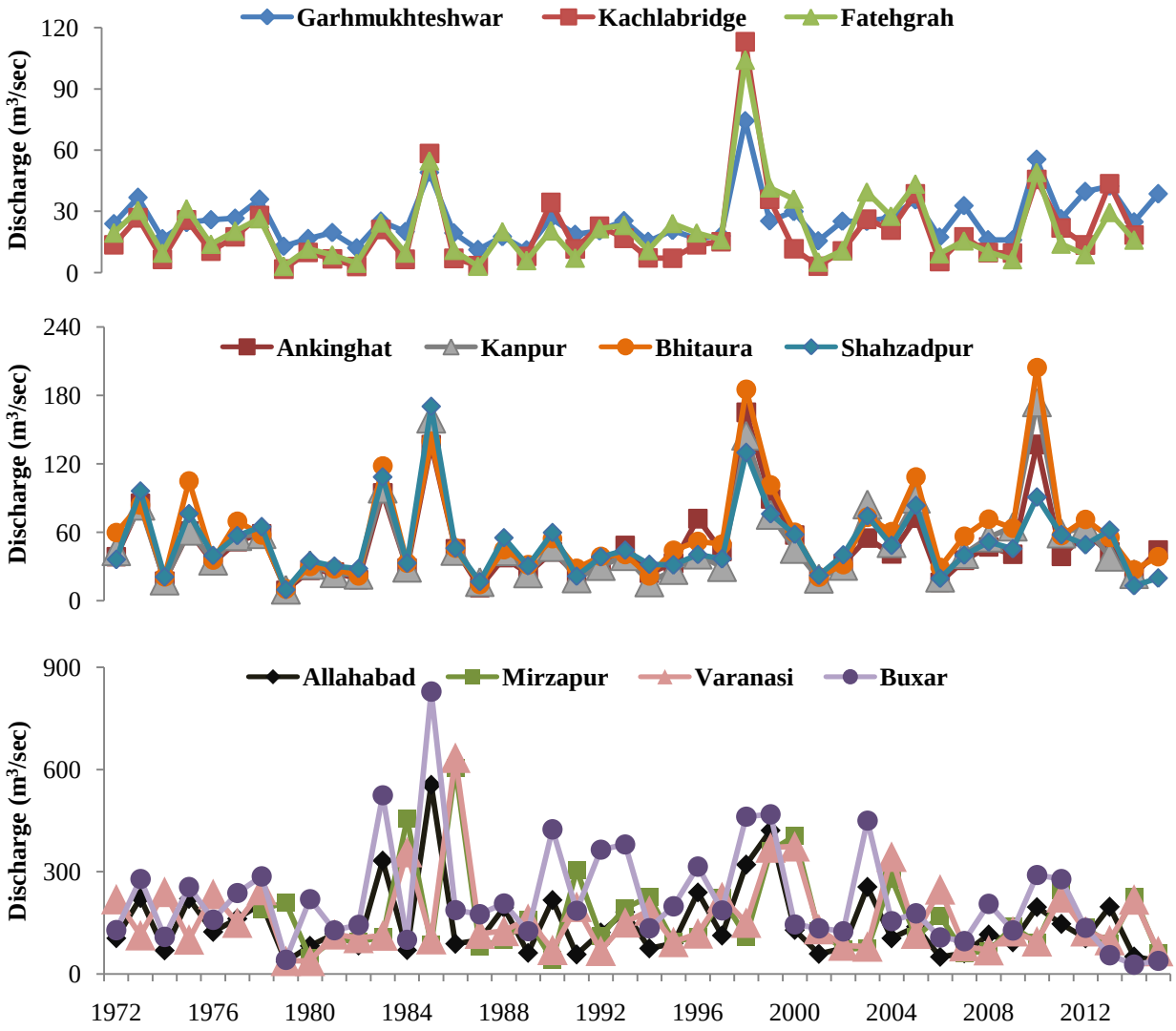


Figure Error! No text of specified style in document..**10: Temporal and Spatial Flow Variation in Post-Monsoon Season**

Out of above 5 seasons, 4 seasons represent the Non-Monsoon Season. Hence to have a complete understanding of how flows vary in Monsoon and Non-Monsoon season, Flow variation is also plotted considering only these two seasons for all stations. Non-monsoon season period is from September to June while monsoon season is from July to August. For this, the time-series has been divided into mainly 5 parts based on some structural and seasonal changes along the river. These 5 parts are – 1972-1980; 1981-1988; 1989-1996; 1997-2006; 2007-2015. After 1980 the Parallel Lower Ganga Canal became operational for irrigation purpose, high rainfall was noticed in non-monsoon seasons from 1997 to 2000, and then Tehri Dam operations started after 2006. Figure 5.6 shows flow variation plotted as median,

maximum and minimum flows over these five time spans in monsoon and non-Monsoon season.

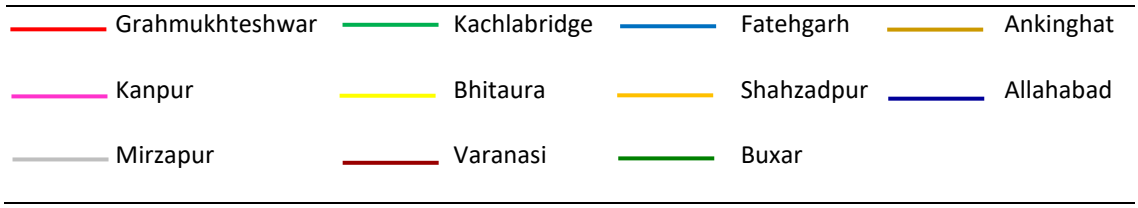
In recent 10 years, the maximum flows for Garhmukhteshwar to Shahzadpur is found to increase and after Shahzadpur decreased as compared with earlier flows. Hence in recent 10 years, the maximum flows at all stations are comparable which not the case was for earlier years. The effect of high rainfall and Tehri Dam is hardly noticed in these graphs. Parallel Lower Ganga Canal shows very little effect on flows at Fatehgarh and Kachla Bridge.

To see the effect of tributaries and canals on river flow,an average factor by which flow changes in every seasondue to two main tributaries Ramganga and Yamuna and Lower Ganga Canal has been calculated.

Table Error! No text of specified style in document..**9: Factor by Which Flow Changes due to Tributaries and Canals**

Effect of Lower Ganga Canal (Garhmukhteshwar-Fatehgarh)					Effect of River Ramganga (Fatehgarh- Ankinghat)					Effect of River Yamuna (Shahzadpur- Allahabad)				
W	PW	PM	M	POM	W	PW	PM	M	POM	W	PW	PM	M	POM
039	0.25	0.25	1.01	0.77	4.35	4.47	2.92	1.36	2.70	2.86	3.13	3.41	4.12	2.96

From Table 5.1, we can observe that Lower Ganga Canal reduces the flow to almost 25% of total flow at Grahmukhteshwar. Also flow increases by 4 times after Fatehgarh due to joining of Ramganga and Kali in non-monsoon season. In case of river Yamuna, the maximum increase in flow is observed during monsoon season than non-monsoon. But in general the increasein flow due to Yamuna in all seasons is almost comparable.



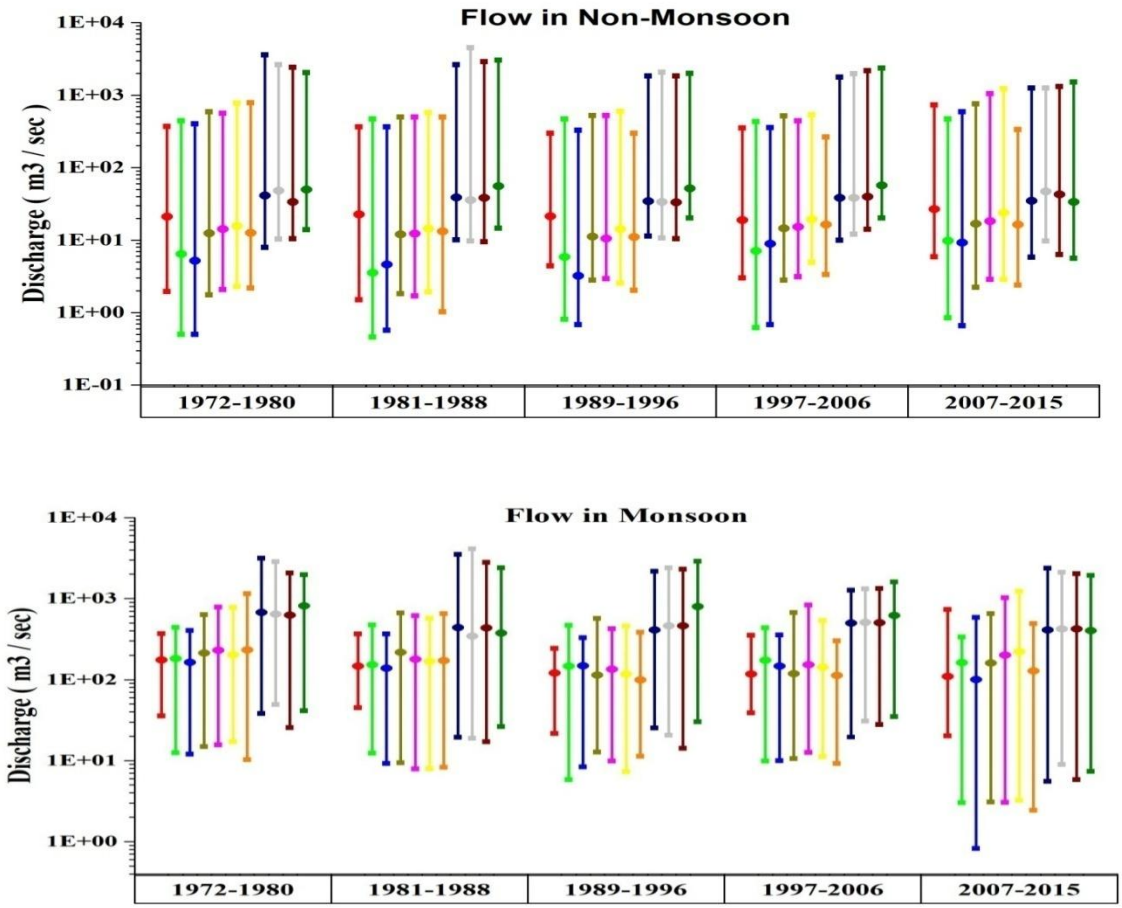


Figure Error! No text of specified style in document..**11: Flow Variation in Monsoon and Non-Monsoon Seasons**

Statistical Analysis of River Flow

After studying the temporal and spatial plots of river flow over these year in different seasons, one can notice the seasonal variation in river flow but this variation can be more Preciously demonstrated by statistical analysis. The statistical analysis carried on river flow includes Box plots which are mainly important for analyzing extreme flow in any season. Significant seasonal mean difference is observed by One-Way ANOVA and t-Test. Along with extreme flows and significant mean differences, trend in river flow is also important. Trend analysis is done by Mann-Kendall Trend Test and Theil-Sen Slope Estimator.

A] Box and Whisker Plots

To analyze flow distribution over the complete time line of our study, Box and Whisker plots are drawn. From all five season box-whisker plots we can observe that, all Non-Monsoon seasons

have extreme flows whereas in Monsoon season extreme flows are absent. At all stations Monsoon flows are highest then Winter flows then Post-Monsoon and Post-Winter flows and least flows are of Pre-Monsoon. Station wise flow variation can also easily noticed from these plots. These Box plots are added in Annexure.

B] Significant Seasonal Mean Difference

Seasonal mean difference is analysedby One-Way ANOVA and Paird-t-Test. Significance of the test is checked at 95 % confidence interval. One-way ANOVA carried out station wise, showed significant difference in seasonal means at all 11 stations. From Table 5.2, where YES means significant mean different exist between two seasons and blank cell represents no difference between seasons, we can observe that during all seasons the mean flow is different at all stations except Garhmukhteshwar, Kachlabridge and Fatehgarh between Post-Winter and Pre-Monsoon.

Table Error! No text of specified style in document.**.10 Results of Paired-t-Test Analysis for Flow**

Station	W-PW	PW-PM	PM-M	M-POM	POM-W
Grahmukhteshwar			YES	YES	YES
Kachlabridge	YES		YES	YES	YES
Fatehgarh	YES		YES	YES	YES
Ankinghat	YES	YES	YES	YES	YES
Kanpur	YES	YES	YES	YES	YES
Bhitaura	YES	YES	YES	YES	YES
Shahzadpur	YES	YES	YES	YES	YES
Allahabad	YES	YES	YES	YES	YES
Mirzapur	YES	YES	YES	YES	YES
Varanasi	YES	YES	YES	YES	YES
Buxar	YES	YES	YES	YES	YES

C] Trend Analysis

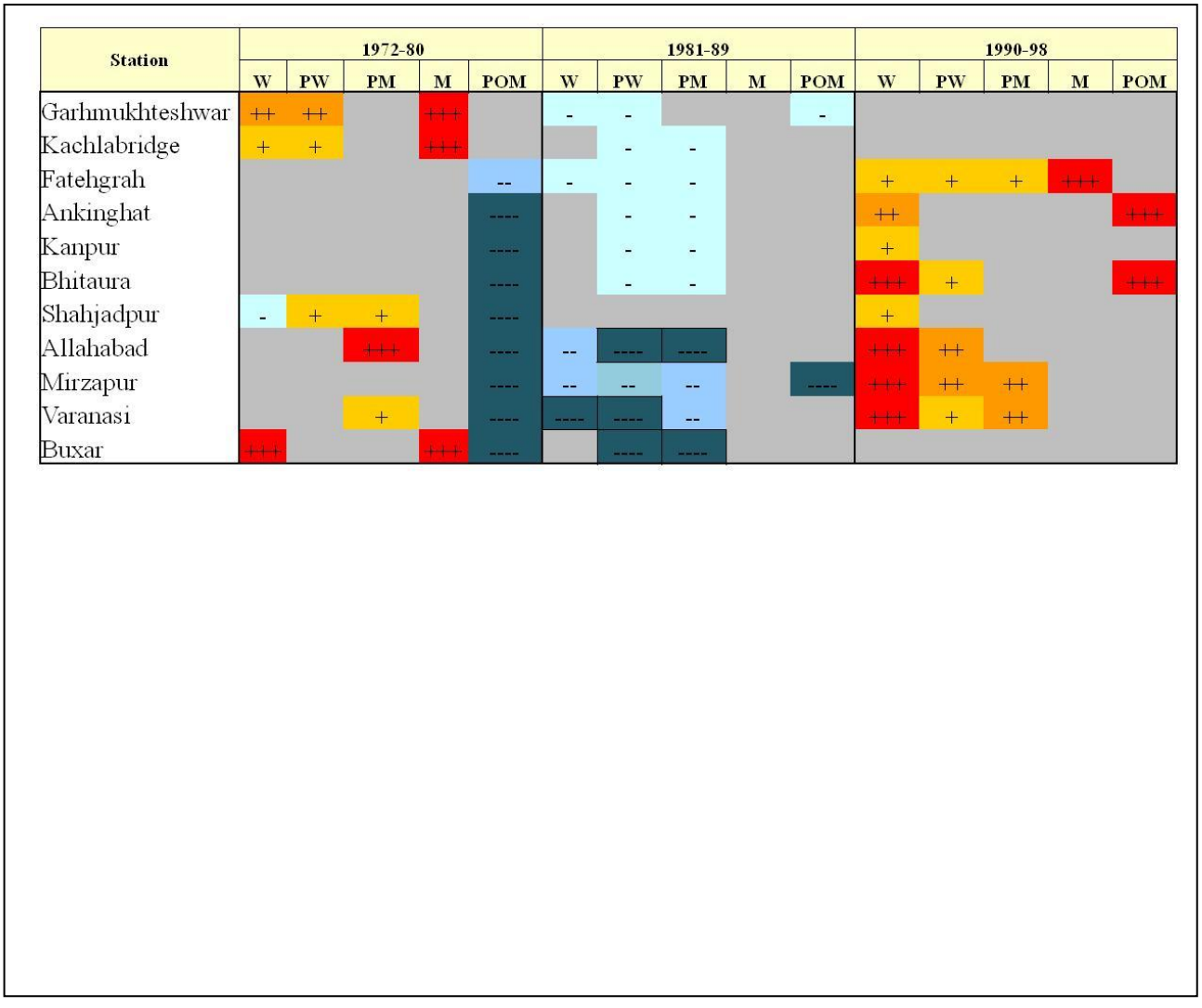
Non-Parametric, Mann-Kendall trend test is used to determine the trend in river flow. Along with detecting the trend, its magnitude is also important. The magnitude of slope (change per timeline i.e. yearly, monthly) of the trend is calculated by Theil-Sen slope estimator.

For better understanding of trend in flow, complete flow data isdivided into 5 groups each of 9 years starting from 1972 to 2015.Trends are observed in each season separately for these 5 groups.If yearly data is considered for 9 year trend analysis, then only 9 data points will be available which are not sufficient to carry the test hence ten daily data is considered here. The

slope obtained in this test is thus change per ten daily observations. Apart from this, trends are also calculated by considering all years together. Trend analysis slopes are added in Annexure.

Magnitudes of significant slope for lean seasons are very less as almost 80% slope values are less than 5 m3/sec per ten daily time period. Highest slope observed in these seasons is 13. Whereas magnitudes of significant slope in Monsoon season are very high and vary from 20 to130 m3/sec per ten daily. But it can be seen that hardly any slopes are significant in Monsoon which explains no trend in Monsoon season.

Again in Post-Monsoon season the significant slopes reduce to large extent from Monsoon except stations Shahzadpur and all downstream stations. From Figure 5.7 in all seasons, significant increase in slope is observed during 1990-98 and 2008-15 while slopes are decreasing during 1981-89 and 1999-2007. In all 9 year groups, Post-Monsoon flows are decreasing except for 1990-98. When the trend analysis carried for complete time-line as shown in Figure 5.8, flows in winter and Post-Winter are increasing while flows in Monsoon are decreasing. All these changes are not noticeable in simple 2D plots due to very less slope and hence it can be explained in detail by trend analysis.



Station	1999-07					2008-15				
	W	PW	PM	M	POM	W	PW	PM	M	POM
Garhmukhteshwar				----		+++	++	++	+++	+++
Kachlabridge			-			+	+	+		
Fatehgrah		-	-		----	++	++	++		
Ankinghat	--	-	-		----		++	++		
Kanpur	-	-	-				++	++		----
Bhitaura			-						+++	----
Shahjadpur	----	-	-	----	----		++		+++	
Allahabad	----	----	--		----		+++	+++		----
Mirzapur	----	--	-		----	+++	+++	+++		----
Varanasi	----				----		+++	+++		----
Buxar	----	--	--		----	----		--		----

W	Winter
PW	Post-Winter
PM	Pre-Monsoon
M	Monsoon
POM	Post-Monsoon
Positive Trend with increasing Slope	+ ++ +++
No Trend	
Negative Trend with Decreasing slope	- -- ---

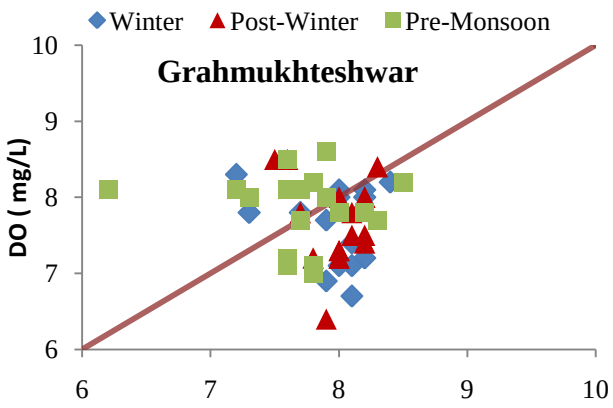
Station	Winter	Post Winter	Pre monsoon	Monsoon	Post Monsoon
Garhmukhteshwar	+	++		-	
Kachlabridge	+	+			
Fatehgrah	+	+			
Ankinghat	+	+		-	
Kanpur	++	++		-	
Bhitaura	++	++			
Shahjadpur	++	++		-	
Allahabad				----	
Mirzapur				----	
Varanasi		++		----	
Buxar			--	----	

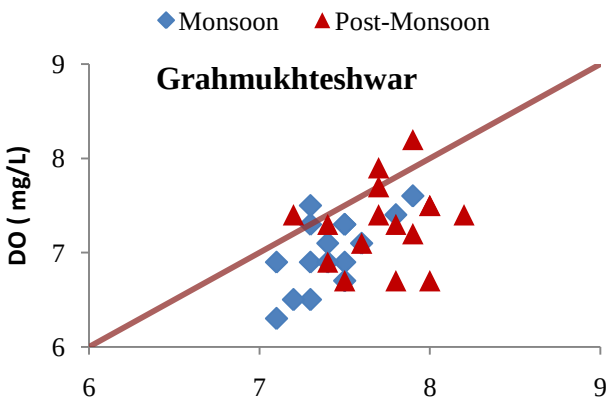
Figure Error! No text of specified style in document.**.12 Trend Analysis considering 9 Years Interval and Complete Timeline**

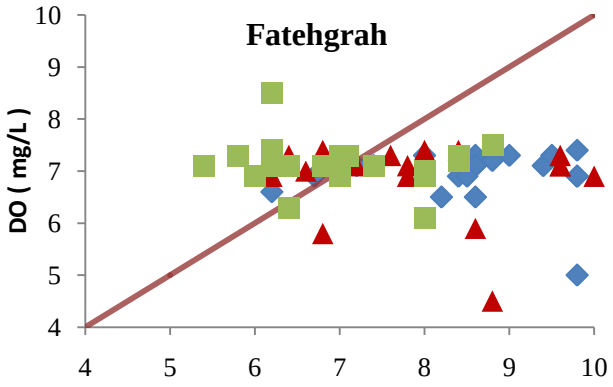
5.2 Comparison between Two Water Quality Datasets

CWC and NRCD, Two water quality data sets are used in this study for analyzing the river water quality as explained earlier. Before going into detail analysis of water quality based on these two data, comparison of various water quality parameters analyzed by these two agencies separately is very important. The NRCD data is available only for DO, BOD, COD and Coli Forms.

X Axis : NRCD Data Y Axis : CWC Data


Winter
Post-Winter
Pre-Monsoon
Grahmukhteshwar
DO (mg/L)
10
9
8
7
6
6
7
8
9
10


Monsoon
Post-Monsoon
Grahmukhteshwar
DO (mg/L)
9
8
7
6
6
7
8
9


Fatehgrah
DO (mg/L)
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6
7
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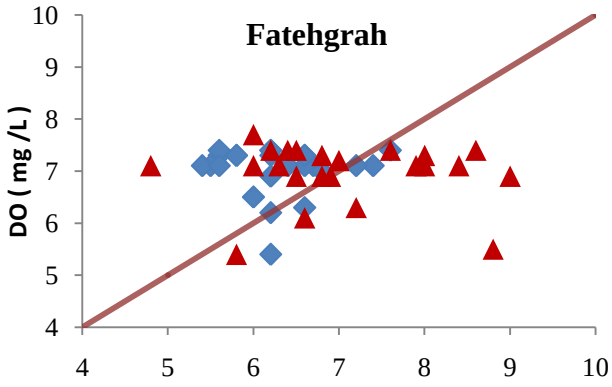
10


Fatehgrah
DO (mg /L)
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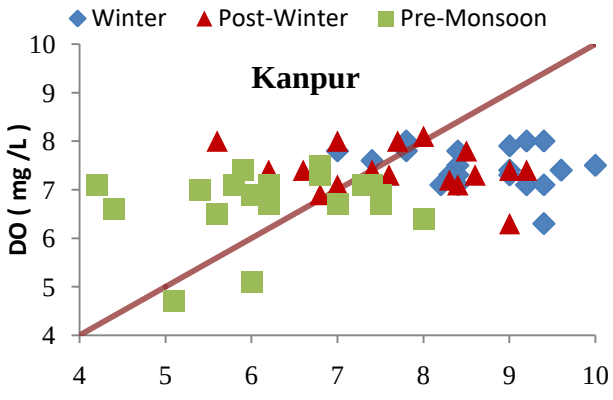
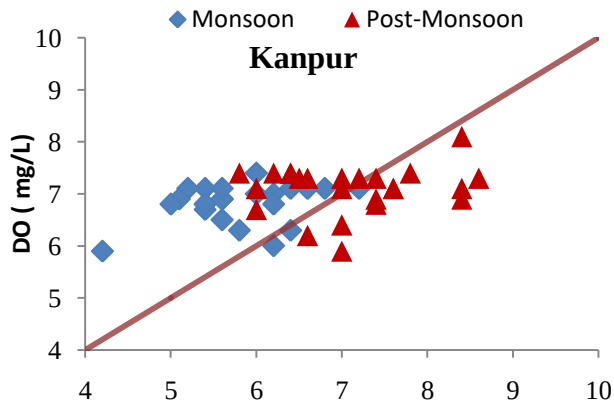

Winter
Post-Winter
Pre-Monsoon
Kanpur
DO (mg /L)
10
9
8
7
6
5
4
4
5
6
7
8
9
10


Monsoon
Post-Monsoon
Kanpur
DO (mg/L)
10
9
8
7
6
5
4
4
5
6
7
8
9
10

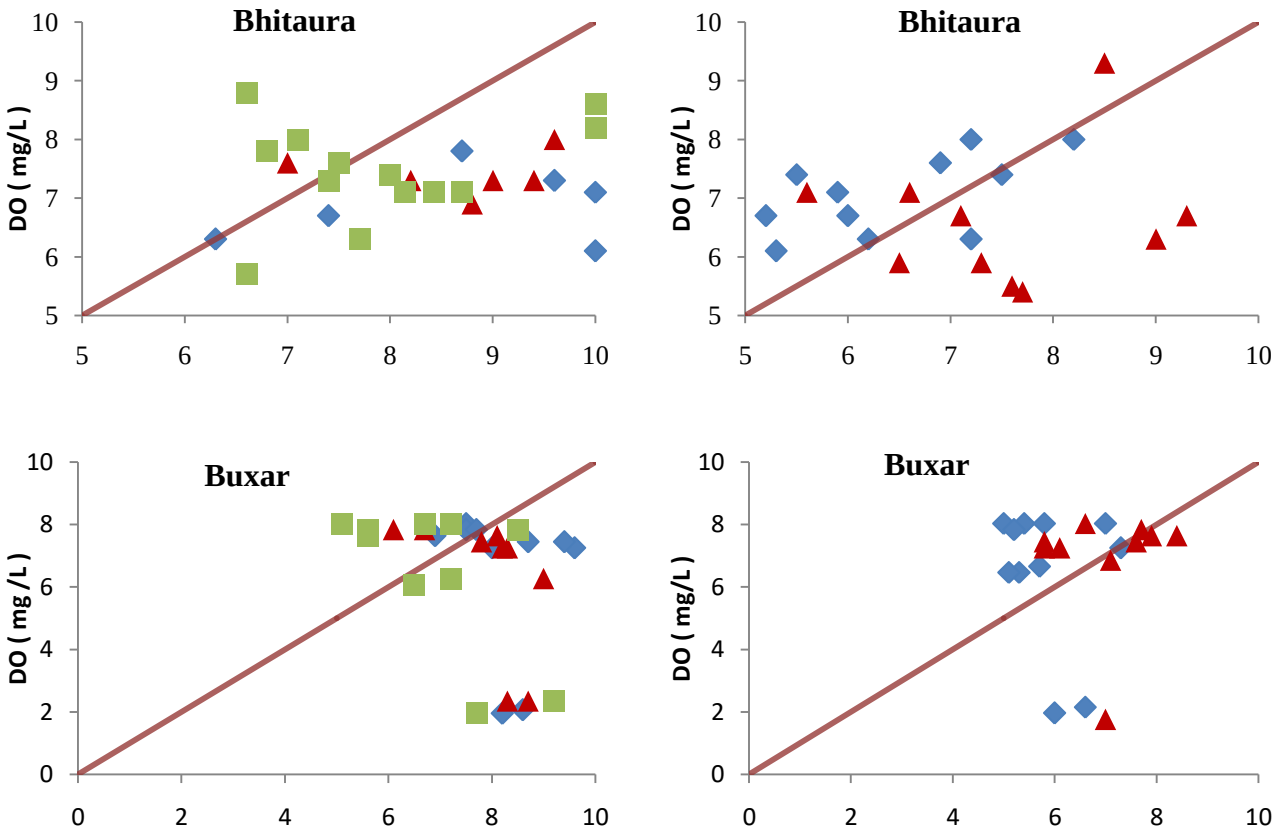


Figure Error! No text of specified style in document.**.13 Comparison of Dissolved Oxygen**

Figure 5.8 shows in DO comparison at some stations where the red line represents a 45^0 line. At Garhmukhteshwar and Bhitaura, DO monitored by CWC and NRCD is comparable in all seasons. For Fatehgarh and Kanpur, CWC mainly reports a constant DO between 6-8 mg/L in all seasons where as the variation in DO is captured by NRCD data. NRCD data shows DO variation in 5 to 10 mg/L. At Buxar, for some duration CWC reported very low DO in range of 2-3 mg/L while NRCD reported high DO in all seasons.

For Allahabad, Mirzapur and Varanasi,CWC data is available from 1987 while NRCD data is available only after 2000. In case of Pre-Monsoon a comparable DO values are reported by NRCD and CWC. During Winter the NRCD reports high DO values while during Monsoon low values as compared with CWC.

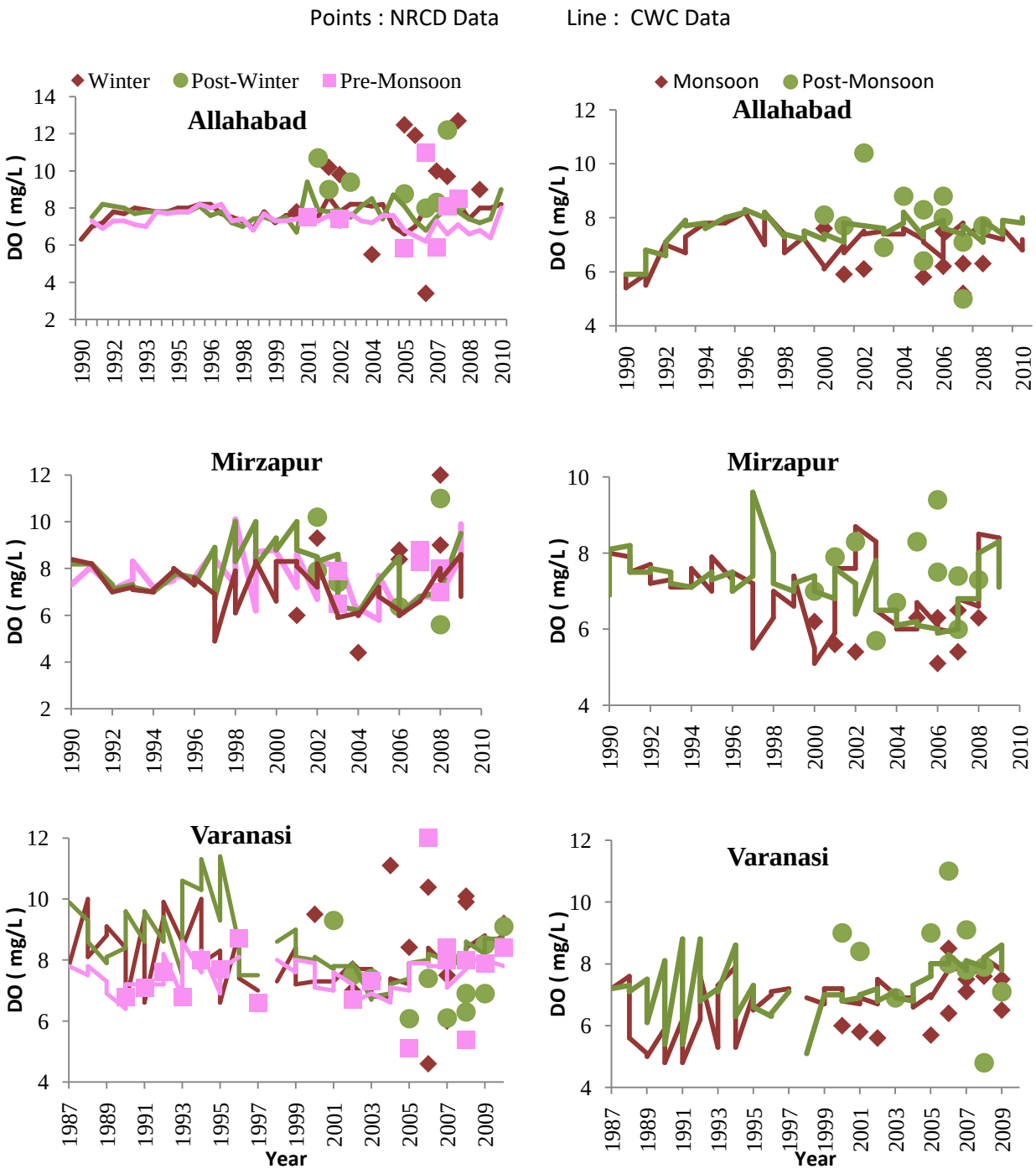


Figure Error! No text of specified style in document..**14 Dissolved Oxygen Comparison At Allahabad ,Mirzapur and Varanasi**

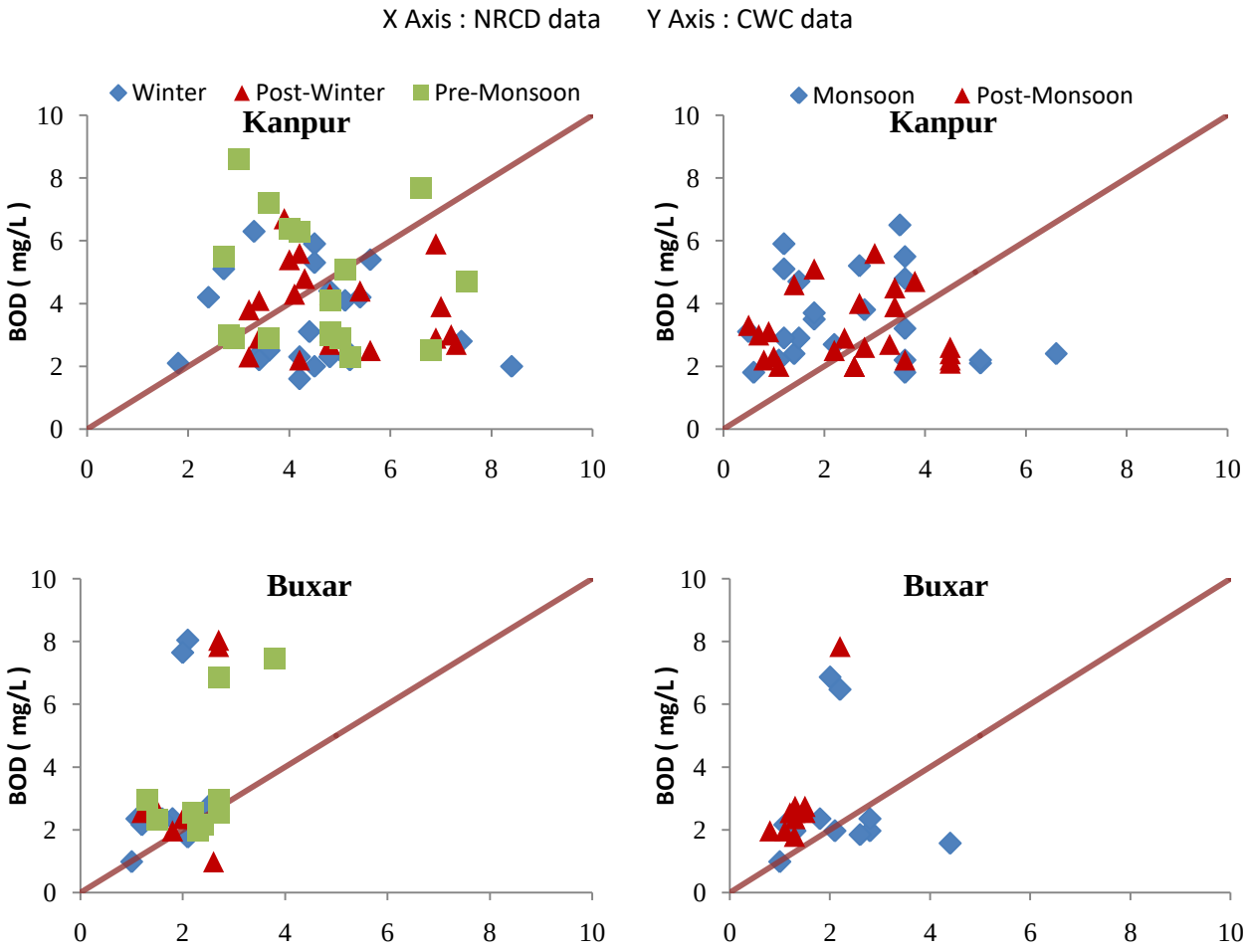


Figure Error! No text of specified style in document.**.15 BOD Comparison at Kanpur and Buxar**

From Figure 5.10 and 5.11 , in the selected stretch BOD data monitored by both agencies is available for Kanpur, Allahabad, Mirzapur, Varanasi and Buxar only. During lean seasons BOD values reported by both the agencies at Kanpur are comparable. But for Monsoon and Post-Monsoon at Kanpur and all seasons at Buxar, NRCD reports high BOD than CWC.For stations Allahabad, Mirzapur and Varanasi, variation in BOD is observed in NRCD data over seasons as compared with CWC. But in general the BOD monitored by both the agencies is in range of 0 to 9 mg/L.

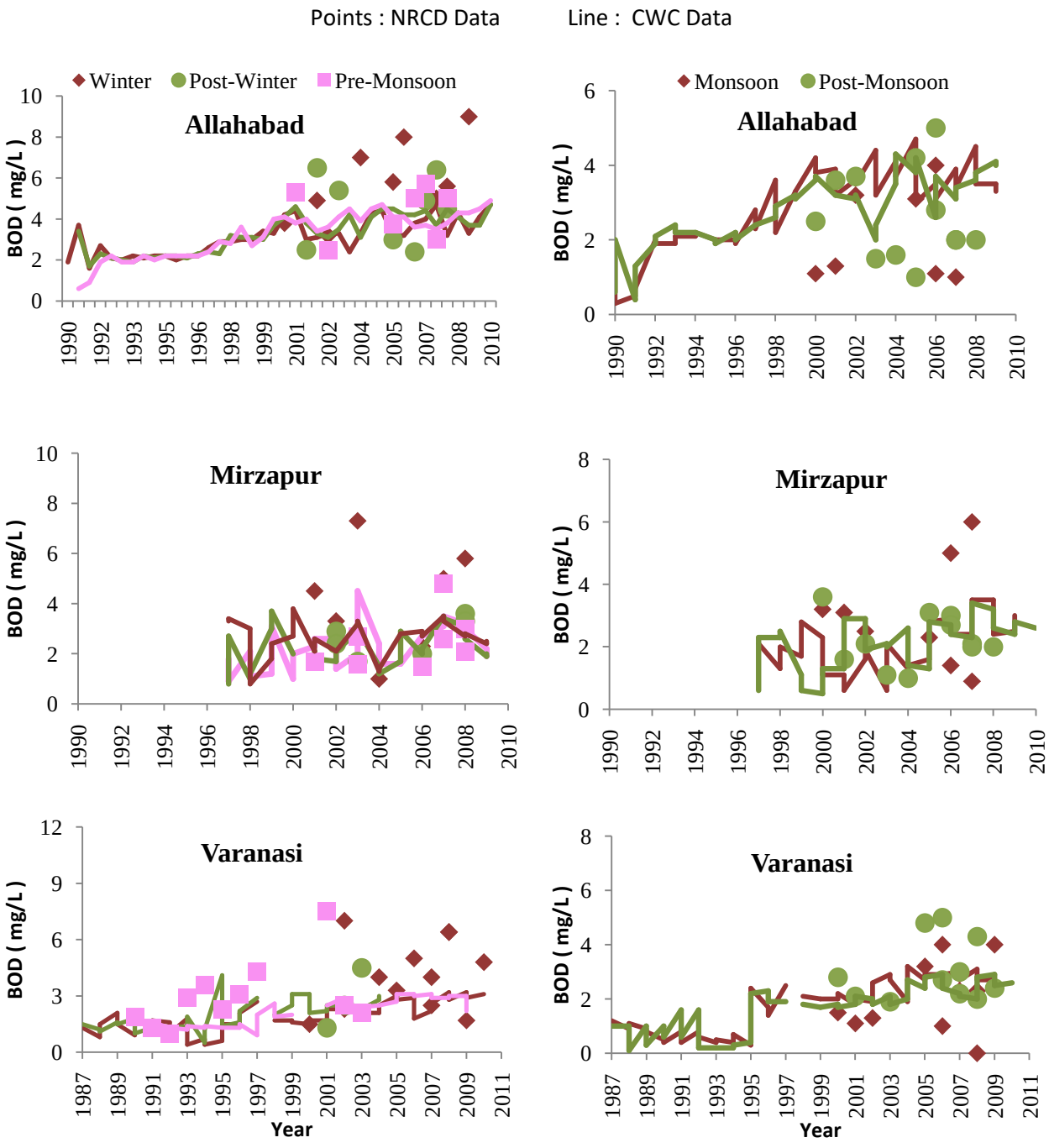


Figure Error! No text of specified style in document.**.16 BOD Comparison at Allahabad, Mirzapur and Varanasi**

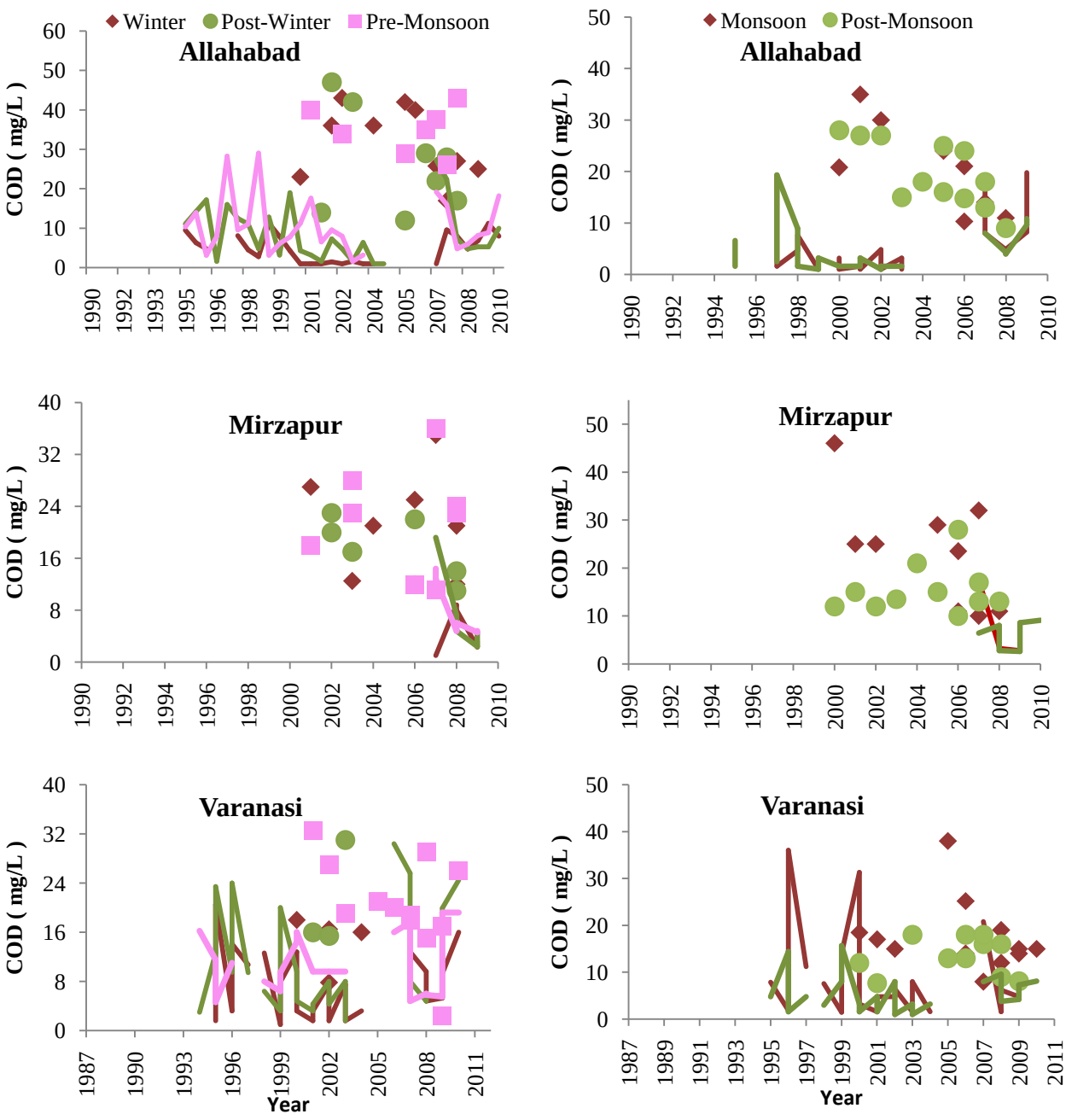


Figure Error! No text of specified style in document.**.17 Comparison of COD at Allahabad ,Mirzapur and Varanasi**

COD and Coli forms data monitored by CWC is availableonly at Allahabad, Mirzapur and Varanasi after 1995 while NRCD data is available after 2000. From Figure 5.12, for all stations COD reported by CWC is less than that of NRCD. Maximum COD values reported by CWC areat

Varanasi while NRCD reported at Allahabad.At Mirzapur COD reported by CWC is for hardly 4 years as compared with other stations. COD ranges from 0 to 50 mg/L for all the three stations.

CWC reports almost constant coli forms concentration but NRCD data shows variation over time.As per figures 5.13 and 5.14,Coli form ranges reported by CWC are 100 to 100,000 MPN/100 ml while those reported by NRCD are 0 to 10,00,000 MPN/100 ml. No seasonal variation is observed in both data sets for COD and Coli Forms over these years.

From comparison of NRCD and CWC data we can infer that in case of DO, BOD and COD, the data reported by both the organizations in all seasons is comparable with each other. Hence where CWC data is not available for BOD and COD the NRCD data has been used in further water quality analysis. In case of Coli Forms we can deduce that CWC data is available for longer time duration (25 years) but for only 3 stations and almost constant data has been reported by CWC while NRCD data is available for shorter time period (10-15 years) but a good variation is observed in data. Hence for stations where CWC Coli Forms data is not available NRCD data has been used in further water quality analysis.

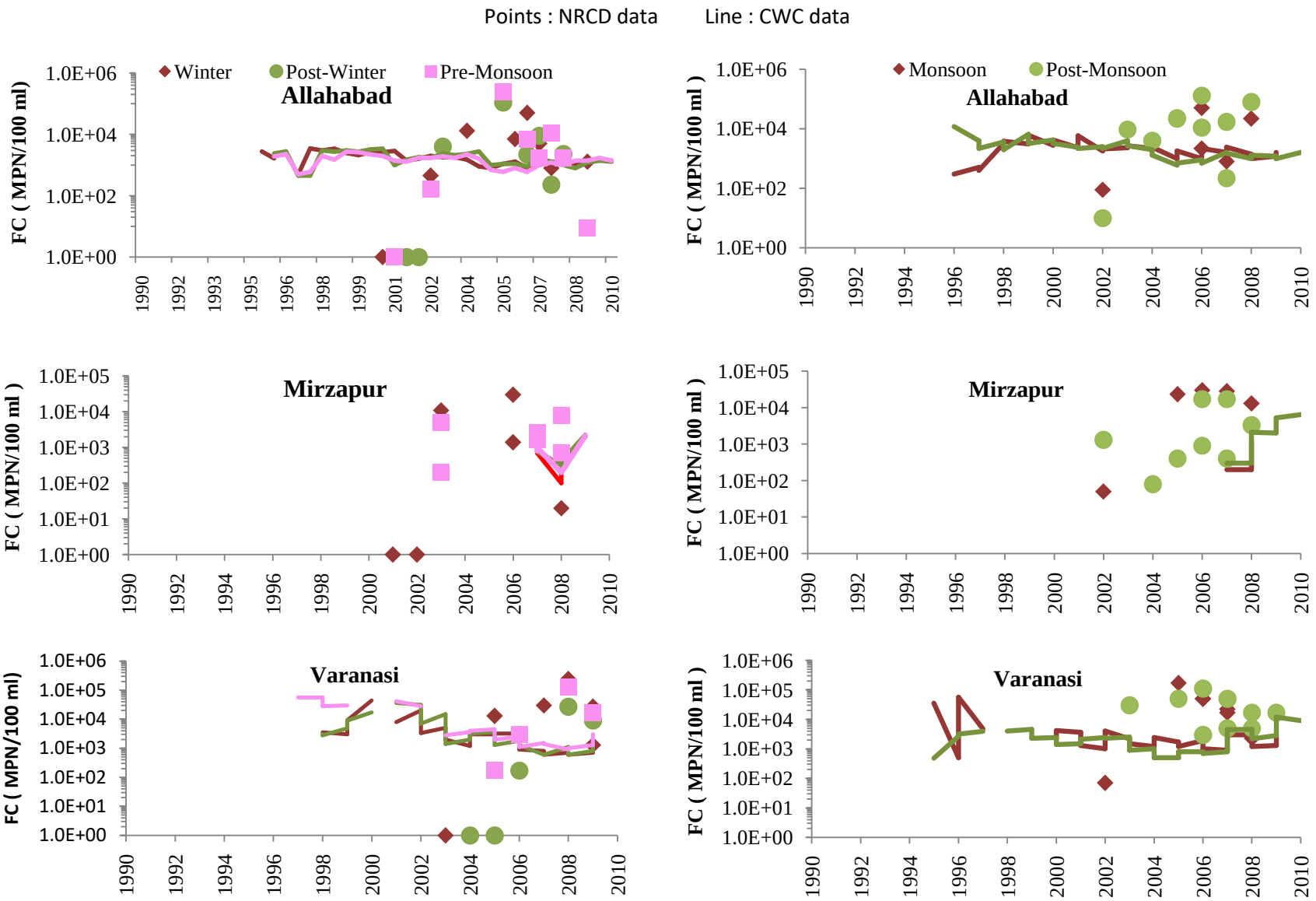


Figure Error! No text of specified style in document..**18 Comparison of Faecal Coli Forms at Allahabad, Mirzapur and Varanasi**

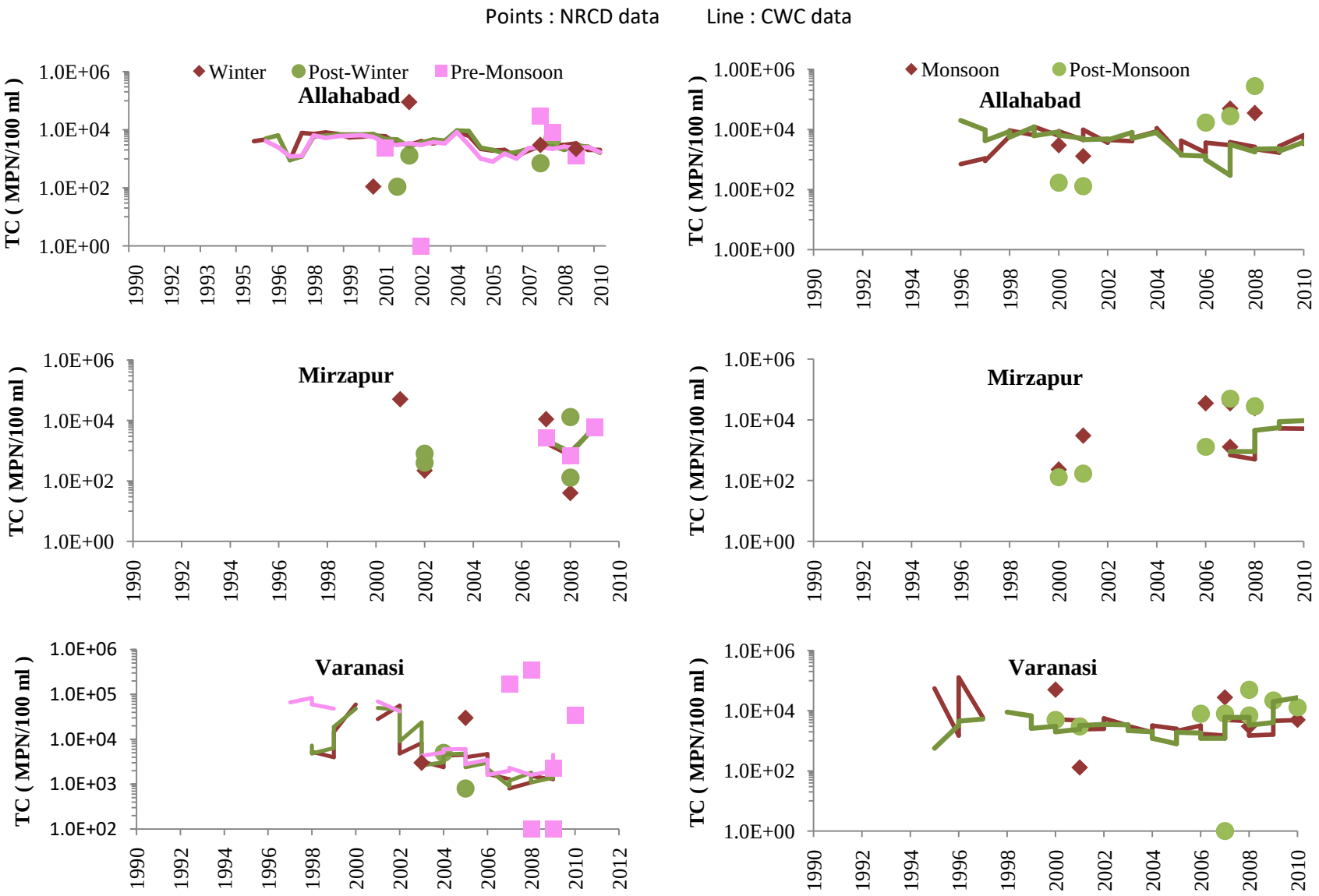


Figure Error! No text of specified style in document.**.19 Comparison of Total Coli Forms at Allahabad, Mirzapur and Varanasi**

5.3 Temporal and Spatial Variation in Water Quality of River Ganga

To study the temporal and spatial variation in Ganga river water quality for selected stretch, monthly water quality data has been collected from 11 CWC stations and NRCD data for same stations for duration of 1972-2015. The water quality parameters available at various stations are divided into 6 groups as shown in Table 5.3.

Table Error! No text of specified style in document.**.11 Water Quality Parameters**

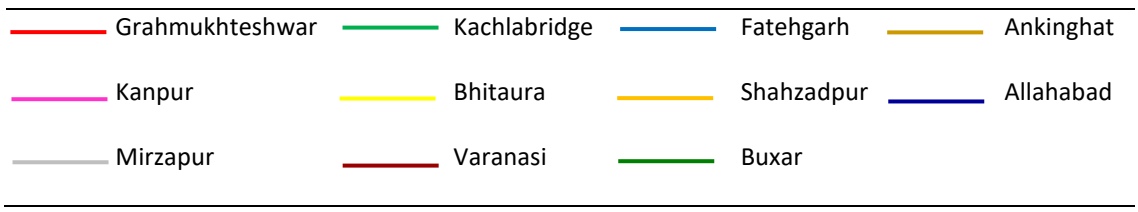
Sr. No.	Water Quality Parameters
Group 1	DO, BOD, COD, Temperature
Group 2	Total Coli Forms, Faecal Coli Forms
Group 3	NH_3-N, NO_2, NO_3, PO_4
Group 4	Total Alkalinity, HCO_3, CO_3, pH
Group 5	EC, TDS, Total Hardness, Na, K, Ca, Mg
Group 6	F, Cl, SO_4, SiO_2

Temporal and Spatial plots for Water Quality

Temporal and spatial plots are plotted for all water quality parameters at all 11 stations considering Non-Monsoon and Monsoon seasonal variation.

A. Temporal and Spatial Variation in DO, BOD and COD (Group 1)

As per Figures, 5.15 and 5.16 ,DO values range from 4 to 10 mg/L in complete stretch for past 29 years in both seasons. Some exceptions observed at Varanasi where high DO (11.5 mg/L) while at Shahzadpur, Mirzapur and Fatehgarh low DO (2-3 mg/L) observed only in Non-Monsoon. Median of DO ranges between 6 to 8 mg/L for both seasons except Buxar where median is around 2-3 mg/L in both seasons.As per IS 2296:1982, the minimum DO level in surface water which is a drinking water source with conventional treatment and disinfection (Surface water class C) is 4 mg/L. DO values At all stations except Buxar are more than this limit.



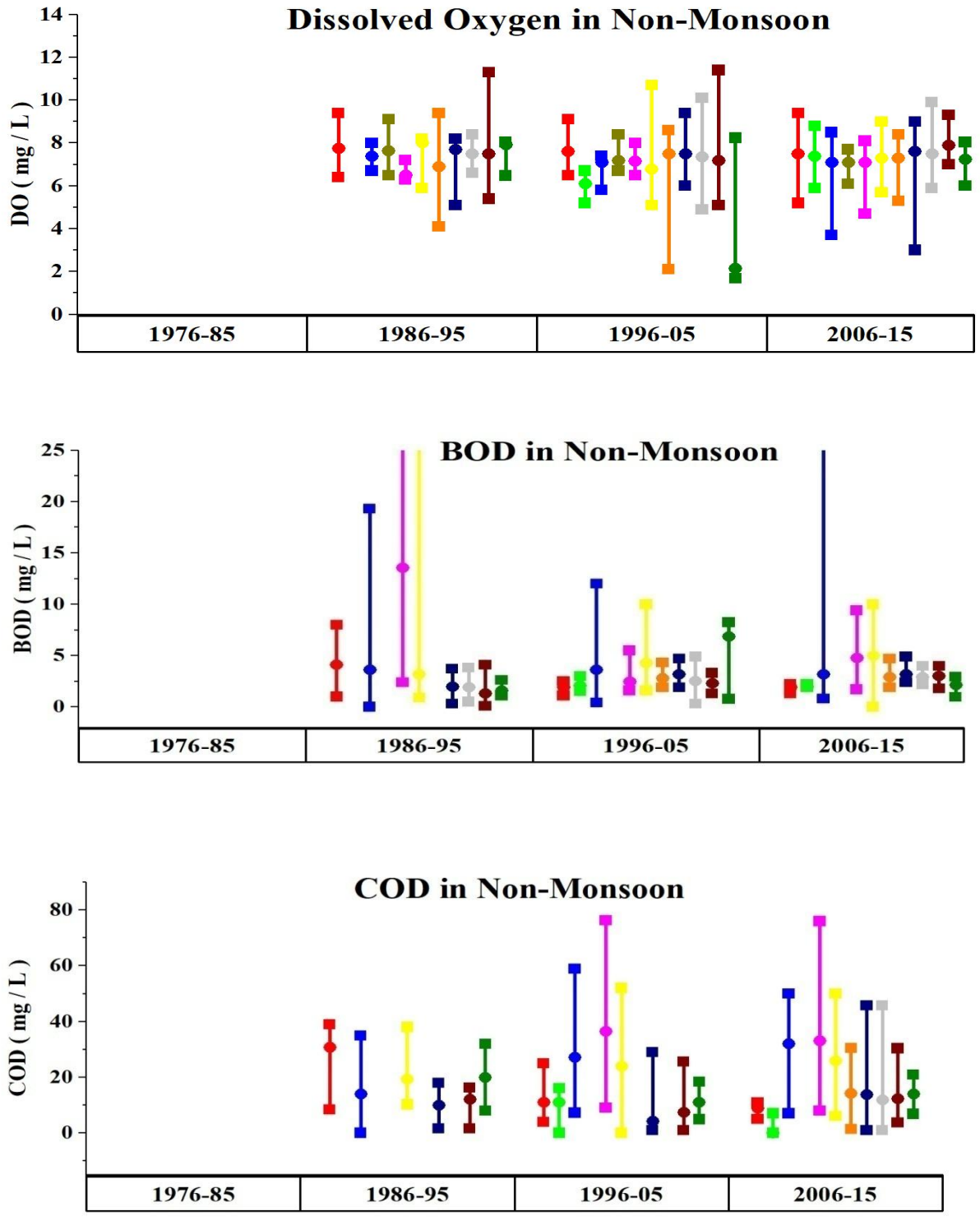


Figure Error! No text of specified style in document..**20 DO, BOD and COD Variation in Non-Monsoon season**

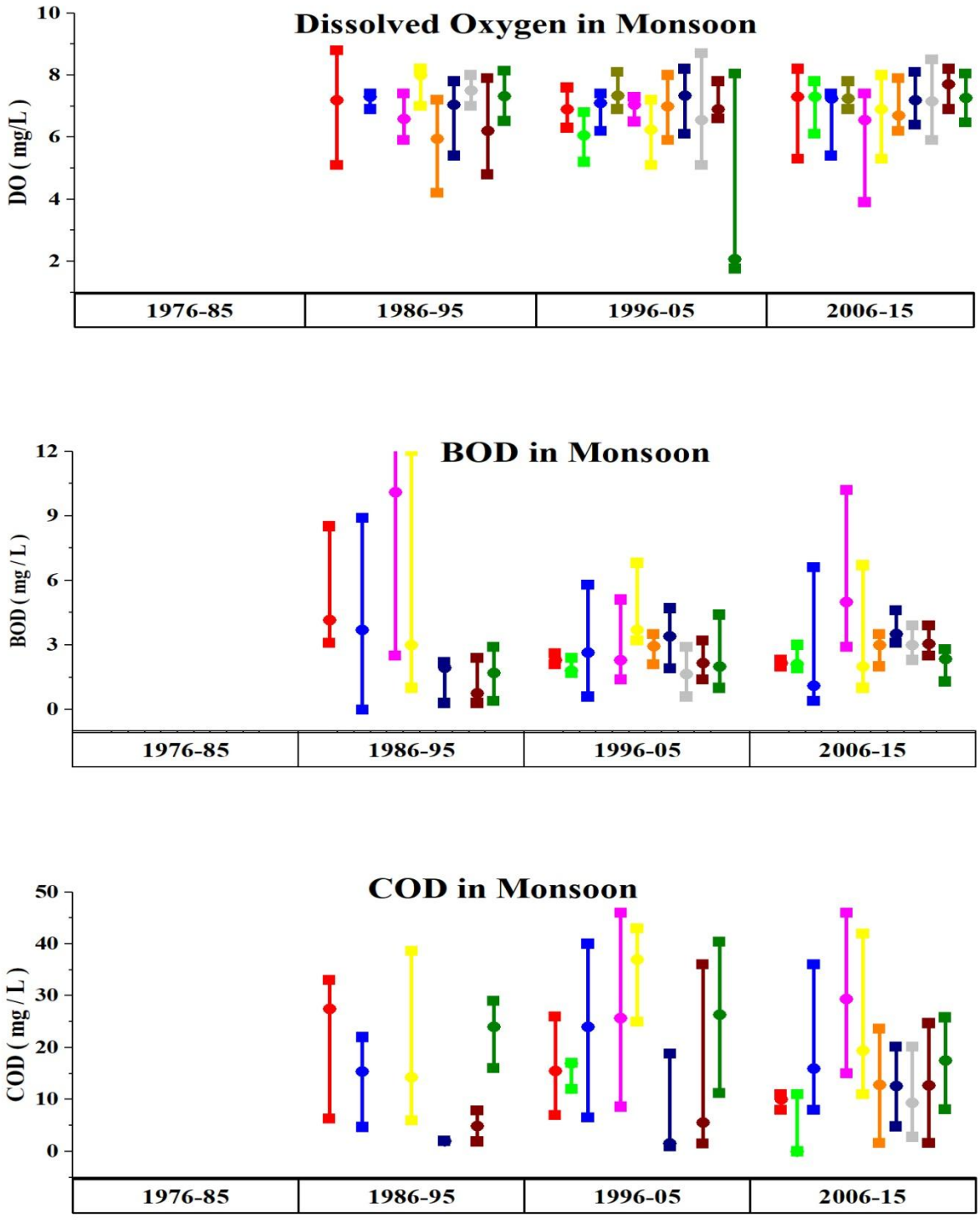


Figure Error! No text of specified style in document.**.21 Variation in DO, BOD and COD in Monsoon**

BOD values vary between 0 to 5 mg/L with median around 2-3 mg/L in both seasons for most of the stations in complete study period. At Fatehgarh, maximum BOD values are always more than other stations with extreme value observed during 2006-15 is around 35 mg/L during lean seasons. At Kanpur and Bhitaura, high BOD values are observed during 1986-95 in range of 45 mg/L. During Monsoon season also at Fatehgarh, Kanpur and Bhitaura high BOD observed as compared with other stations but concentration has reduced than that of Non-Monsoon.COD values range between 0 to 40 mg/L and a wide spatial variation is observed over these years with median varying from 5 to 30 mg/L in both seasons. High COD values are observed for Fatehgarh, Kanpur and Bhitaura for past 20 years. Kanpur shows maximum COD levels with median between 30-40 mg/L and highest COD value around 80 mg/L.

High COD and BOD values are observed from Fatehgarhto Bhitaura in both seasons. This can also be attributed to lowest flow observed duringNon-Monsoon seasons at Fatehgarh. According to (*CPCB ,Pollution Assessment : River Ganga*, 2013), out of total sewage generated in Farrukhabad-cum-Fatehgarh only 25% is being treated and rest flows into river untreated. For other stations also the sewage treatment capacity available is around 40-50% of total sewage generated. After Fatehgarh, Ramganga and Kali, these two tributaries meet river Ganga at Kusumkher and Kannauj discharging large amount of polluted water into river Ganga. Same CPCB report narrates direct waste water discharge in Ganga is hardly 10 % where that in Ramganga is around 70% and 22 % in Kali that of total waste water generated in Uttarakhand and Uttar Pradesh up to Kannauj downstream. Various gross polluting industries like chemical, Pulp and paper , Distilleries , Sugar , Textiles and Tanneries led their partially treated or untreated waste water into river contributing to increase in BOD and COD values as in case of Kanpur.

B. Temporal and Spatial variation in Coli Forms (Group 2)

From Figures, 5.17 and 5.18, wide temporal and spatial variation is observed in Faecal and Total coli forms. Medians ranging from 200 MPN/100 ml at Kachlabridge to 13,000 MPN/ 100 ml at Varanasi can be seen for Faecal Coli forms. Total Coli forms show variation in median from 300 to 90,000 MPN/100 ml. Maximum Faecal coli forms range around 3 ,00 , 000 MPN/100 ml at Varanasi while maximum total coli forms range up to 5- 10 lakhs at Fatehgarh , Kanpur and Varanasi. In recent 10 years, a spatial increase in coli forms is observed as median at Grahmukhteshwar is around 200 MPN/100 ml for both FC and TC while at Buxar around 9,000 and 30,000 respectively. During Monsoon season medians for coli forms range from 500 to 1,00,000 MPN/100 ml.

The maximum tolerance limit for total coli forms is 5000MPN/100 ml for C category water body as per IS 2296:1982, but in both the seasons the coli forms concentration is always more than the tolerance limit at all stations except Grahmukhteshwar and Kachlabridge. Maximum

permissible limit for Faecal Coli forms in case of outdoor bathing is 2500 MPN/100 ml. This is also applicable only at Garmukhteshwar and Kachlabridge.

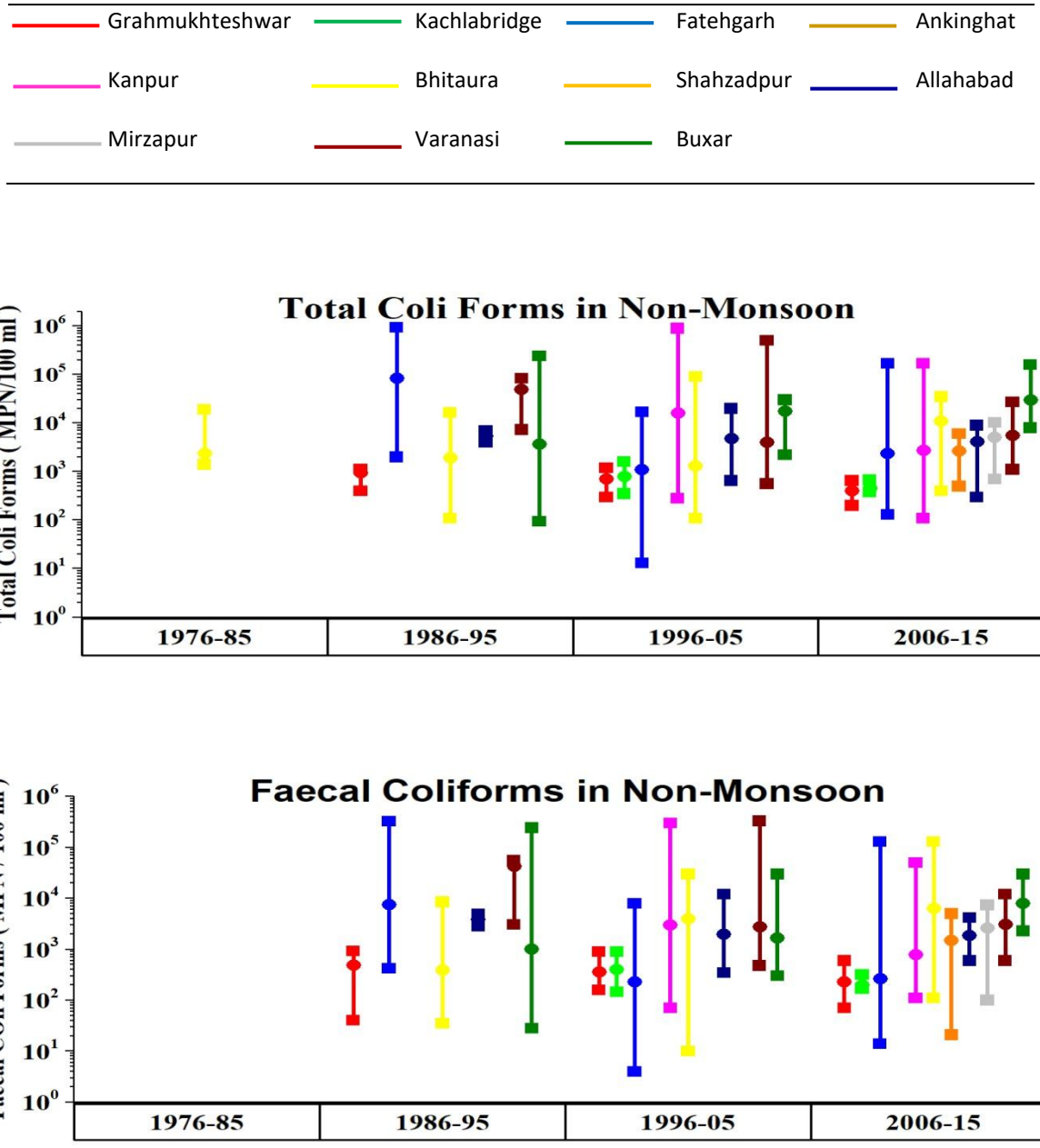


Figure Error! No text of specified style in document..**22 Coli Forms Variation in Non-Monsoon**

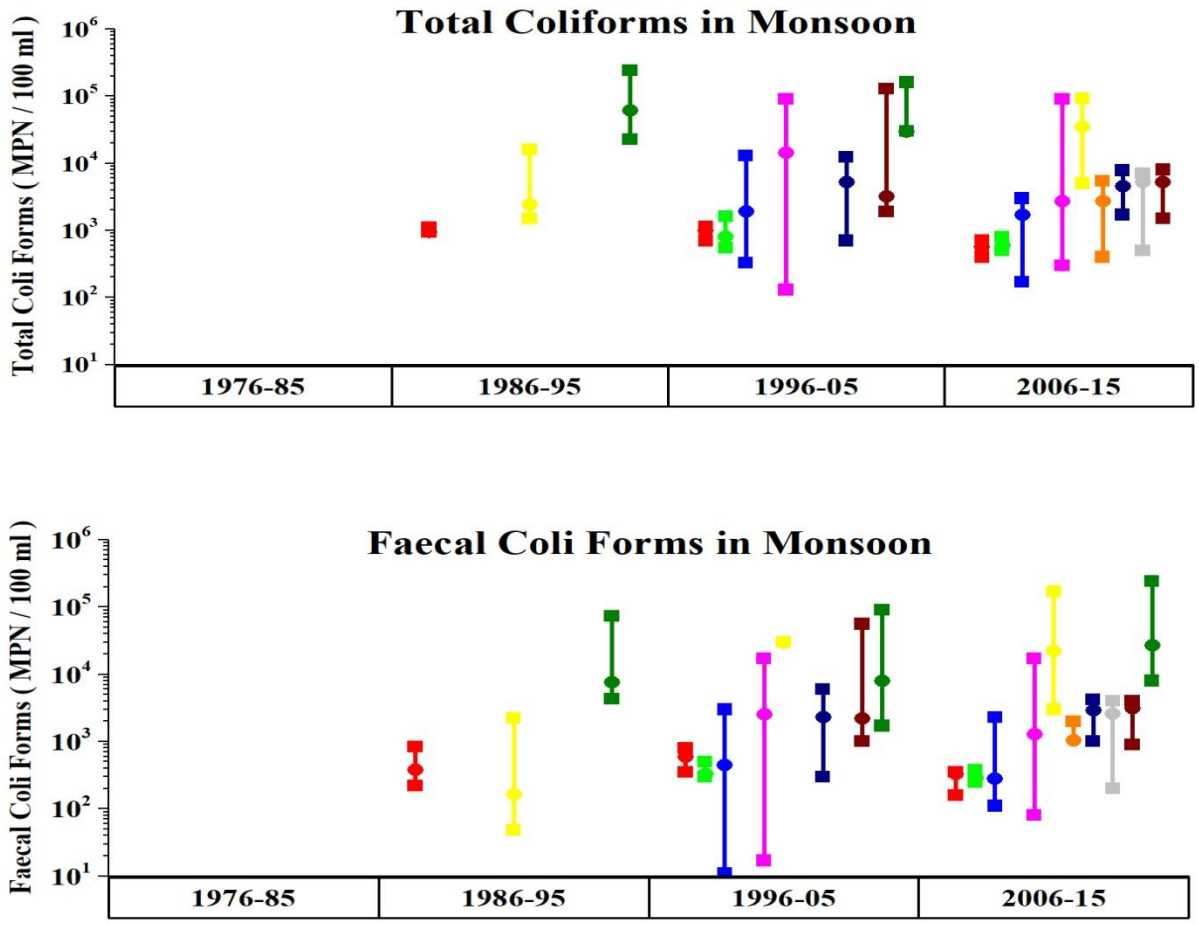
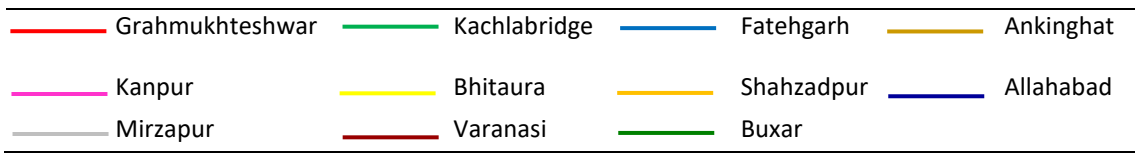


Figure Error! No text of specified style in document..**23 Coli Forms in Monsoon**

C. Temporal and Spatial Variation in forms of Nitrogen and Phosphorus (Group 3)

From Figures 5.19 and 5.20, Very low Ammonical nitrogen concentration is noticed in this stretch for past 30 years. Ammonical-nitrogen and Phosphates range from 0 –1 mg/L. Medians for Ammonical-Nitrogen, Nitrates and Phosphates in both seasons is almost nearly 0 mg/L i.e. hardly any form of nitrogen and phosphorus is present. For these 30 years, from 1996-2005 comparatively some ammonical nitrogen concentration is observed. Maximum concentration of 4.5 mg/L is observed at Bhitaura while at other stations NH4-N range between 1-4.5 mg/L. During Monsoonmaximum NH4-N (2 mg/L) observed at Varanasi. Nitrite concentration in complete selected stretch is less than 0.5 mg/L.



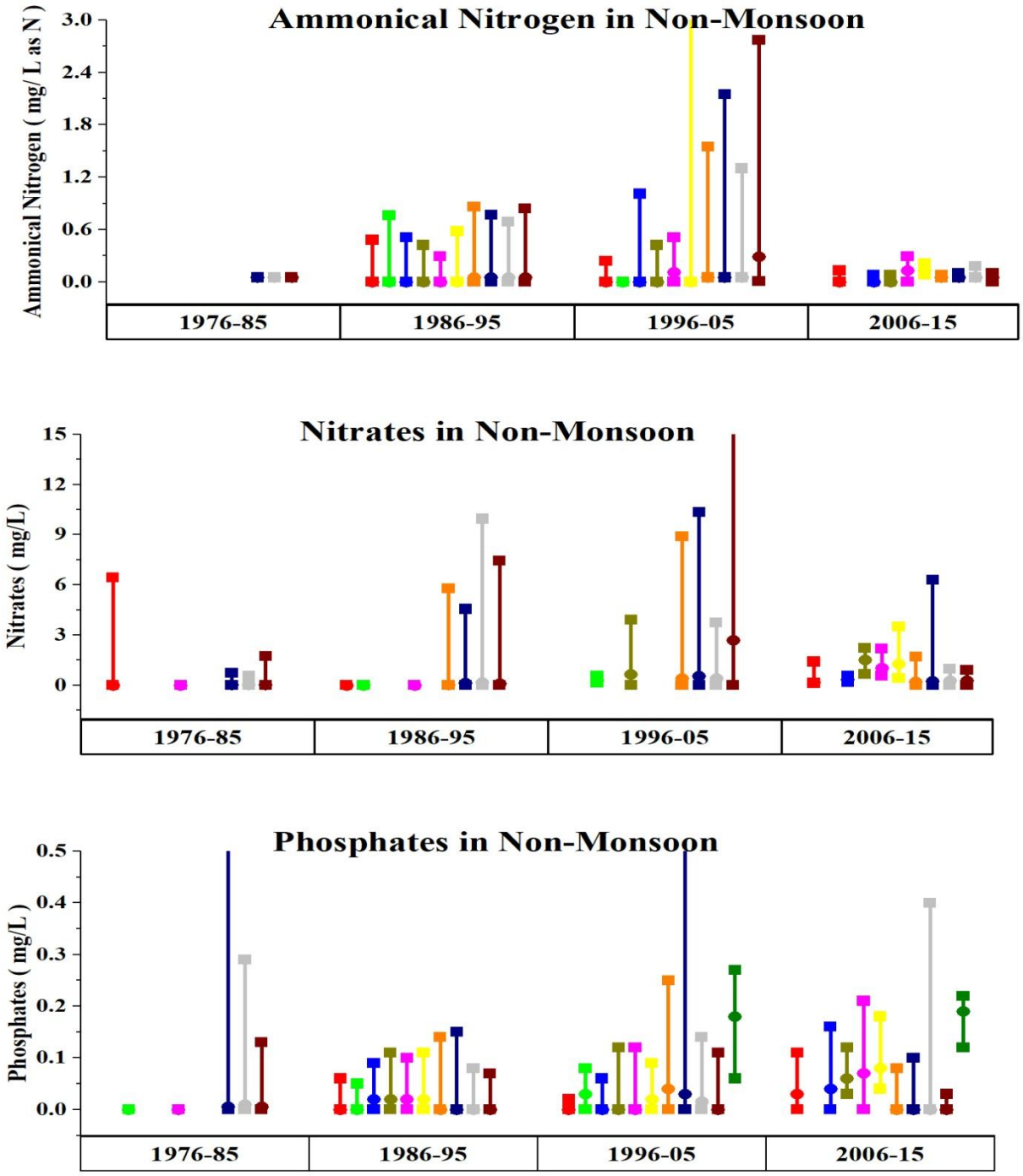


Figure Error! No text of specified style in document..**24 Nitrogen and Phosphorus Variation in Non-Monsoon**

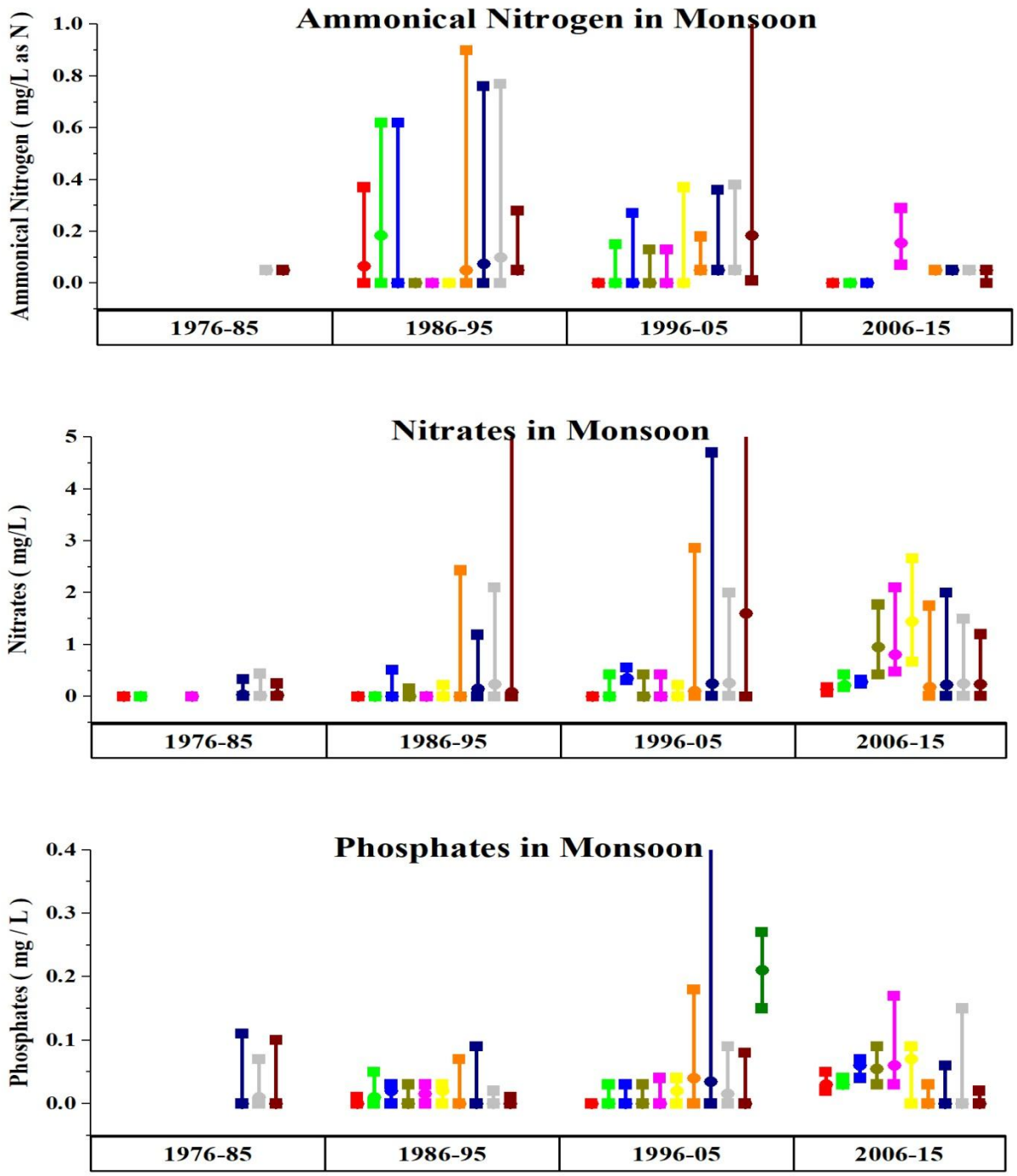


Figure Error! No text of specified style in document..**25 Nitrogen and Phosphorus Variation in Monsoon**

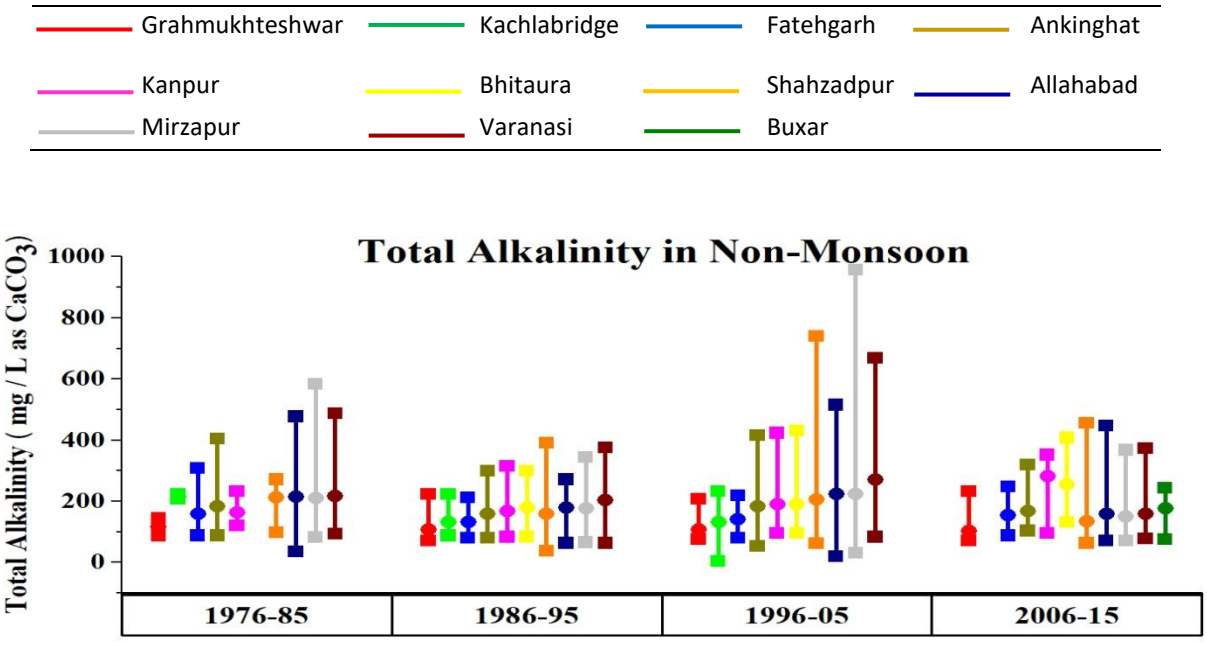
Nitrate concentration in both seasons is almost less than 10 mg/L. During 1996-2005, exceptionally high nitrate concentration is observed at Varanasi in range of 35 mg/L for Non-Monsoon and around 20 mg/L for Monsoon season. According to IS 2292:1982 , nitrates

concentration can be maximum up to 50 mg/L for class C water body , from the above analysis it can be inferred that nitrate concentration at all stations is within the tolerance limit. Some exception seen at Allahabad where phosphates ranges up to 4.5 mg/L in Non-Monsoons and 1.6 mg/L in Monsoon.

In general, Ammonical nitrogen, Nitrates and Phosphates are very negligibly present in the selected stretch of river. Nitrates concentration is more than Ammonical-nitrogen leading to autotrophic state of river Ganga.

D. Temporal and Spatial Variation in Alkalinity and pH (Group 4)

From Figures, 5.21 and 5.22, Alkalinity varies from 50 to 500 mg/L with median ranging between 100-300 mg/L in Non-Monsoon season. Some exceptions observed at Mirzapur and Shahzadpur where alkalinity values range up to 1000 mg/L in Non-Monsoon. During the Monsoon, in general alkalinity range reduces with median less than 200 mg/L. The gradual spatial increase in alkalinitycan be clearly observed in Monsoon than Non-Monsoon. High alkalinity values are observed from Shahzadpur to Varanasi during Monsoon where maximum alkalinity observed in Monsoon is at Varanasi. Total alkalinity is predominantly due to Bicarbonates. In general Bicarbonates are less than 400 mg/L with some exceptions as observed in Total Alkalinity in selected stretch.



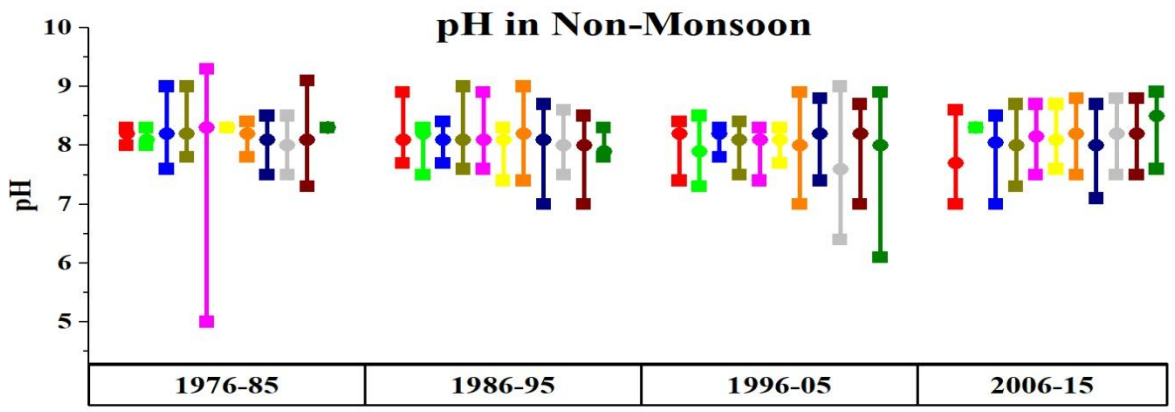


Figure Error! No text of specified style in document.**.26 Alkalinity and pH Variation in Non-Monsoon**

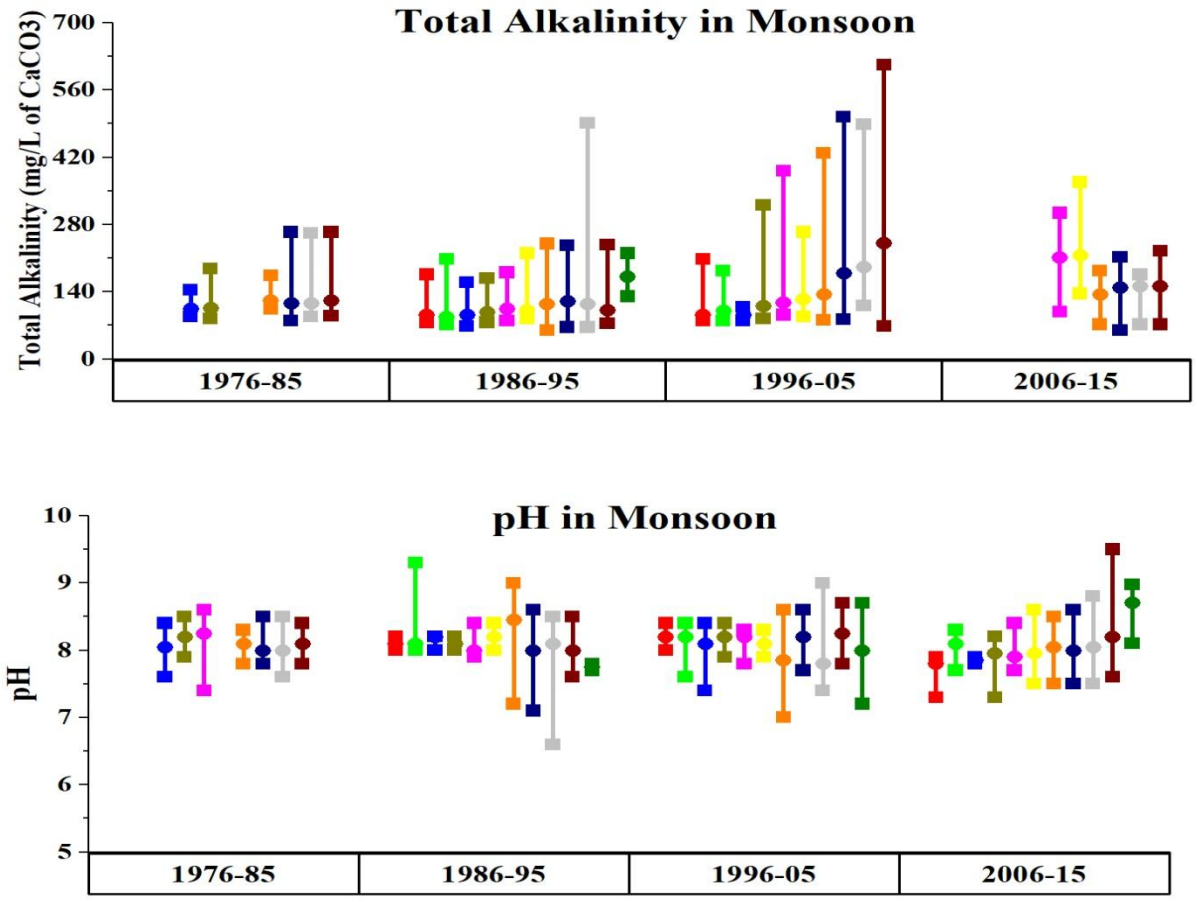


Figure Error! No text of specified style in document.**.27 Alkalinity and pH Variation in Monsoon**

For past 40 years, pH varies from 6 to 9.3 with exceptionally low pH observed at Kanpur(5) and exceptionally high pH observed at Varanasi (9.3) during 1976-85 in preciously Pre-Monsoon

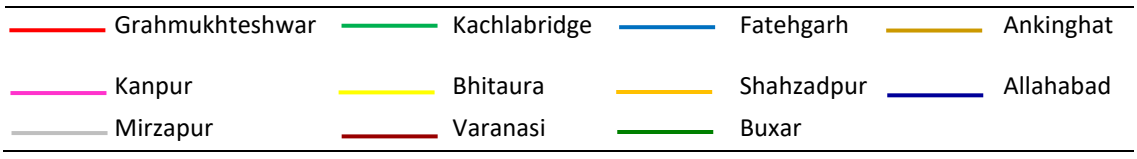
season. Median of pH varies from 7.8 to8.4 i.e. river water is slightly basic in both seasons. For recent 10 years of duration in complete study area pH reported is more than 8.3 and median is almost constant at 8.2-8.3. In general pH is within the tolerance limit of Class C surface water standards.

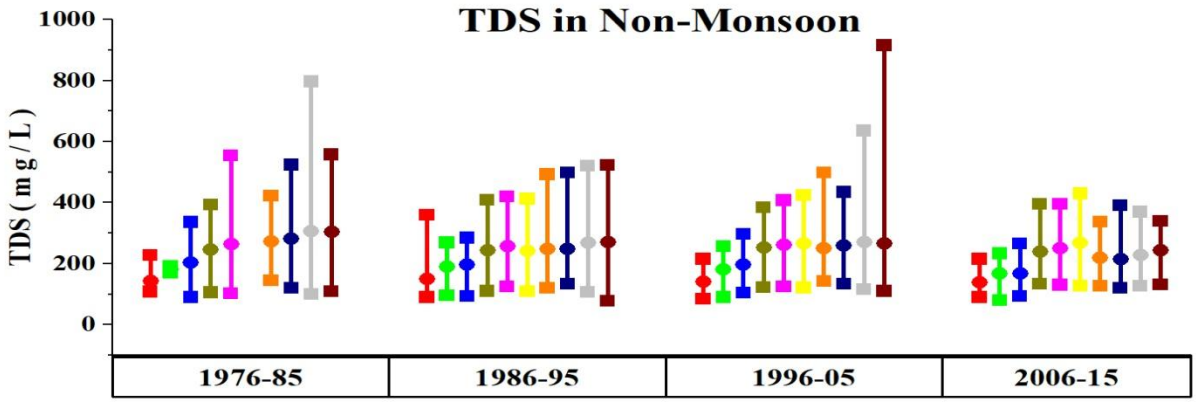
It can be observed that pH is mostly more than 8.3 at many stations which lead to presence of carbonate alkalinity in water along with bicarbonate alkalinity. From Garhmukhteshwar to Bhitaura carbonates are Present in early 1980 and after 2000 but from Shahzadpur to Varanasi carbonates are present in complete study period. Maximum carbonates are observed in range of 60-80 mg/L. In general Alkalinity is very important for aquatic life and fish as it has a buffering capacity which reduces sudden changes in pH. From aquatic life point of view, the pH range in river Ganga is very good for their growth.

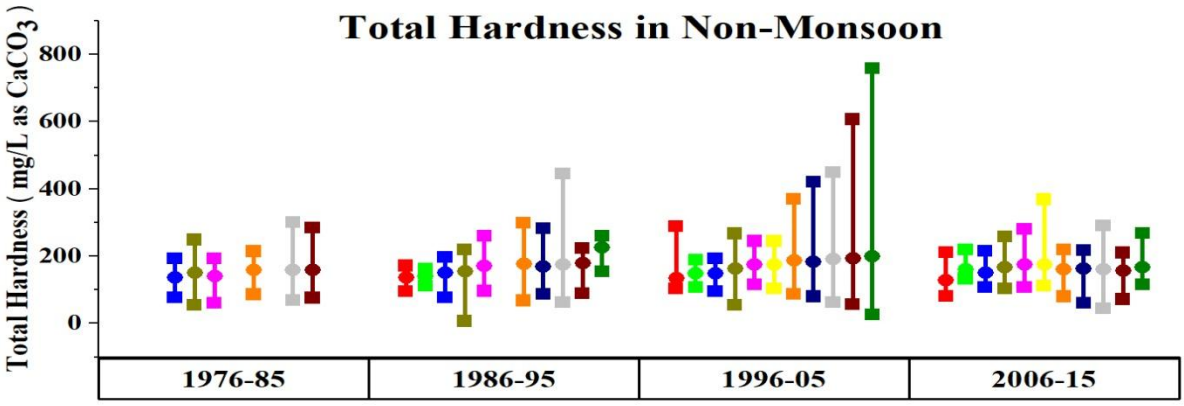
E. Temporal and Spatial Variation in TDS, Hardness and Cations (Group 5)

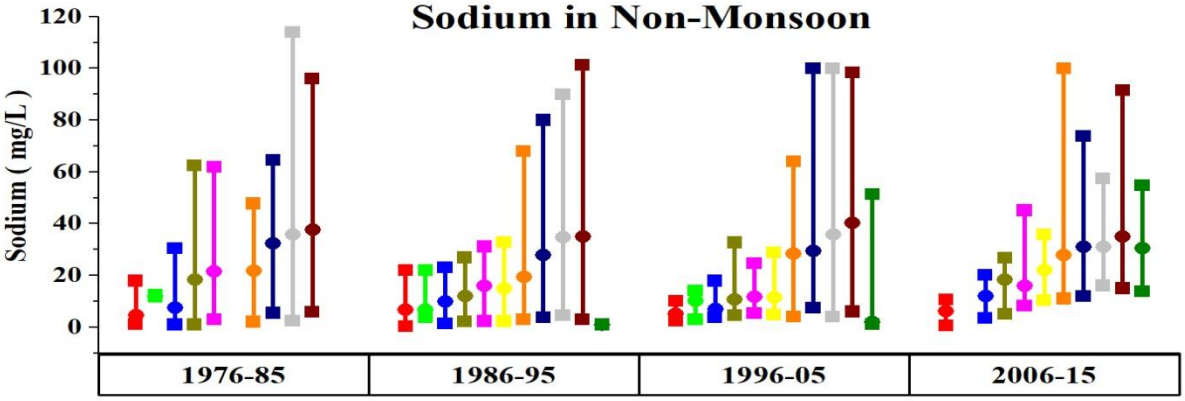
From Figures 5.23 and 5.24, Over last 40 years, TDS varies from 100 to 400 mg/L where median changes from 150-300 mg/L in Non-Monsoon season. Some exceptionally high TDS reported at Mirzapur and Varanasi in range of 800 mg/L. A gradual spatial increase in TDS is observed only during 1976-85 such as median at Grahmukhteshwar is around 100 mg/L while that at Buxar is around 300 mg/L. After 1985 the trend in TDS at all stations is almost similar. From Figure 5.24, during Monsoon, TDS shows an increasing trend over downstream stations and rate of increase is maximum in recent 10 years of duration. In recent 10 years of duration median concentration of TDS becomes almost double from Grahmukhteshwar to Buxar. According to IS 2296:1982, TDS limit for Class C water body is 1500 mg/L and TDS in this river stretch is within tolerance limit.

Hardness varies from 50- 300 mg/L with median almost constant between 150-200 mg/L in Non-Monsoon. River water in this stretch is moderately hard at Grahmukhteshwar and hard at all other stations. During 1996-05, high maximum hardness concentration is reported from Shahzadpur to Buxar in range of 400-800 mg/L as compared with other decades. During Monsoon season, median range reduces and less variation is observed than Non-Monsoon. Definite trend is not observed over decades in Monsoon




TDS in Non-Monsoon
TDS (m g / L)
1000
800
600
400
200
0
1976-85
1986-95
1996-05
2006-15


Total Hardness in Non-Monsoon
Total Hardness (mg/L as $CaCO_3$)
800
600
400
200
0
1976-85
1986-95
1996-05
2006-15


Sodium in Non-Monsoon
Sodium (mg/L)
120
100
80
60
40
20
0
1976-85
1986-95
1996-05
2006-15

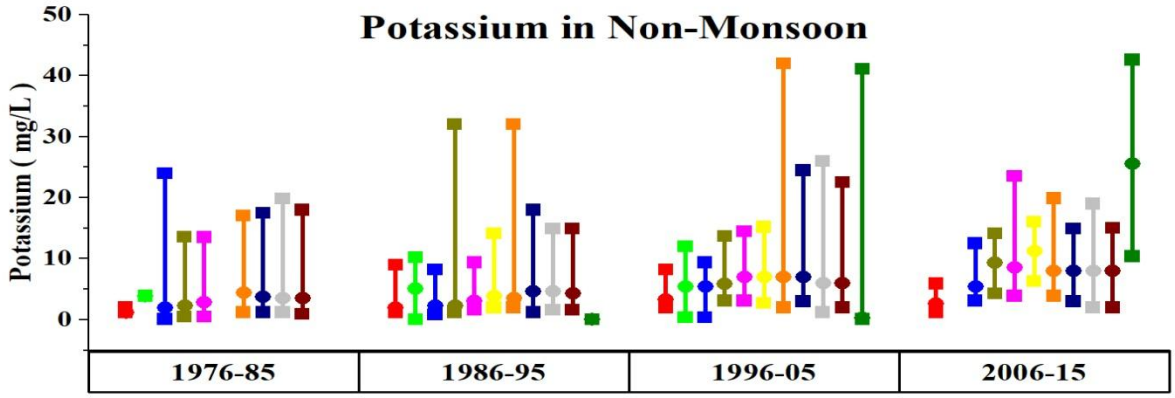
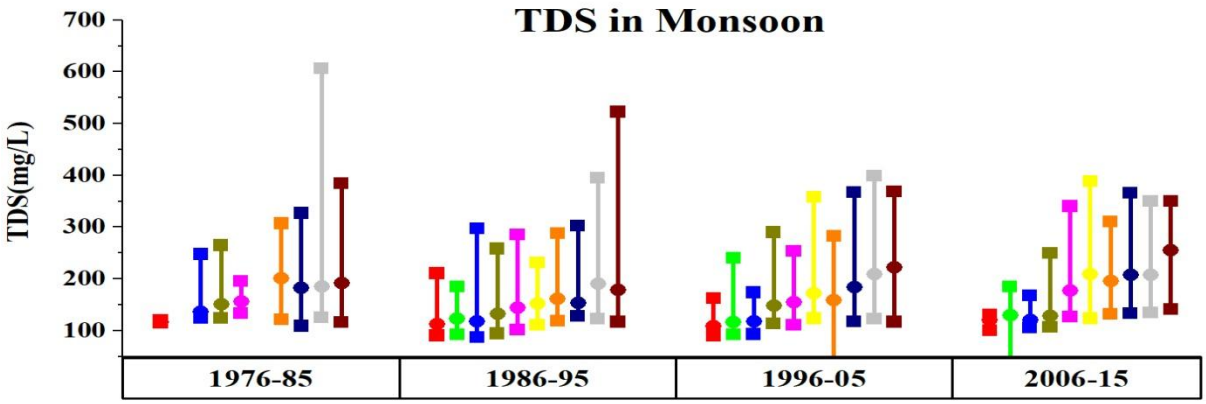
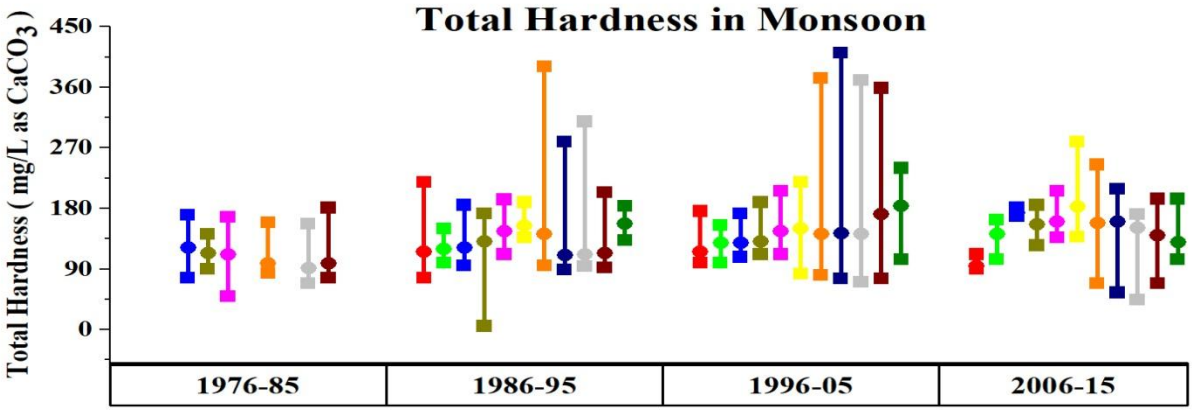


Figure Error! No text of specified style in document..**28 Variation in TDS , Hardness and Cations in Non-Monsoon**





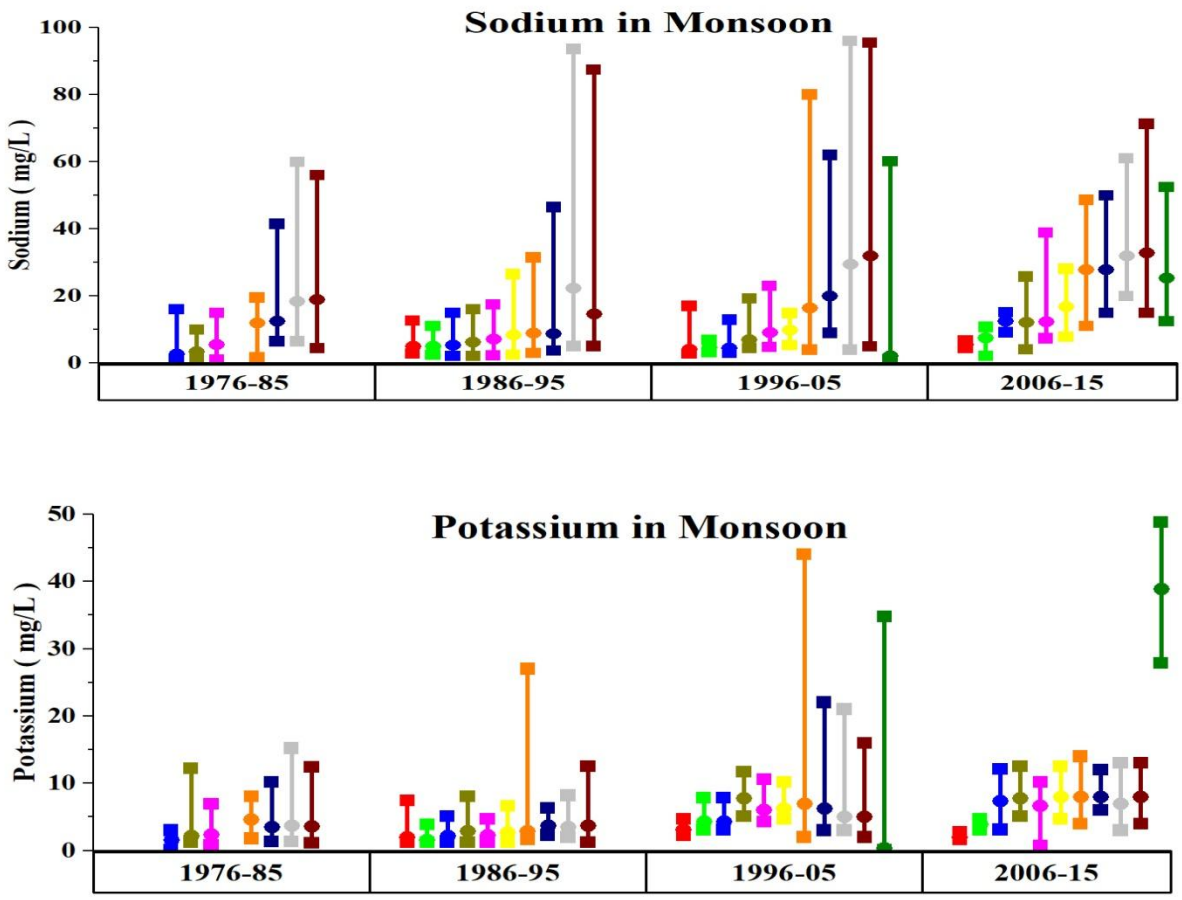


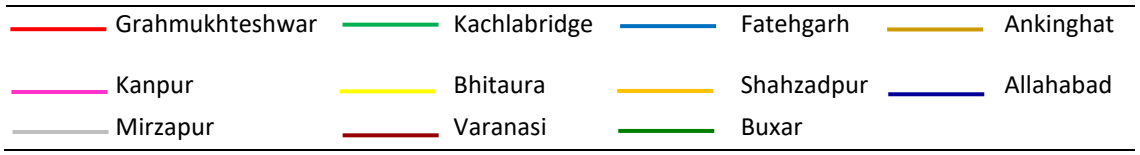
Figure Error! No text of specified style in document.**.29 Variation in TDS, Hardness and Cations**

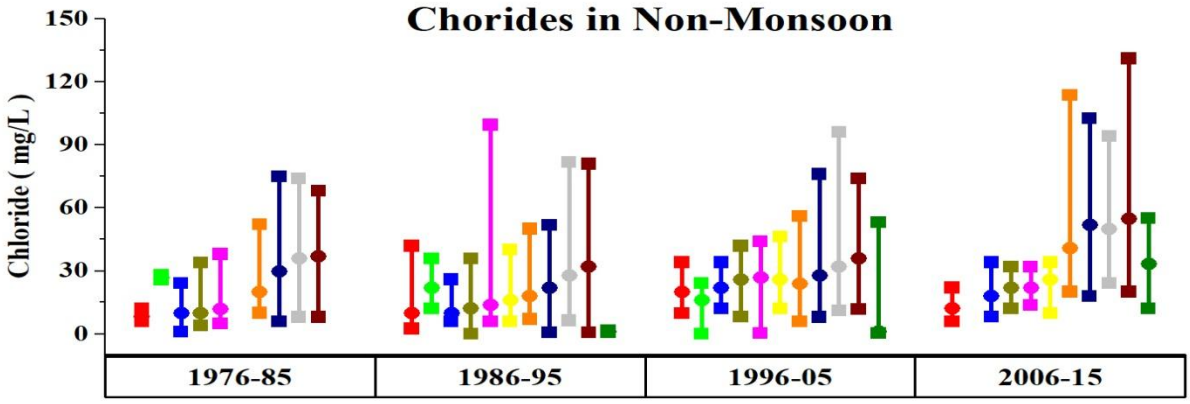
Over 4 decades, sodium concentration shows an increasing trend with the course of river as described in Figures 5.23 and 5.24. Median varies from 5 to 40 mg/L in both seasons. From Shahzadpur to Buxar, wide variation in sodium is observed. Maximum sodium concentration observed at Mirzapur and Varanasi. In general sodium concentration ranges from 0 to 100 mg/L in both seasons. Spatial increase in sodium concentration is more preciously observed in last 2 decades during Monsoon. The median of potassium varies between 0-10 mg/L. In general range varies from 0-40 mg/L in both seasons. At Shahzadpur and Buxar, high potassium concentration is observed between 30-50 mg/L.

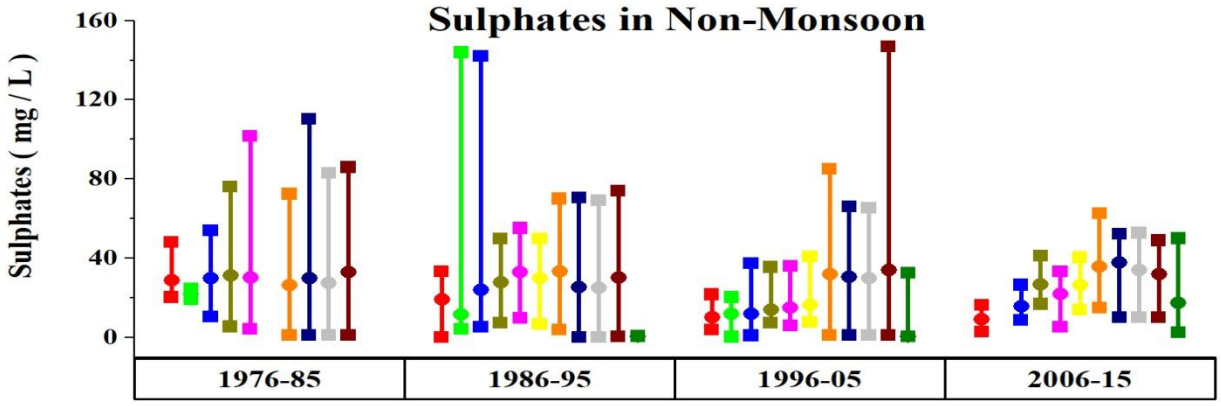
F. Temporal and Spatial Variation in Anions (Group 6)

From Figures Over 4 decades, chloride concentration increases gradually from Grahmukhteshwar to Varanasi. This increasing rate is maximum in last decade as in last decade median increases from 10 to 50 mg/L in complete selected stretch in Non-Monsoon. In general chloride concentration varies from 0 to 80 mg/L with some exceptionally high values at Mirzapur between 1996-2005 and Shahzadpur ,Varanasi in last decade. Out of these, maximum chloride concentration around 130 mg/L in Non-Monsoon is observed at Varanasi. During

Monsoon, median varies from 10-30 mg/L. In last decade chloride concentration suddenly increases from Shahzadpur to Varanasi where median ranges between 40-60 mg/L in Monsoon season.







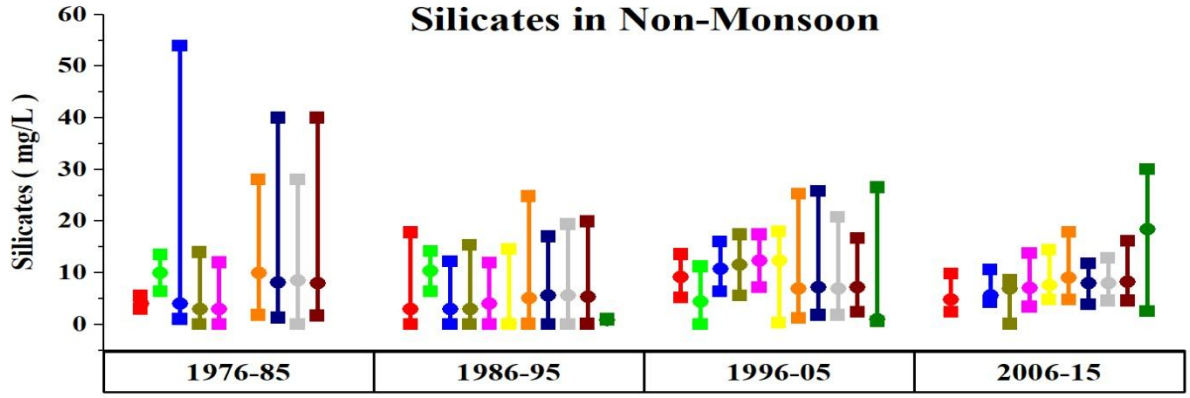
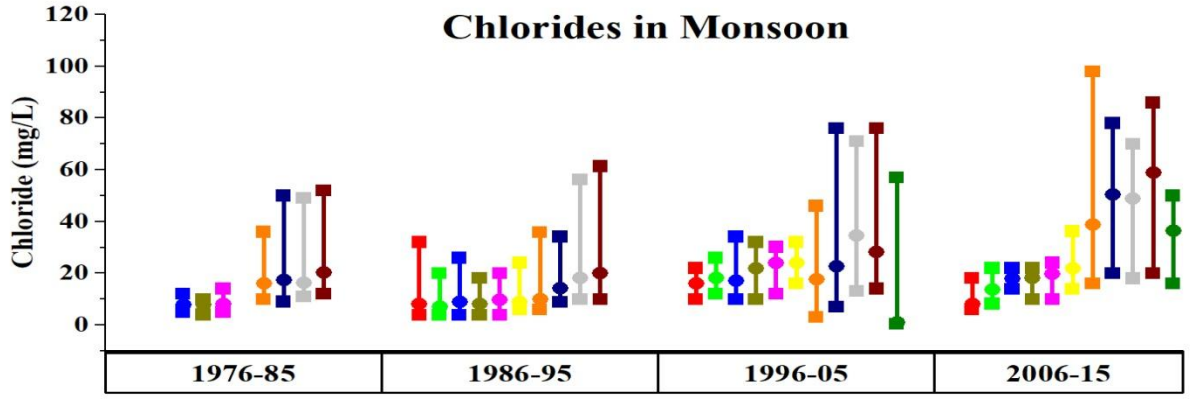


Figure Error! No text of specified style in document.**.30 Variation in Anions in Non-Monsoon**

Sulphate concentration varies from 0-80 mg/L with median varies between 20-40mg/L with some exceptional peaks are observed at Kachlabridge ,Fatehgarh and Varanasi during Non-Monsoon. Sulphate concentration increases in Monsoon in last decade where median changes from 10-35 mg/L. Silicates vary from 0 to 30 mg/L and median between 0-15 mg/L in both seasons. Peaks are observed in 1976-1985 only. From Grahmukhteshwar to Bhitaura, fluoride concentration is less than 1 mg/L but after Bhitaura till Buxar values range upto 2 to 2.5 mg/L.



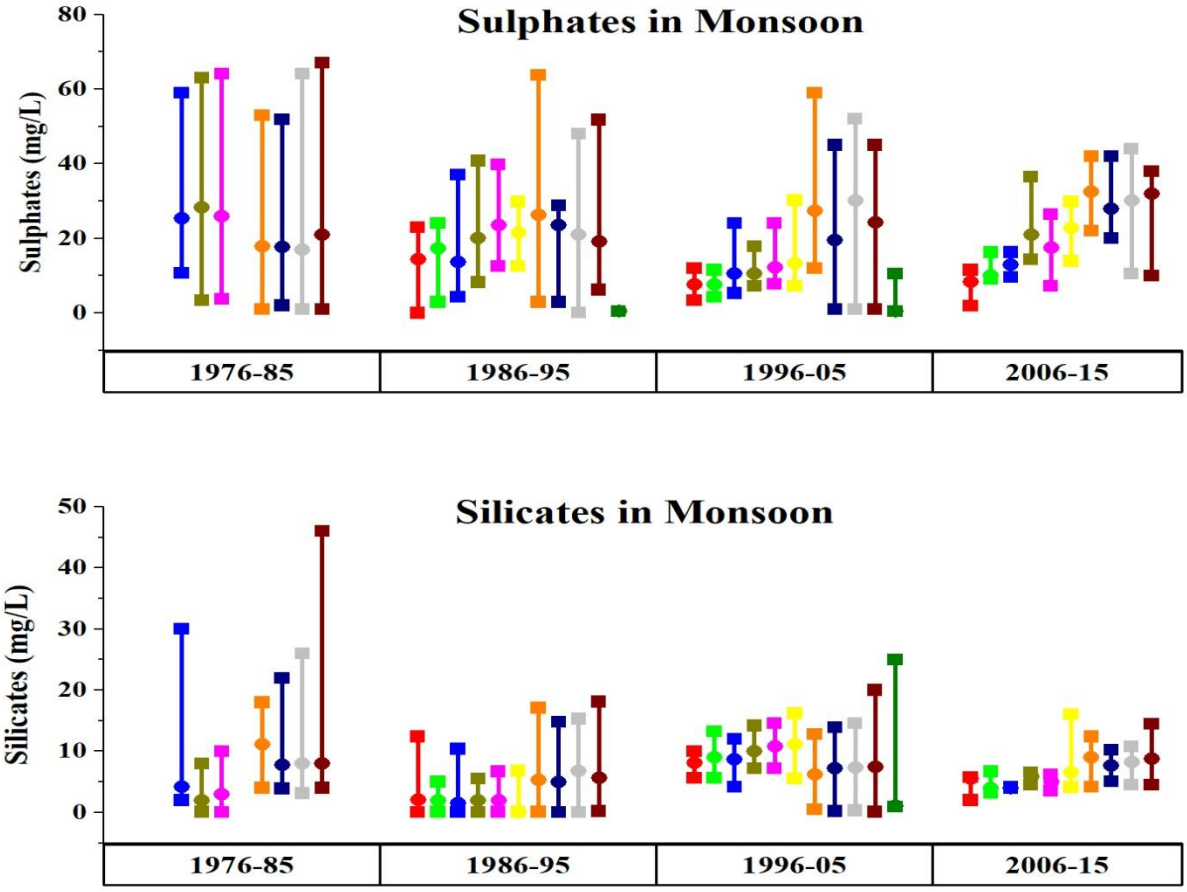


Figure Error! No text of specified style in document.**.31 Variation in Anions in Monsoon**

From the surface water standards IS 2296:1982 , Fluoride concentration should be less than 1.5 mg/L for Class C and Class B water bodies which is the case from Garhmukhteshwar to Bhitaura. From chloride point of view the selected stretch is within the tolerance limit of Class C water body.

Statistical Analysis of River Water Quality

For understanding the physico-chemical and biological characters of river water, the statistical and trend analysis of river water quality in terms of concentration or load along with stream flow is very important(Antonopoulos, Papamichail and Mitsiou, 2001). It further helps in planning and executing the monitoring and restoration programs of rivers.

A. Seasonal Mean Variation

The seasonal mean difference is checked for various water quality parameters by One-Way ANOVA and Paired-t-test between the 5 seasons and its significance analysed at 95% confidence interval.

In Table 5.5, YES means the water quality parameter show seasonal mean difference for at least one seasonal pair like Pre-Monsoon and Monsoon.Majority of water quality parameters like Cations, TDS, EC, Alkalinity, Hardness, Chlorides, Sulphates etc. show significant variation overseasonal means from Garhmukhteshwar to Varanasi. pH, Fluorides, Silicates and forms of nitrogen and phosphorus do notshow any seasonal variation over means. Seasonal variation in DO BOD and COD is observed at many stations likeFatehgarh, Kanpur ,Bhitaura, Allahabad , Varanasi etc. Coli forms show seasonal variation only at Garhmukhteshwar and Buxar. Very few water quality parameters like Hardness, COD and Coliforms show seasonal variation in mean at Buxar.

Table Error! No text of specified style in document.**.12 Seasonal Mean Variation in Water Quality by One-Way ANOVA**

<table>
<tr><th rowspan="2">Stations</th><th colspan="11">Parameters showing Significant Variation In Seasonal Means</th><th rowspan="2">Parameters NOT showing significant Variation in Seasonal Means</th></tr>
<tr><th>TDS Bicarbonates Total Alkalinity</th><th>Carbo-nates</th><th>Calcium Sodium</th><th>Magnesium Potassium</th><th>EC Temperature Total Hardness</th><th>Chlorides</th><th>Sulphates</th><th>DO</th><th>BOD</th><th>COD</th><th>TC FC</th></tr>
<tr><td>Grahmukh-teshwar</td><td rowspan="9">YES</td><td rowspan="6">NO</td><td rowspan="9">YES</td><td>NO</td><td rowspan="9">YES</td><td rowspan="9">YES</td><td>YES</td><td>YES</td><td>NO</td><td>NO</td><td>YES</td><td rowspan="9">pH Turbidity Fluorides Silicates Ammonical-N Nitrites Nitrates Phosphates</td></tr>
<tr><td>Kachla-bridge</td><td rowspan="8">YES</td><td>YES</td><td rowspan="3">NO</td><td>NO</td><td>NO</td><td rowspan="8">NO</td></tr>
<tr><td>Fatehgarh</td><td>NO</td><td>YES</td><td>NO</td></tr>
<tr><td>Ankinghat</td><td rowspan="7">YES</td><td rowspan="7">NO</td><td colspan="2">NA</td></tr>
<tr><td>Kanpur</td><td rowspan="6">YES</td><td>YES</td><td>YES</td><td>YES</td></tr>
<tr><td>Bhitaura</td><td rowspan="5">YES</td><td>NO</td><td>YES</td><td>YES</td></tr>
<tr><td>Shahzadpur</td><td rowspan="4">YES</td><td>YES</td><td>YES</td></tr>
<tr><td>Allahabad</td><td rowspan="3">YES</td><td>NO</td><td>YES</td></tr>
<tr><td>Mirzapur</td><td>NO</td><td>NO</td></tr>
<tr><td>Varanasi</td><td>YES</td><td>YES</td></tr>
<tr><td>Buxar</td><td>NO</td><td>NO</td><td>NO</td><td>NO</td><td>NO</td><td>NO</td><td>NO</td><td>NO</td><td>NO</td><td>YES</td><td>YES</td></tr>
</table>

Table 5.5 shows seasonal variation between various seasonal pairs which is analysed by Paired-t-Test. The pink colored cells show significant seasonal variation over mean in those seasons. All 5 seasons show significant DO variation with maximum DO variation is observed between Post-Monsoon andWinter seasons. In case of COD, Pre-Monsoon and Monsoon along with Winter and Post-Winter, these two pairs show good seasonal variation as compared with other seasonal pairs.

Table Error! No text of specified style in document.**.13 Seasonal Mean Variation in water Quality by Paired-t-Test**

Stations	Dissolved Oxygen				
	W-PW	PW-PM	PM-M	M-POM	POM-W
Grahmukh-teshwar					
Fatehgarh					
Kanpur					
Shahzadpur					
Allahabad					
Mirzapur					
Varanasi					
Stations	**Chemical Oxygen Demand**				
Kanpur					
Bhitaura					
Allahabad					
Varanasi					
Buxar					
Stations	**Biochemical Oxygen Demand**				
Fatehgarh					
Kanpur					
Bhitaura					
Shahzadpur					
Varanasi					
Stations	**Total Coli Forms**				
Grahmukh-teshwar					
Buxar					
Stations	**Faecal Coli Forms**				
Buxar					

Stations	Total Alkalinity				
	W-PW	PW-PM	PM-M	M-POM	POM-W
Grahmukh-teshwar					
Kachlabridge					
Fatehgarh					
Ankinghat					
Kanpur					
Bhitaura					
Shahzadpur					
Allahabad					
Mirzapur					
Varanasi					
Stations	**Hardness**				
Grahmukh-teshwar					
Kachlabridge					
Fatehgarh					
Ankinghat					
Kanpur					
Bhitaura					
Shahzadpur					
Allahabad					
Mirzapur					
Varanasi					
Buxar					

Stations	Chlorides				
Grahmukh-teshwar					
Kachlabridge					
Fatehgarh					
Ankinghat					
Kanpur					
Bhitaura					
Shahzadpur					
Allahabad					
Mirzapur					
Varanasi					

Stations	TDS				
Grahmukh-teshwar					
Kachlabridge					
Fatehgarh					
Ankinghat					
Kanpur					
Bhitaura					
Shahzadpur					
Allahabad					
Mirzapur					
Varanasi					

Stations	Sodium				
	W-PW	PW-PM	PM-M	M-POM	POM-W
Grahmukh-teshwar					
Kachlabridge					
Fatehgarh					
Ankinghat					
Kanpur					
Bhitaura					
Shahzadpur					
Allahabad					
Mirzapur					
Varanasi					

Stations	Potassium				
	W-PW	PW-PM	PM-M	M-POM	POM-W
Grahmukh-teshwar					
Kachlabridge					
Fatehgarh					
Ankinghat					
Kanpur					
Bhitaura					
Shahzadpur					
Allahabad					
Mirzapur					
Varanasi					

Stations	Sulphates				
	W-PW	PW-PM	PM-M	M-POM	POM-W
Grahmukh-teshwar					
Kachlabridge					
Ankinghat					
Kanpur					
Bhitaura					
Shahzadpur					
Allahabad					
Mirzapur					
Varanasi					

BOD, TC and FC show significant seasonal variation mainly between Pre-Monsoon and Monsoon. Other parameters like TDS, Na, K, SO4, and Alkalinity show significant mean difference at all stations during all seasons.In case of Ca, Mg, Hardness, Cl, temperature, seasonal mean difference is mainly noticed for lean seasons with Monsoon or Post-Monsoon. Within lean seasons hardly any variation is observed for these parameters.

B. Trend Analysis of River Water Quality

To understand the changes in river water quality over years, trend analysis is carried out for concentration and load of water quality parameters. Non-Parametric Mann-Kendall Trend test

and Theil-Sen Slope estimator is used for this. Trend is observed within various 5 seasons over these years at all stations. In following tables, yellow cells represent upward trend, blue cells indicate downward trend and grey cells indicate no trend in water quality.

Table Error! No text of specified style in document.**.14 Trend Analysis in DO, BOD and COD**

Seasonal Trend in Dissolved Oxygen					
Stations	W	PW	PM	M	POM
Flow_Kachlabridge	+	+			
Kachlabridge	+	+	+	+	+
Load_Kachlabridge	+	+			
Flow_Fatehgarh	+	+			
Fatehgarh					
Load_Fatehgarh	+				
Flow_Ankinghat	+	+		-	
Ankinghat					
Load_Ankinghat		+			
Flow_Kanpur	++	++		-	
Kanpur					
Load_Kanpur	+	+			+
Flow_Bhitaura	++	++			
Bhitaura					
Load_Bhitaura		+			
Flow_Shahzadpur	++	++		-	
Shahzadpur					
Load_Shahzadpur	+	+			
Flow_Buxar			-	-	
Buxar					
Load_Buxar	-	-	-		

Seasonal Trend in BOD					
Stations	W	PW	PM	M	POM
Flow_Varanasi		+		-	
Varanasi					
Load_Varanasi	+	+	+	+	+
Flow_Buxar			-	-	
Buxar					
Load_Buxar	-	-			

Seasonal Trend in COD					
Stations	W	PW	PM	M	POM
Flow_Grahmukh-teshwar	+	+		-	
Grahmukhteshwar	-	-	-	-	-
Load_Grahmukh-teshwar					
Flow_Kachlabridge	+	+			
Kachlabridge				-	
Load_Kachlabridge					
Flow_Fatehgarh	+	+			
Fatehgarh	+	+	+		
Load_Fatehgarh			-		
Flow_Kanpur	+	+		-	
Kanpur		-			
Load_Kanpur					
Flow_Bhitaura	+	+			
Bhitaura			+		
Load_Bhitaura					
Flow_Shahzadpur	+	+		-	
Shahzadpur				+	+
Load_Shahzadpur			+	+	+
Flow_Allahabad				-	
Allahabad	+	+	+	+	+
Load_Allahabad					
Flow_Mirzapur				-	
Mirzapur	+	+			+
Load_Mirzapur	+	+	+		
Flow_Varanasi		+		-	
Varanasi	+			+	+
Load_Varanasi					

DO as concentration hardly shows any trend at any station except Kachlabridge where positive trend is observed but rate of increase of DO is less than 0.5mg/L per year. DO as load shows increasing trend in Winter and Post-Winter at many stations which can be attributed to upward trend in flow. At Buxar, downward trend is observed in DO as load. Mostly slope for load of DO is in range of 0.5-1.5 kg/sec per year. Stations which are not listed in the table like Allahabad, Varanasi etc. do not show any trend in DO. Except upward trend at Varanasi, no trend is

observed in BOD. Concentration of COD shows a downward trend at Grahmukhteshwar while an upward trend at Allahabad in all season but the rate of change is very low. For stations like Fatehgarh, Mirzapur, Shahzadpur and Varanasi, upward trend in COD as concentration and load is observed in Lean seasons. Increasing trend in COD load will be mainly due to increase in its concentration at these stations.

Table Error! No text of specified style in document.**.15 Trend Analysis in Coli Forms**

Seasonal Trend in Faecal Coli Forms					
Stations	W	PW	PM	M	POM
Flow_Grahmukh-teshwar	+	+		-	
Grahmukhteshwar			-	-	
Load_Grahmukh-teshwar					
Flow_Kanpur	+	+		-	
Kanpur	+	+			+
Load_Kanpur					
Flow_Bhitaura	+	+			
Bhitaura	+	+	+	+	+
Load_Bhitaura					
Flow_Shahzadpur	+	+		-	
Shahzadpur	+	+	+	+	+
Load_Shahzadpur		+		+	
Flow_Allahabad				-	
Allahabad			+		
Load_Allahabad					
Flow_Mirzapur				-	
Mirzapur	+	+	+	+	+
Load_Mirzapur	+	+	+	+	+
Flow_Buxar			-	-	
Buxar	+		+		
Load_Buxar					

Seasonal Trend in Total Coli Forms					
Stations	W	PW	PM	M	POM
Flow_Grahmukh-teshwar	+	+		-	
Grahmukhteshwar	-	-	-		-
Load_Grahmukh-teshwar					
Flow_Fatehgarh	+	+			
Fatehgarh	-				-
Load_Fatehgarh			-		
Flow_Bhitaura	+	+			
Bhitaura				+	+
Load_Bhitaura					
Flow_Shahzadpur	+	+		-	
Shahzadpur	+	+	+	+	+
Load_Shahzadpur	+	+	+	+	+
Flow_Mirzapur				-	
Mirzapur	+	+	+	+	
Load_Mirzapur	+	+	+	+	
Flow_Varanasi		+		-	
Varanasi					+
Load_Varanasi					

From Table 5.7, An increasing trend in Faecal coli forms is observed in lean seasons. At Shahzadpur, Mirzapurand Bhitaura an upward trend and downward trend at Grahmukhteshwaris obtained in all seasons for Faecal and Total coli forms. The rate of increase in Coli Forms is around 100-200 MPN/100 ml per year for Coli Forms concentration. And rate of increase in load is exceptionally high. At Grahmukhteshwar the rate of decrease is in range of 10-20 MPN/100 ml per year. In the similar manner trends are analysed for all water quality parameters at all stations. They are reported in form of water quality trend at a particular station. For example the following table reports water quality trend at Kanpur station.

Table Error! No text of specified style in document..**16 Trend Analysis for Water Quality Parameters at Kanpur**

Kanpur Trend Analysis							
Parameters	All seasons	Monsoon Season	Non-Monsoon Seasons				
			Winter	Post-Winter	Pre-Monsoon	Post-Monsoon	All
Flow			+	+			
Concentration							
TDS		+	-				
EC		+					
Bicarbonates							-
Total Alkalinity , Calcium , chlorides, Silicates	+						
Total Hardness		+	`		+	+	
Sulphates	-						
Sodium		+	-	-	-		
COD						-	
FC						+	
No Concentration Trend Parameters :			pH , Temperature , Turbidity , CO3 , F , NH4-N , NO2, NO3 , PO4 ,Magnesium ,Pottasium ,DO,BOD, TC				
LOAD							
EC		-					
Total Alkalinity , Calcium , chlorides , silicates							+
Potassium	+						
Total Hardness			+	+		+	
Sodium		`		`	-	`	
Sulphates		-			-		
DO			+	+		+	
No Load Trend Parameters			All other parameters				

EC and TDS show negative trend at many stations during lean seasons. EC and TDS as load hardly shows any trend except for stations like Shahzadpur, Ankinghat where the trend is mostly upward and similar to flow trend. **Bicarbonates** have a downward trend in lean season and no trend in Monsoon season at all stations except Kachlabridge and Buxar where positive trend obtained in both concentration and load of bicarbonates. **Total alkalinity**have a mixed

trend condition in this stretch like increasing for Garhmukhteshwar to Bhitauraand decreasing for Shahzadpur to Buxar.

Calcium has an increasing trend in all seasons at all stations while Calcium as load shows increasing trend only in lean seasons. **Magnesium** has a mixed trend such as decreasing trend from Grahmukhteshwar to Kanpur while increasing from Allahabad to Buxar in mostly lean seasons. **Hardness** shows opposite trend that of magnesium, increasing till Bhitaura and no trend from Shahzadpur to Varanasi. From Garhmukhteshwar to Shahzadpur hardly any trend is observed in **Sodium** but an upward trend is observed from Shahzadpur to Buxar in both seasons. **Potassium** shows upward trend in all seasons and at all stations in terms of load and concentration.

Chlorides show increasing trend in all seasons at all stations. Chlorides as Load show upward trend only in lean seasons for all stations except Shahzadpur and Allahabad. **Sulphates** as concentration and load show decreasing trend in all seasons from Garhmukhteshwar to Kanpur. After Kanpur an upward trend is observed predominantly in Non-Monsoon seasons in sulphate concentration and no trend in sulphates as load. **Silicates** also show increasing trend in all seasons from Grahmukhteshwar till Bhitaura in both load and concentration. After that hardly any trend is obtained in silicates.**Forms of nitrogen and phosphorus** do not show any trend as their concentrations are very negligible.

Correlation between Water Quality Parameters

Correlation between water quality parameters is analysed by Pearson's Correlation Coefficient (r) and its significance is checked at 95 % confidence limit.Correlation analysis is carried out in Monsoon and Non-Monsoon season. Following groups are considered in analysis-

Table Error! No text of specified style in document.**.17 Correlation Analysis**

Sr. No.	Water Quality Parameters
Group 1	EC, TDS, Ca, Mg, Na, K
Group 2	TDS, F, Cl, SiO2, SO4
Group 3	HCO_3, CO_3, Total Alkalinity, pH, PO_4
Group 4	Total Hardness, Ca, Mg, Total Alkalinity
Group 5	NH_3-N, NO_3, PO_4, DO, Temperature
Group 6	BOD, COD, TC, FC, DO

A. Correlation between EC, TDS, Cations and Anions

From Table 5.10, A strong significant correlation is noticed between EC and TDS at all stations in both seasons with r values > 0.7. Sodium show significant positive correlation with TDS

Predominantly in Non-Monsoon which may be due to anthropogenic activities lead to increase in sodium composition while magnesium show in both the seasons with r values range from 0.4 -0.7 as source of magnesium in river water is chemical weathering of rocks. TDS and potassium show significant positive correlation at some stations in both seasons. Among cations and TDS least significant correlation is observed between TDS and Calcium. Though the Calcium concentration in selected stretch is more than magnesium but TDS shows good correlation with magnesium than calcium.

Table Error! No text of specified style in document.**.18 Correlation among TDS, Cations and Anions**

Sr. No.	Station	TDS-CATIONS								TDS-ANIONS					
		TDS-Ca		TDS-Mg		TDS-Na		TDS-K		TDS-SiO2		TDS- Cl		TDS-SO4	
Season		N M	M	N M	M	N M	M	N M	M	N M	M	N M	M	N M	M
1	Grahmukhteshwar														
2	Kachlabridge														
3	Fatehgarh														
4	Ankinghat														
5	Kanpur														
6	Bhitaura														
7	Shahzadpur														
8	Allahabad														
9	Mirzapur														
10	Varanasi														
11	Buxar														

Colour Code		
r > 0.7	Insignificant correlation	
0.4 < r < 0.7	Blank cell - No Data Available	
r < 0.4		

TDS and fluorides show significant positive correlation with r value greater than 0.7 only in Non-Monsoon from Kachlabridge to Bhitaura. TDS and chlorides show good positive correlation in Non-Monsoon at all stations excluding Allahabad as compared with Monsoon. Anthropogenic activities like municipal and industrial waste water increases chloride concentration in river water its effect is seen in Non-Monsoon season due to low flow conditions. Silicates and TDS

show significant correlation at few stations in Non-Monsoon while at Fatehgarh in Monsoon. At some stations good correlation observed between TDS and Sulphates in Non-Monsoon than in Monsoon. It can also be attributed to point sources such as Tanneries, Pulp mills or municipal waste letting sulphates in river water.

B. Correlation between Hardness, Alkalinity and corresponding ions

From Table 5.11, A significant positive correlation is observed between alkalinity and bicarbonates at all stations in both seasons. Alkalinity and carbonates are significantly correlated at some stations primarily in Non-Monsoon and from Bhitaura to Varanasi in Monsoon season also. A weak significant positive correlation is seen between alkalinity and phosphates Predominantly in Non-Monsoon and at some stations in Monsoon. Correlation coefficient for Alkalinity, Carbonates and Phosphates is always less than 0.7.

Table Error! No text of specified style in document.**.19 Correlation among Hardness, Alkalinity and corresponding ions**

Sr. No.	Station	Hardness-Ca		Hardness-Mg		Hardness-Alkalinity		Alkalinity-CO3		Alkalinity-HCO3		Alkalinity-PO4	
Season		N M	M	N M	M	N M	M	N M	M	N M	M	N M	M
1	Grahmukhteshwar												
2	Kachlabridge												
3	Fatehgarh												
4	Ankinghat												
5	Kanpur												
6	Bhitaura												
7	Shahzadpur												
8	Allahabad												
9	Mirzapur												
10	Varanasi												
11	Buxar												

Colour Code					
	Insignificant correlation		-0.4 < r < -0.7		r > 0.7
					0.4 < r < 0.7
	Blank cell - No Data Available		r < -0.4		r < 0.4

Hardness and Magnesium are strongly correlated with r value greater than 0.7 as compared with Hardness and Calcium. Hardness and Calcium show strong positive correlation in Monsoon as compared with Non-Monsoon season from Kanpur to Allahabad. Hardness and alkalinity are weakly correlated at all stations in both seasons except Allahabad to Varanasi during Monsoon where strong correlation observed. From Gramukhteshwar to Varanasi non-carbonate hardness is more than carbonate hardness in Non-Monsoon season while Allahabad to Mirzapur

carbonate hardness is more in Monsoon. No positive correlation observed at Buxar but a negative correlation is observed between Hardness and Calcium.

C. Correlation between Temperature, DO and Forms of Nitrogen and Phosphorus

A significant weak negative correlation is observed between Temperature and DO at many stations during Non-Monsoon seasons as compared with Monsoon. Here the r values vary between 0 to -0.7. Only at Kanpur, all forms of nitrogen and phosphorus show significant negative correlation with DO.

Table Error! No text of specified style in document.**.20 Correlation among Temperature, DO and Forms of Nitrogen and Phosphorus**

Sr.No.	Station	Temp-DO		DO-Ammonical-N		DO-NO3		DO-PO4	
Season		**N M**	**M**	**N M**	**M**	**N M**	**M**	**N M**	**M**
1	Grahmukhteshwar								
2	Kachlabridge								
3	Fatehgarh								
4	Ankinghat								
5	Kanpur								
6	Bhitaura								
7	Shahzadpur								
8	Allahabad								
9	Mirzapur								
10	Varanasi								
11	Buxar								
Colour Code		Insignificant correlation				r > -0.7		r > 0.7	
						- 0.4 < r <- 0.7		0.4 < r < 0.7	
	Blank cell - No Data Available					r < - 0.4		r < 0.4	

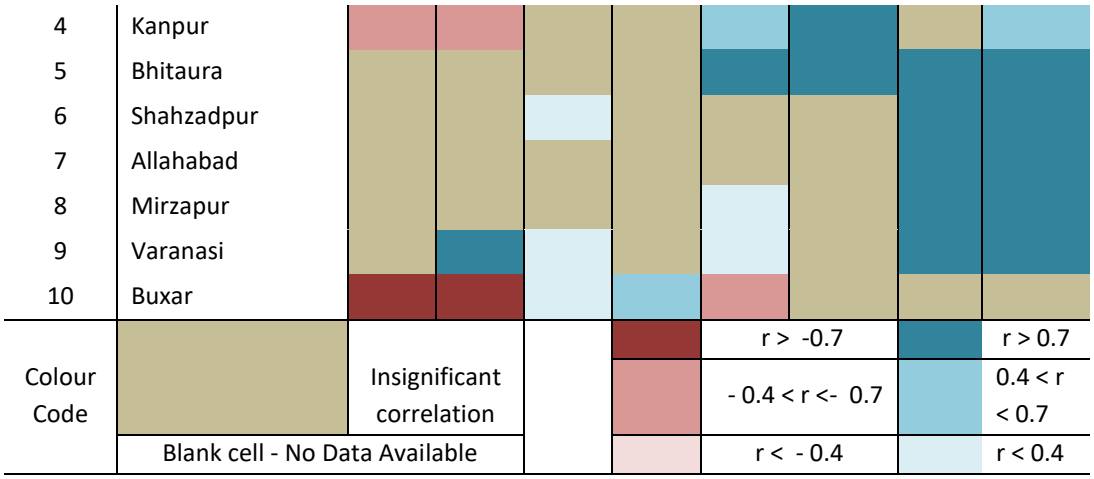
For other stations, rarely correlation noticed between these parameters. Negligible concentration is observed for Nitrogen and Phosphorus as discussed earlier hence the correlation is also not significant.

D. Correlation between DO, BOD, COD and Coli Forms

A weak negative correlation is observed between DO and BOD at few stations.

Table Error! No text of specified style in document.**.21 Correlation among DO, BOD, COD and Coli Forms**

Sr.No.	**Station**	**DO-BOD**		**DO-COD**		**BOD-COD**		**TC-FC**	
Season		**N M**	**M**	**N M**	**M**	**N M**	**M**	**N M**	**M**
1	Grahmukhteshwar								
2	Kachlabridge								
3	Fatehgarh								



But at Varanasi a positive correlation is obtained between DO and BOD. A weak negative correlation observed between DO and COD at Grahmukhteshwarand Fatehgarh during Non-Monsoon seasons on the contrary a positive correlation is obtained at Shahzadpur, Varanasi and Buxar. A significant positive correlation is obtained between BOD and COD. TC and FC shows a strong positive correlation at all stations with r value always greater than 0.7 except Kanpur and Buxar. COD do not show significant correlation at any station with chlorides, sulphates and nitrates.

5.4 A detail Analysis of DO-BOD and Coli Forms relation in River Ganga

As per A status report on River Ganga published by MOEF in 2009 and Pollution Assessment of River Ganga a report published by CPCB in 2013 , BOD and Coli Forms exceed the tolerance limits but DO is always within the limit. Even from the temporal and spatial plots of DO, BOD and Coli Forms same is observed. From the correlation analysis in the selected stretch, it is concluded that DO and BOD show hardly any correlation while TC and FC are very well correlated. Hence here an attempt is made to know the DO-BOD relation and Coli Form sources in complete stretch of river Ganga from Source till Buxar. NRCD data is available from Source of river Ganga for DO, BOD and Coli Forms. There are total 37 stations between this complete stretch. A correlation analysis is carried for DO-BOD and TC-FC.

From Table 5.14, out of total 37 stations, 18 stations show significant negative correlation between DO and BOD. Out of these 18 stations only 3 stations show strong negative correlation between DO and BOD. Rest all stations show a weak correlation with r value between 0 to - 0.7. Few stations before and after confluence of Alaknada and Bhagirathi at Devprayag even show a positive correlation. Even from DO-BOD cluster plot it can be noticed that , mostly the BOD values are less that 10 mg/L but DO varies from 2 to 10 mg/L. Few times BOD is very high in range of 30-50 mg /L but DO values are still more than 4 mg/L. From Correlation analysis and

graphical rePresentation, DO and BOD are hardly correlated whereas a good negative correlation is expected between them.

Out of total 37 stations in this stretch, 33 stations show a significant positive correlation between TC and FC. Out of these 30 stations, 24 stations show strong positive correlation where r value greater than 0.7. Hence we can say that TC and FC are well correlated in this stretch and most of the coli forms Present in river are of faeces origin. This very well correlation can also be noticed by cluster plot. At some locations high TC-FC values are reported but majority of times coli forms are less than 1,00,000 MPN/100 ml .

Table Error! No text of specified style in document..**22 Correlation for DO-BOD and Coli Forms from Ganga River Source till Buxar**

Sr.No.	Station	No. Observations	DO-BOD	FC-TC
1	Uttarkashi u/s Bhagirathi)	35		
2	Uttarkashi d/s(Bhagirathi)	33		
3	Deoprayag u/s (Bhagirathi)	39		
4	Deoprayag u/s (Alaknada)	39		
5	Deoprayag d/s (Ganga)	39		
6	Ranipur u/s (Ganga)	39		
7	Ranipur d/s (Ganga)	40		
8	Rishikesh u/s	240		
9	Rishikesh d/s	120		
10	Haridwar u/s	155		
11	Har-Ki-Pauri	120		
12	Lalta Rao	120		
13	Dam Koti	250		
14	Mishrpur	120		
15	Bishnoi us ganga	36		
16	Bijnoi ds ganga	36		
17	Garhmukteshwar u/s	180		
18	Garhmukteshwar d/s	90		
19	Anoopshahar u/s(Ganga)	36		
20	Anoopshahar d/s(Ganga)	97		
21	Fatehgarh u/s(Ganga)	214		
22	Kannauj u/s (a/c with Ramganga & b/c with kali)	206		
23	Kannauj d/s (a/c with kali)	190		
24	Kanpur u/s (Bithoor)	190		
25	Kanpur d/s (Shuklaganj)	140		
26	Kanpur d/s (Jane village)	140/82		
27	Allahbad : u/s (ujahni), fatehpur	140		

28	Bathing ghats at sangam	58	
29	d/s Deenaghat	120	
30	Vindhyachal ,pakkaghat	40	
31	Varanasi u/s	140	
32	Dashashwmedhghat	55	
33	d/s at kaithy	50	
34	Near Malviya Bridge	120	
35	Tarighat	160	
36	Buxar u/s	120	
37	Buxar d/s	90	

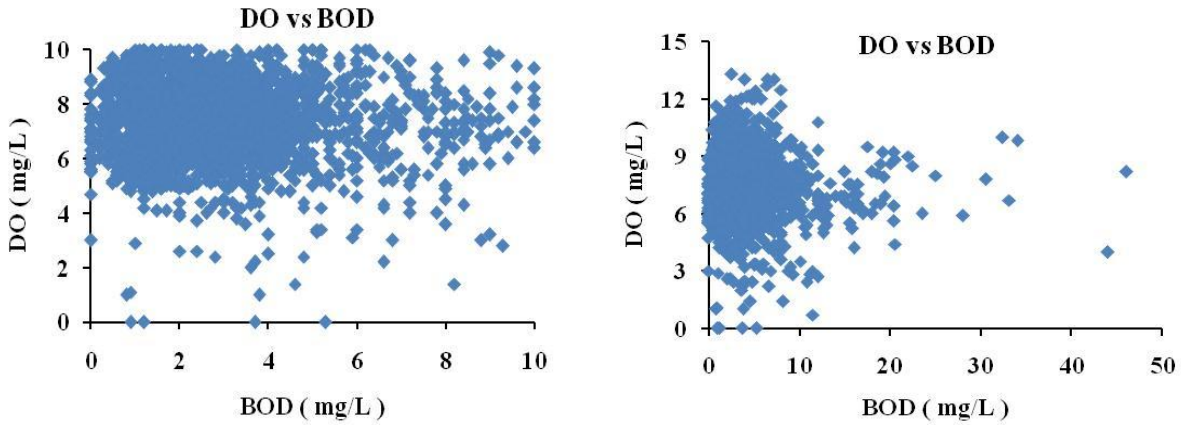


Figure Error! No text of specified style in document..**32 DO-BOD Variation in River Ganga**

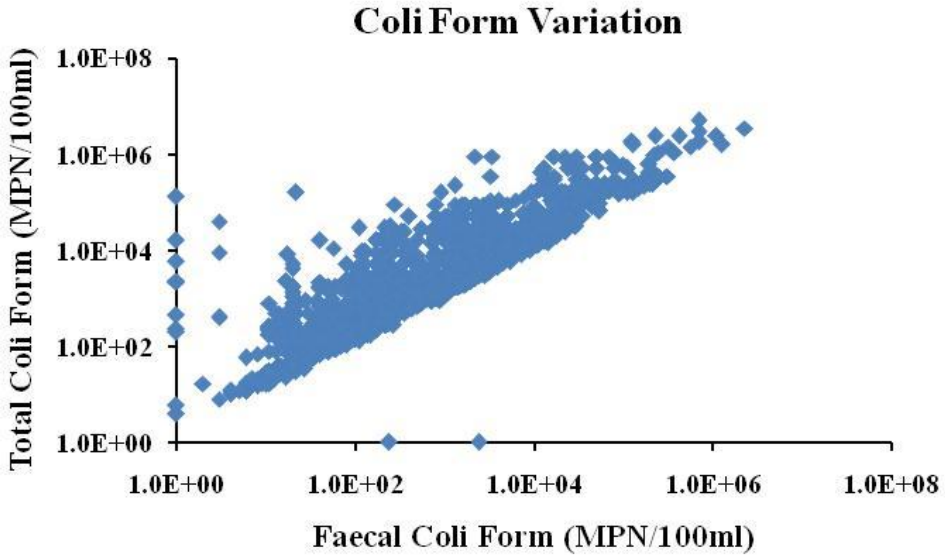


Figure Error! No text of specified style in document..**33 Coli Forms Variation in River Ganga**

From DO-BOD correlation analysis, hardly strong negative correlation is observed. That is high DO levels in river Ganga does not support low organic loading. But DO levels are maintained due to significant photosynthetic activity in the river which leads to augment DO. This significant photosynthetic activity can be assessed by studying diurnal DO variation in river stretch. This study has been carried for Kannauj to Kanpur stretch which supports the diurnal DO variation with maximum DO observed before sunset and minimum DO before sunrise(Tare *et al.*, 2003). Instead of focusing on BOD levels and formulating more stringent norms for BOD, diurnal measurement of DO is necessary because minimum diurnal DO variation will reduce the BOD load in river.

From the coli forms concentration over almost 25-30 years in this stretch of river Ganga, it can be inferred that huge amount of total coli forms are of faecal origin. The river stretch contains many industrial, densely populated and pilgrimage centers. Huge drains in these cities carry the large amount of domestic sewage, industrial effluent along with surface runoff which ultimately discharge into river Ganga leading to increase Feacal Coli Forms concentration. Soil particles Present in surface runoff can foster and protect bacteria invertebrate Predators(Marino and Gannon, 1991). Naturally occurring particles in surface water can harbor the indigenous colifoms and E.Coli((Cantwell and Hofmann, 2008). Studies also suggest that Faecal coli forms densities in surface water are directly related with density of population , housing , impervious areas, domestic animals, open defecation((Young, 1999). All these activities increase the coli form load in the river.