

Pattern of Flows and Water Quality in River Yamuna over the Past Four Decades

By



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1. Introduction

1.1. Background

Water being the elixir of life, rivers have been the cradles of all historic civilizations. The fact that all ancient civilisations have developed along the river side indicates the importance of rivers in our life. We have been using the river water for meeting our basic needs. Since long we have been disposing the waste generated in the rivers. There was a time when water was said to be available in abundance and the oceans were considered to have infinite potential for dilution. But with increasing population and an exponential rate of development, the complete scenario has changed. Freshwater has now become a precious commodity. No doubt it is said that if at all there would be a third world war, it would be because of water.

Surface water bodies have been undergoing changes both in terms of quantity and quality. Water quality is not a simple phenomenon depending on a single parameter. It is a complex phenomenon which depends on the physical, chemical and biological characteristics of water(CPCB, 2007). The water quality standards depend on the end use of water, whether it is to be used as a drinking water supply, irrigation, domestic use or for meeting the industrial demands.

The water bodies in which we have been dumping wastes, themselves serve as the raw water source for drinking and other purposes. With the deteriorating condition of river water quality, the ecology of surface water bodies is getting affected. It is of utmost importance to initiate policy measures which will aim to restore this ecological balance. Water treatment has become mandatory for any consumptive use of water. Water quality programs have therefore been chalked out with the objective of identifying the possible sources for raw water supply. To improve the condition of rivers, it is important to identify the polluted stretches where a check on pollution needs to be ensured. With this view, several water quality monitoring programs have been implemented to analyse the state of the art of the river water quality.

1.2. Problem Overview

In a country like India, rivers have been considered to be of great spiritual as well as religious significance. River Ganga, with a length of 2525 km is the longest river of India. River Yamuna, with a stretch of 1376 km is the main tributary of Ganga. The natural assimilative capacity of the rivers was once adequate to sustain life and take care of domestic wastes discharged in the rivers. Had rural sources like agricultural and cattle wastes been the only sources contributing to the rivers then the self-purification capacity

would have sufficed the purpose. But it is domestic wastes and industrial effluents from cities being discharged as point loads, which is responsible for deteriorating the condition of the river (CBPC, 1978). The rivers Ganga and Yamuna have been considered as the Goddess enhancing life of humans. But we have left no stone unturned in polluting the rivers to such an extent that these holy rivers are now being identified as the Goddess of death (Sharan, 2016).

On the basis of a CPCB survey done in 1982-83, an action plan, called the Ganga Action Plan (GAP) was chalked out in 1985 with a view of restoring the degraded water quality of national river Ganga. The primary objective of GAP was to make the river Ganga suitable for bathing purpose. The strategy adopted for this was IDT – Interception, diversion and treatment works to reduce the incoming pollution load (Tareet *et al.*, 2003). After the implementation of GAP I, which was conceptualized in 1985, it was realised that targeting only the mainstream river to ensure a clean Ganga is not sufficient. The most significant tributary of Ganga was subjected to severe water quality stress. It was then realised that to achieve the goal of clean Ganga, it was equally important to ensure a clean Yamuna. During the implementation of GAP II, the important tributaries, especially Yamuna was included. The holy river Yamuna has unfortunately been listed as one of the worst polluted rivers of the country by the CPCB. The major reasons for the worsening pollution levels of Yamuna were identified as 45% of un-sewered population and large open drains directly pouring the wastes in the river.

In our country, the contribution of agricultural sector to the national economy is significantly higher than the world's average. The states Uttar Pradesh, Rajasthan and Madhya Pradesh which contribute to almost 20, 30 and 40% of the catchment area of Yamuna basin, are reported to have almost 68, 44 and 50% actual cultivated land respectively. It is clear from these figures that agriculture is practiced on a large scale in the fertile plains of Yamuna basin. CPCB and MoEF have reported that 93% of Yamuna water is used for irrigation. About 49% of the irrigated land in Yamuna basin meets its water demand from surface water (Mehra, 2012). With this background, it is of utmost importance to ensure the suitability of river water for irrigation.

In the name of development, along with partially treated or untreated sewage wastes, we have been dumping industrial wastes containing toxic pollutants in river bodies. The green revolution facilitated an increased agricultural production but at the cost of environment as it resulted in an indiscriminate use of pesticides and fertilisers containing toxic metals. Increasing concentrations of heavy metals in potable water has led to biological magnification, thereby posing a risk to human health (Bhardwaj *et al.*, 2017). Hence, monitoring of heavy metal contamination has become the need of the day to come up with strategies for removal of the same.

2. Study Area

2.1. Geographic Details of Yamuna River Basin

Yamuna river originates at Yamunotri glacier in the Mussourie range of lower Himalayas. The river traverses a length of 1376 km from an elevation of about 6387 m from mean sea level and joins river Ganga at Allahabad at an elevation of 100 m above mean sea level. With a catchment area as large as 6223 km² Yamuna basin constitutes almost 42.5% of the entire Ganga river basin (Sharma *et.al*, 2017). Out of the total catchment area of Yamuna, nearly 70.9 % catchment area is contributed by sub basin tributaries whereas the main stem accounts for only 29.1 % of the drainage. The river flows through seven states namely Uttara Khand, Uttar Pradesh, Himachal Pradesh, Haryana, Rajasthan, Madhya Pradesh and the national capital territory of Delhi. 42% of the basin area is constituted by alluvial soil (Pollution & Board, 2006).

As far as the drinking water supply of Delhi is concerned, more than 70% of it is abstracted from the river directly. The livelihood of an estimated population of 57 million is entirely dependent on the Yamuna (Sharma & Chaudhry, 2013). Several large industrial cities like Yamunanagar, Sonapat, Panipat, Delhi, Agra and Mathura are situated on the banks of river Yamuna. These cities are industrial hubs with clusters of industries like pulp and paper, tannery, steel plants, glass, chemicals, plastics, food processing and rubber. 22, 42 and 17 such units in Haryana, Delhi and Uttar Pradesh have been found to directly polluting the Yamuna river (Sharma & Chaudhry, 2013).

2.2. Organisations Measuring Water Quality

CPCB and CWC are two Government organisations which measure water quality at certain stations on a regular basis. The objective behind water quality monitoring is different for both organisations. While CWC measures water quality with the focus of assessing the suitability of water from irrigation point of view, CPCB analyses water quality with a view of assessing the pollution. Salinity, cations, ions and all chemical parameters constituting dissolved solids are mainly the parameters measured by CWC. Sodium absorption ratio (SAR) is a chemical index governing the use of water body for the beneficial use of irrigation, which is calculated from cation concentrations. On the contrary, monitoring of organic pollution being the prime focus of water quality analysis for CPCB, the important parameters monitored are DO, BOD, COD, coliform and nitrogen.

At its source in Yamunotri, many hill streams constitute the river. Within a distance of 120 km from the source lies Dakpathar barrage, 22 km downstream of which lies the first CWC station Paonata (refer Figures 2.1 and 2.2). The river water at Dakpathar is indicative of the water quality prior to the confluence of tributary Tons with Yamuna. The second barrage in

the upper stretch is Hathnikund/ Tajewala, which lies 12 km downstream of Paonata after the confluence of both rivers, Tons and Giri. The water quality of river at Kalanaur is mainly influenced by groundwater and the tributary Tons. Between Kalanaur and Mawji, the Eastern Yamuna canal and Western Yamuna canal abstract significant amount of water. The water quality of river at Palla indicates the quality of the raw water source for water supply of the capital city of Delhi (Pollution & Board, 2006).

Wazirabad barrage lies 6 km upstream of Delhi, immediately after which the Najafgarh drain finds its way in river Yamuna. Okhla barrage lies about 16 km downstream of Delhi, after which Shahdara drain empties its wastewater discharge in Yamuna. This stretch of 22 km between the two severely polluting drains of Delhi constitutes nearly 70% of pollution of Yamuna (Pollution & Board, 2006). Around 40 km downstream of Mohana, the Agra canal diverts water from Yamuna to meet the demands of Agra city. The Gokul barrage lies around 6 km downstream of Mathura. Almost all freshwater prior to Delhi is abstracted in the form of barrages and canals to meet the ever increasing domestic as well as industrial demands. This stretch of river from Delhi to Agra is so heavily polluted that it is almost considered to be dead. The water quality in this part is equivalent to a sewer, carrying wastewater and toxic substances from the urban cities of Delhi, Mathura and Agra (Misra, 2010).

Etawah is the last station with low flow as river Chambal joins Yamuna around 75 km downstream of this station. In spite of Chambal being a tributary of Yamuna, it is responsible for contributing to almost 5-10 times of the flow of mainstream Yamuna (Pollution & Board, 2006). Udi is a station on Chambal, which is a representative of the water quality of tributary Chambal. Yamuna river meets Ganga at Allahabad, around 30 km downstream from Pratappur.



Figure 2.1: The Three Stretches Considered for Analysis

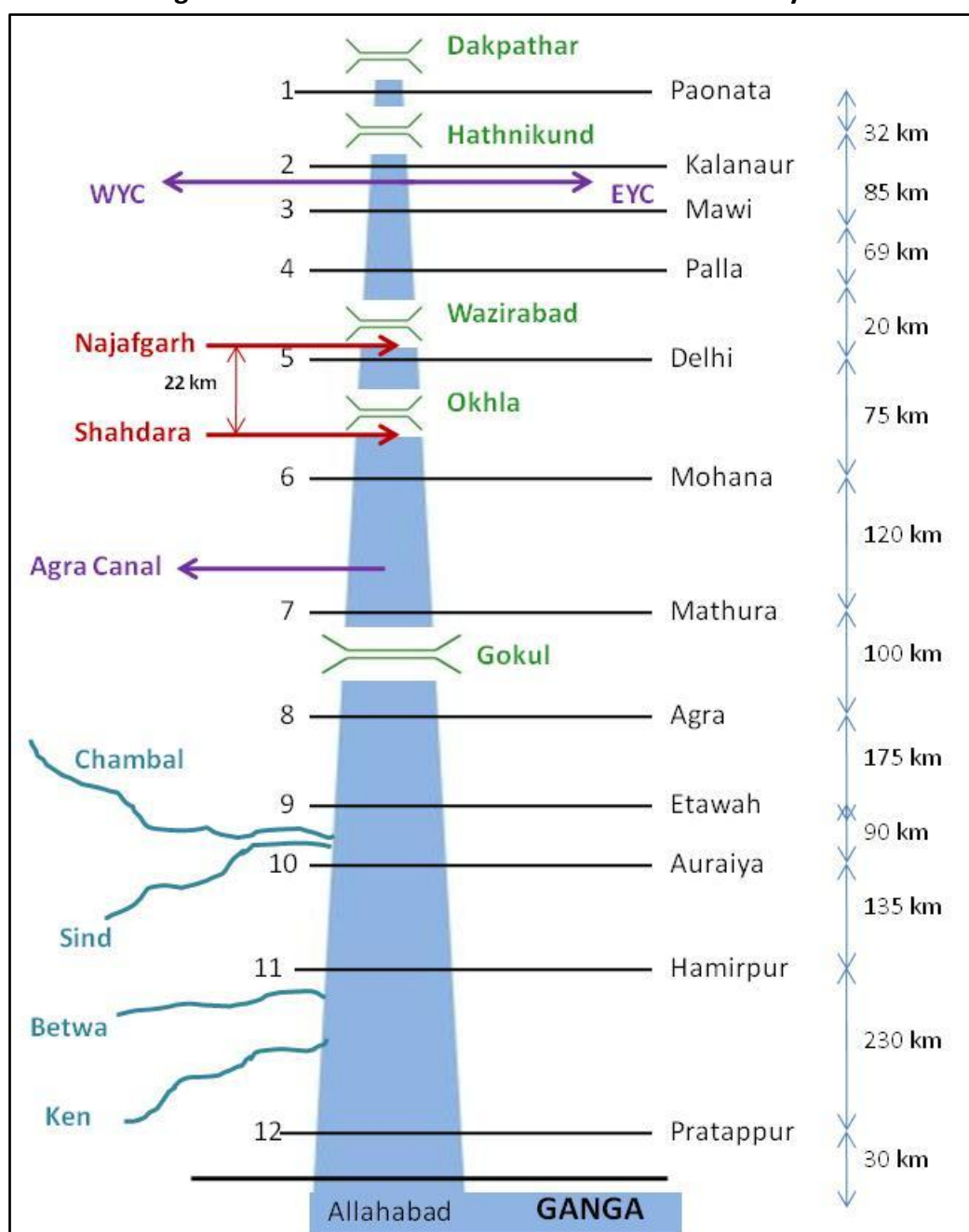


Figure 2.2: Block Diagram of Yamuna Mainstream with CWC Stations, Barrages and Tributaries

2.3. Details of CWC Stations

As per the “Hydrological Observation Stations in India under Central Water Commission 2012 report”, CWC monitors Ganga river flows at about 283 locations (Hydrological Observation Sites) under an organisational structure of 11 CWC divisions (CWC, 2012). Out of total 283 stations reported by CWC, water quality is observed at about 106 stations. The state of river water quality is different at different stages of rivers and is mainly affected by population density and land use pattern in its catchment area. Some stations on the

upstream side of river show less variation in water quality measures so it is not economical to monitor the quality at intervals similar to those stations located relatively on the downstream side. Based on the frequency of monitoring, the CWC water quality stations are classified as follows:

Table 2.1: Categorisation of CWC Stations on the Basis of Frequency of Measurement

SNo	Type of Station	Frequency of Monitoring	Description
1	Base	One sample in 2 months	Water quality is relatively free from the influence of human activities
2	Trend	Monthly	Location designed to understand how a particular point on a water course varies over time normally, under anthropogenic influence
3	Flux	Thrice monthly Toxic and trace metal: monthly	The extent of pollution due to geological feature or human activities is considered, which is necessary to analyse the impact of pollution control measures adopted

2.4. CPCB Stations

Along with policy making, an important objective of water quality monitoring is to assess the impact of human intervention and the success of the river action plans. CPCB was entrusted the responsibility of water quality monitoring of river Yamuna during 1977. After the implementation of YAP-Phase 1, CPCB has carried out water quality analysis on Yamuna river stations for a seven year period from 1999 to 2005. During this analysis, 19 locations on mainstream of river were analysed. Besides this, monitoring of 16 drains contributing to pollution from Delhi was also carried out. Out of these, the following 12 locations have been considered for water quality analysis of parameters indicating organic pollution.

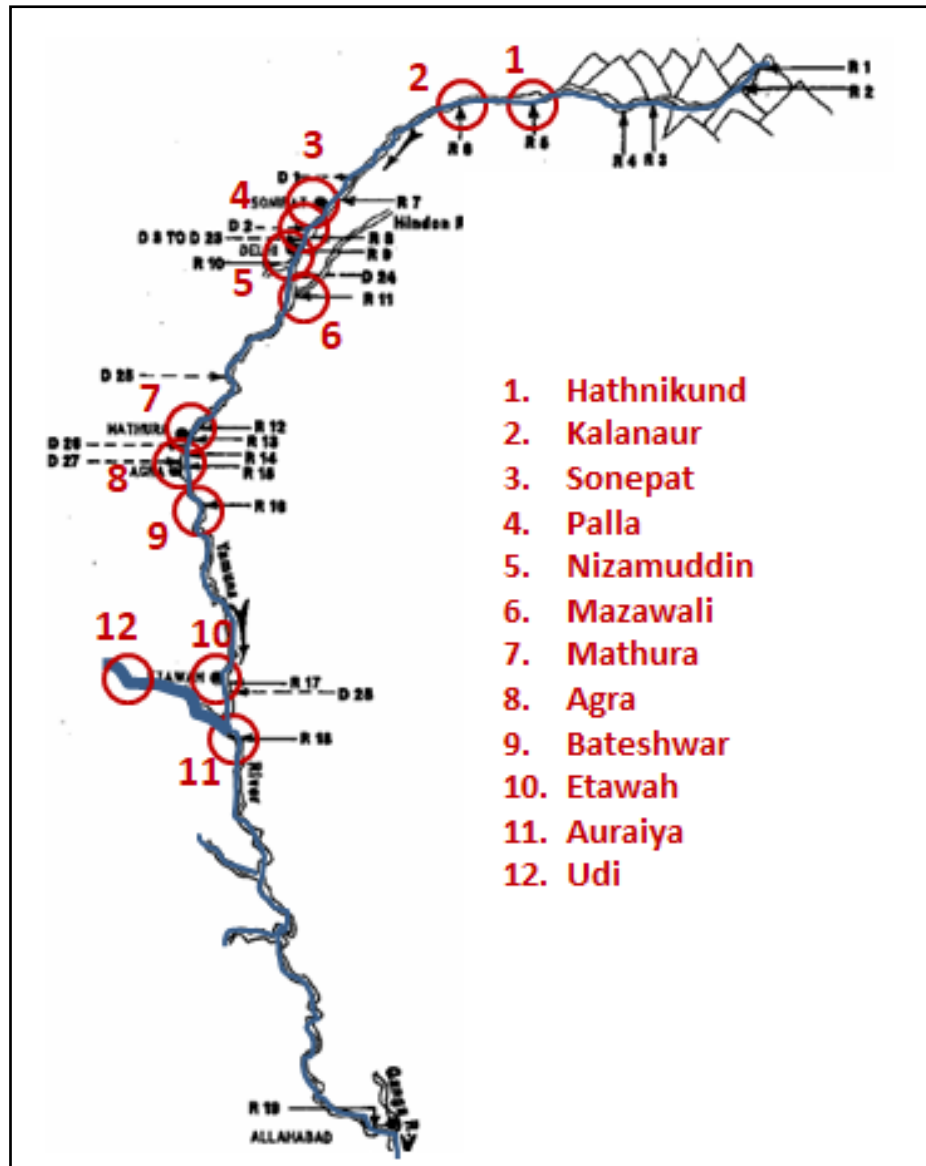


Figure 2.3: CPCB Stations where Monitoring was Done Post YAP Phase I

3. Literature Review

3.1. Segments of River Yamuna

Over the years, significant structural interventions have been taking place on Yamuna river to meet the increasing water demands of human population. Various canals and barrages constructed on the mainstream have been abstracting significant amount of freshwater regularly from the river. This has resulted in the fragmentation of the river in five segments. Almost all studies have considered the following segmentation of the river.

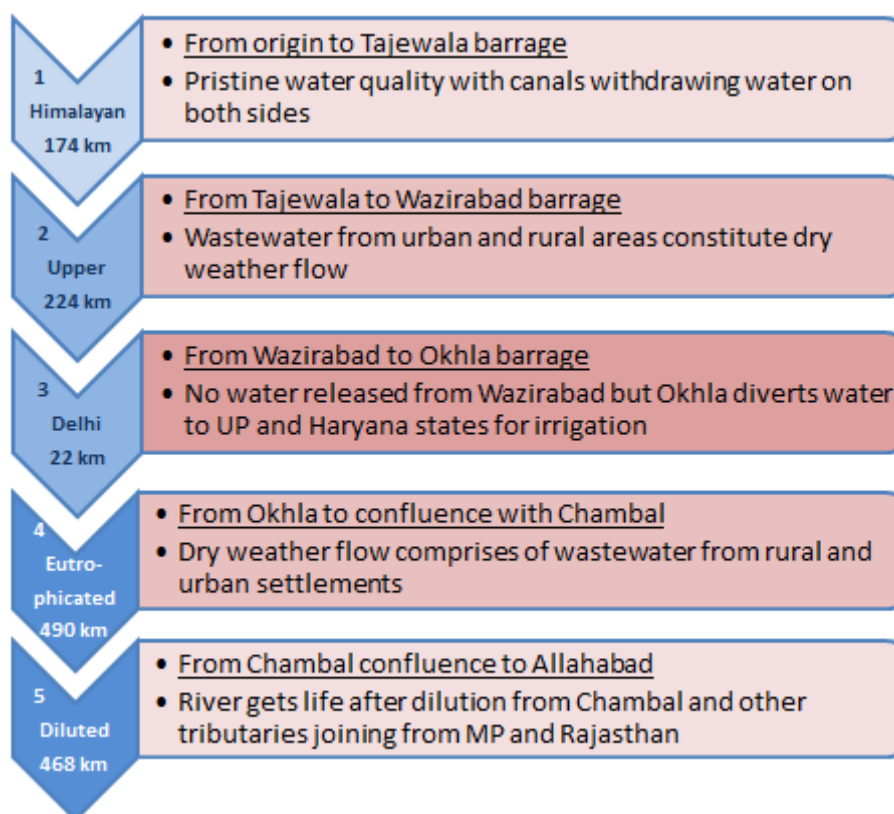


Figure 3.1: Segmentation of River Yamuna due to Barrages

Figure 3.1 schematically presents the description of the five segments of river, which are defined on the basis of the location of barrages. The magnitude of flow and extent of deterioration in water quality of river in a particular segment is represented by the intensity of the colour.

3.2. Studies Conducted on Water Quality of River Yamuna

With Delhi generating approximately 1900 MLD sewage as against having treatment facilities for only 1270 MLD, 630 MLD of untreated sewage flows in the river. CPCB has reported that 1-10% of parent chemicals used in the process of production is eventually turned into waste materials and useless by-products. With sewage treatment not given the required priority and attention, polluted rivers are emerging as an environmental problem in developing countries. Based on studies carried out on Yamuna in last 10 years, Sharma & Chaudhry, (2013) have reviewed the impact of industrial pollution on the river, which has been reported to be a significant contributor to a deteriorating Yamuna apart from domestic and agricultural wastes.

3.2.1. Chemical Parameters

Groundwater is a major source of water in the north Indian states which is used by industries, residential colonies as well as slum dwellers. This groundwater with high salt concentration is turned into wastewater ultimately finding way in the Yamuna. This has been reported to be the main cause of increased chloride content beyond Delhi in both seasons (Bhargava, 1985).

CPCB (1978) reports Oct-March as the critical period for chlorides and fixed dissolved solids, indicating dilution of minerals due to water from snow melt in summer. The entire river flow in winter being attributed to seepage and groundwater flow, the mineral concentration is found to be the highest in winter.

3.2.2. Indicators of Organic Pollution

Bhargava (1985) is one of the reported studies conducted for the entire course of the river from the source to its confluence. This study was conducted in 1977 for winter and summer. The BOD values have been reported to increase steeply after all wastewater outfalls in the urban areas. The DO which is seen to increase up to Delhi, is observed to reduce beyond Agra. The relatively less polluted Chambal contributes to a rise in DO downstream (Misra, 2010).

Winter has been found to be the critical season for BOD in case of locations upstream of Okhla but for the middle stretch from Okhla to Etawah the critical season was found to be summer. Highest total nitrogen values and lowest DO values have been reported during summers (CBPC, 1978).

The water quality data of surface and groundwater places Yamuna seventh in the list of rivers with highest BOD values. With the average BOD level 93 mg/L as against the permissible limit of 3 mg/L, the DO levels are observed to be less than 4 mg/L with DO even dropping to zero at certain places (Misra, 2010).

3.2.3. Biological Parameters

In spite of the low flows during summer, faecal coliform values have been found to be less in summers, possibly due to a higher death rate of microbial organisms (CBPC, 1978). The coliform concentrations between Delhi to Agra have been reported to be above the bathing standards. Despite of this people use the water for domestic purposes (Bhargava, 1985).

Anand *et al.* (2006) carried out studies in 2002-03 that has been targeted to analyse the impact of monsoon and anthropogenic activities on the coliform levels of Yamuna in Delhi. Increased coliform counts downstream of Palla indicate anthropogenic influence. The

coliform levels on the east and west banks of Nizamuddin bridge have been reported to have a significant difference. The increased count on west bank has been attributed to outfall of industrial drains. Midstream of all barrages has been reported to have low faecal coliform counts, indicating these regions being relatively free from anthropogenic influence. Summer months with reduced flows and elevated temperatures have been observed to support the survival of bacteria. Post monsoon brings the runoff from the catchment areas contributing to increased content of organic matter and elevated coliform counts.

3.2.4. Nutrients

With the occurrence of green revolution, cultivation of crops and animal husbandry gained a boom in the 1960's. With the advent of nitrate and phosphate rich fertilisers, nutrient concentrations in soil have been accumulating gradually. The exponential population growth has resulted in increase in domestic sewage in rivers whereas the industrial development has resulted in an ever increasing disposal of industrial wastes. Groundwater in India has recently been threatened by this increased pollution load and lack of proper management of the same. Along with organic pollution, it is equally important to intervene with the incoming nutrient load to limit the threat of algal blooms, since aquatic systems have a limitation to remove it. It is necessary to understand the impact of change in land use and economic growth on the nutrient and groundwater-surface water interactions. The Indian Nitrogen Assessment has reported Agra, Auraiya, Etawah, Mathura, Hamirpur and Allahabad districts in Uttar Pradesh as having high concentration of nitrates in groundwater. As far as surface water is concerned, nitrate levels in river Yamuna have been reported to range from 1.38 to 2.9 mg/L in summer and from 1.51 to 3.1 mg/L in winter season (Rao *et al.*, 2017).

Although phosphorus is said to occur naturally due to rock weathering, humans have been responsible for releasing 75% more phosphorus in soil than that would have existed naturally. The nutrients from soil are further washed off during monsoon and enter the rivers. Even minute changes in nutrient loading have the potential to aggravate potential algal blooms in surface water bodies. The study conducted by Kaur and Singh(2012) has reported nutrient concentrations in monsoon to be higher than winter and summer, mainly due to runoff received from agricultural areas in catchment of river. Phosphorus has been found to be the primary limiting nutrient in freshwater bodies as a strong correlation between algal biomass in lakes and total phosphorus has been reported by global researchers (Kaur and Singh, 2012).

Sharma *et al.*(2017)have analysed samples of 10 locations from Wazirabad to Okhla barrage in Delhi during June 2015 to December 2015. A comparison of dissolved nutrients observed in Delhi with the concentrations of those in an unpolluted river was a clear indication of changing nutrient chemistry of river due to human influence. The final representation of this

analysis has been represented in the form of a water quality index on a GIS map. The changes in land use pattern from agricultural to urban has been reported to be the factor influencing increasing nitrogen and phosphorus loads in the river. Yamuna in Delhi has been reported to be eutrophic based on the BOD range from 12-39 mg/L, high nitrate concentrations and reduced DO levels. These conditions have led to anoxic conditions leading to death of various aquatic organisms.

Sharma *et al.* (2017) have evaluated the indicator of coastal eutrophication potential (ICEP) and from the positive value of ICEP for nitrogen and phosphates, they have concluded that this excess nutrient load of nitrogen and phosphorus in Yamuna has the potential to ultimately cause eutrophication problems in river Ganga. The ammonia values have been reported to be in the range of 0 to 44 mg/L in the entire Yamuna stretch from 1999 to 2005 (Misra, 2010).

3.2.5. Heavy Metals

No significant concentrations of toxic chemical pollutants have been detected at any point in the river during 1977-78(CBPC, 1978). The maximum concentration of heavy metals such as chromium and zinc has been observed to be 7.91 and 1.37 mg/L at Agra and Delhi respectively (Misra, 2010).

The concentration of heavy metals in the shale is taken to be the worldwide standard and is thus the reference concentration for a natural uncontaminated state. Heavy metals have the tendency of depositing in fine grained sediments due to higher ratio of surface area to grain size. Analysis of fine grain sediments was done by Singh(2001) and the results have been reported in the form of ratio of heavy metal concentration in sample sediments to the concentration in average shale. This study has reported values greater than one for all heavy metals except manganese and iron. For cadmium, chromium, nickel, copper, zinc and lead, the ratios were high. Values greater than one indicate anthropogenic impact.

pH and temperature have been found to be the factors influencing the seasonal variation of heavy metals. The concentration values have been found to be maximum in pre-monsoon and minimum in post monsoon. A significant difference between seasonal values for the heavy metals was observed in these two seasons. The variation was significant between the season pairs namely post monsoon and pre-monsoon and pre monsoon - monsoon whereas monsoon-post monsoon pair has showed almost similar average concentrations. Based on the results of Pearson correlation and principal component analysis, Bhardwaj *et al.* (2017) have concluded that there are 2 groups having same sources, namely Ni, Zn, Cd, Fe, Cd and Cu, Cr.

3.3. Research Gaps

CBPC, (1978) initiated the program of water quality monitoring for 2 years from 1977-1979 for the entire stretch of Yamuna. The monitoring was carried out once during winter, spring and summer. Lack of availability of flow data corresponding to the water quality samples has been stated to be an important limitation of this study, due to which assessment of pollution loads has not been possible. The data has covered the sampling locations on mainstream Yamuna but no water quality data corresponding to significant tributaries like Chambal and Betwa has been monitored.

Almost all of the studies carried out have been clustered in the national capital region of Delhi as it constitutes the most polluted stretch of Yamuna. Very few studies have been carried out whose spatial stretch varies across the entire Yamuna river. Even if such studies are found, they have been carried out for a short time span of 1-2 years. Due to the short analysis period, no study has been found that has conducted statistical temporal trend tests on water quality parameters. Even if seasonal variation is found to be studied, it is done on the basis of simply one sample per season per year. So the standard deviation of variations is not observed in analysis.

3.4. Objectives of Study

While the CPCB data is available online and has been thoroughly analysed, the water quality monitored by the second agency, CWC has not been analysed. An attempt has been made to fill in this gap in water quality studies conducted on river Yamuna. Along with water quality measurements, flow values have also been considered in analysis. A graphical as well as statistical analysis of temporal and spatial trends has been done for all mainstream stations of Yamuna. Long term trends in various water quality parameters have helped in understanding how the flow and quality parameters have been affected over the entire timeline of 38 years from 1978 to 2015. For the biological parameters and factors indicating organic pollution, along with CWC, data reported by CPCB has also been analysed with an objective of checking whether similar trends have been observed from the measurements done by two different organisations. Anthropogenic activities have been significantly affecting the river water quality especially in the middle Yamuna stretch around Delhi. The human influence on this important river has also been looked at.

With this background, the primary objective of this study is stated as:

- Analysis of the temporal and spatial trends in flow and water quality parameters of river Yamuna.
- Analysing the effect of anthropogenic activities and human intervention on river Yamuna.

4. Methodology

4.1. Data Availability

The CWC data was obtained by IIT Kanpur from Central Water Commission under the project for preparation of Ganga River Basin Management Plan (GRBMP) supported by National Mission for Clean Ganga (NMCG), Ministry of Water Resources, River Development & Ganga Rejuvenation, India.

CWC monitors flow data on a daily basis. But for analysis purpose, average of the daily discharge values of a month was considered as the monthly flow. The actual flow values were normalized and the normalized flow values have been presented and used for the analysis.

The data for this long timeline was obtained in various excel files containing multiple sheets. The raw water quality data is mainly available depending on the station type whether it is trend, flux or base station. Mainly the data is available in monthly format.

4.2. Data Processing

The very first step of analysing the data was to convert this raw data from multiple files into a uniform time series format. The time series conversion of 44 parameters (including physical, chemical, biological, chemical indices and heavy metals) was done for all stations individually. For the stations Delhi, Agra and Mathura, the data was partly available as monthly and in thrice daily format for recent years. The data for Kalanaur and Mawi was partly available for alternate months. The month in which sampling was not done was taken to be blank. The data for certain time period for Kalanaur was recorded as a single value for four months namely March to June; July to October and November to February. For this span, the same value was considered for all four months as the value was given to be the representative of these four months.

4.2.1. Removal of Outliers

After the data conversion for all stations, the time series of all quality parameters were observed for analysing the outliers. Three methods were thought of to remove the outliers from time series:

- i. Average + 2*standard deviation
- ii. Box plots with a coefficient of 1.5
- iii. Box plots with a coefficient of 3

After calculating the limits for outlier consideration by the three methods, it was observed that for some parameters, the limit for considering a value as an outlier was quite nearby the median data. The stretch of middle Yamuna being the recipient of domestic sewage and industrial wastewaters from various industry clusters is expected to have significantly high values of some of the water quality parameters. Omitting such data would have resulted in a loss of actual data. Hence manual observation of outliers was resorted to. Only those values which were seen to be lying significantly above the entire time series were deleted. Figure 4.1 presents a sample time series data.

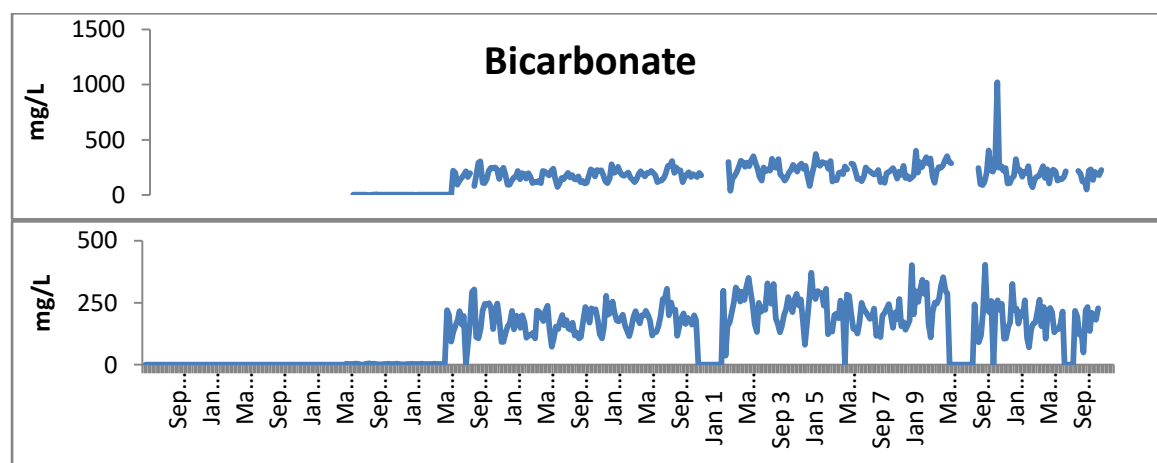


Figure 4.1: Time Series Plots before and after Removal of Outliers (Auraiya)

4.3. Consideration of Seasons

After removing the outliers the dataset was finalized for further analysis. For studying the seasonal variation of water quality parameters, 5 seasons namely monsoon, post monsoon, winter, post winter and pre monsoon were considered. For flow analysis, only 2 seasons were considered namely monsoon and non-monsoon. The considerations of seasons depended on the objective of a study.

4.3.1. Five Season Analysis

Table 4.1: Choice of Seasons for Five Season Analysis

S	Season	Duration
1	Monsoon	July and August
2	Post monsoon	October and November
3	Winter	December and January
4	Post winter	February and March
5	Pre monsoon	April and May

Monsoon – Post monsoon:

The main difference in these 2 seasons is the frequency of rain showers observed during the months. In monsoon, high discharge values are observed almost on a daily basis whereas in post monsoon season, there are occasional peaks occurring due to rainfall. The monsoon season observes vast amounts of organic matter, agricultural wastes, leaves and topsoil being carried in the surface waters from the nearby catchment area.

Post monsoon – Winter:

The low flow conditions commence with the onset of winter. This results in high concentration of some of the water quality parameters. It is the surface runoff from catchment areas contributing to the post monsoon river flow whereas it is the subsurface groundwater flows contributing to the winter flows.

Winter – Post winter:

Winter and post winter seasons mainly vary from the aspect of temperature. After the chilled temperatures during winter, post winter comes with a slight rise in temperature with the onset of spring season. But the flow values remain almost constant during this period.

Post winter – Pre monsoon:

This pair essentially represents the difference between post winter and pre- monsoon (summer) seasons.

Pre monsoon – monsoon:

This pair represents the most significant difference between the summer and the rainy season. The pre monsoon is a critical season for most of the water quality parameters as seasonal rivers get dried up due to significant abstraction of surface water for carrying out day to day activities throughout the year. For rivers in mountainous areas, glacier meltdown in pre monsoon contributes to surface water. Some of the parameters are found in high concentrations which get diluted on the onset of monsoon.

4.3.2. Two Season Analysis

For flow analysis, there is a broad distinction between discharge during monsoon and the flows during the lean period. The monthly flow variation graphs were plotted to observe the months with heavy rainfall. Accordingly classification is done as presented in Table 4.2:

Table 4.2: Choice of Seasons for Two Season Analysis

Sr	Season	Duration
1	Monsoon	July to September
2	Non-monsoon	November to June

4.4. Methodology Adopted for Analysis

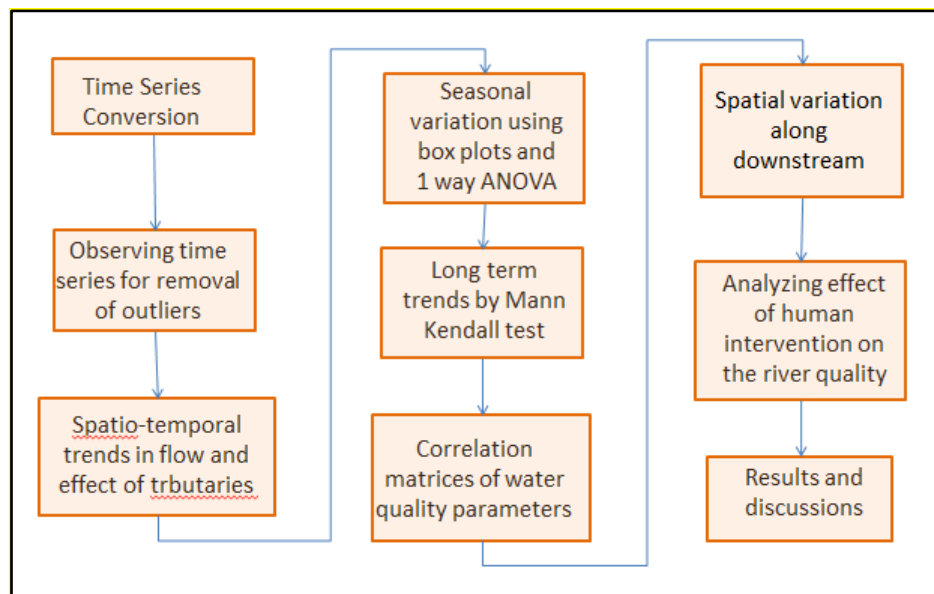


Figure 4.2: Block Diagram Illustrating Methodology adopted for Analysis of Data

The monthly minimum, maximum and average flow values were calculated from the daily flow data. Trend in extreme flow values over the years was also observed along with trend in average flows. The flow analysis has been targeted to understand the interactions taking place between the groundwater and surface water.

The temporal variation of different parameters for all stations was studied by analysing the time series plots. One way ANOVA was used to statistically determine whether significant variation was observed in the mean of seasonal values of water quality parameters and if yes, in which season pair was the actual change observed. Visualisation by box plots has facilitated better understanding of the effect of seasons on water quality parameters. It has aided in concluding whether natural climatic conditions have been responsible for the changing pollution levels. The spatial variation plots have helped in identifying the polluted stretches in the river. Typical seasonal variation plots are presented in Figure 4.3.

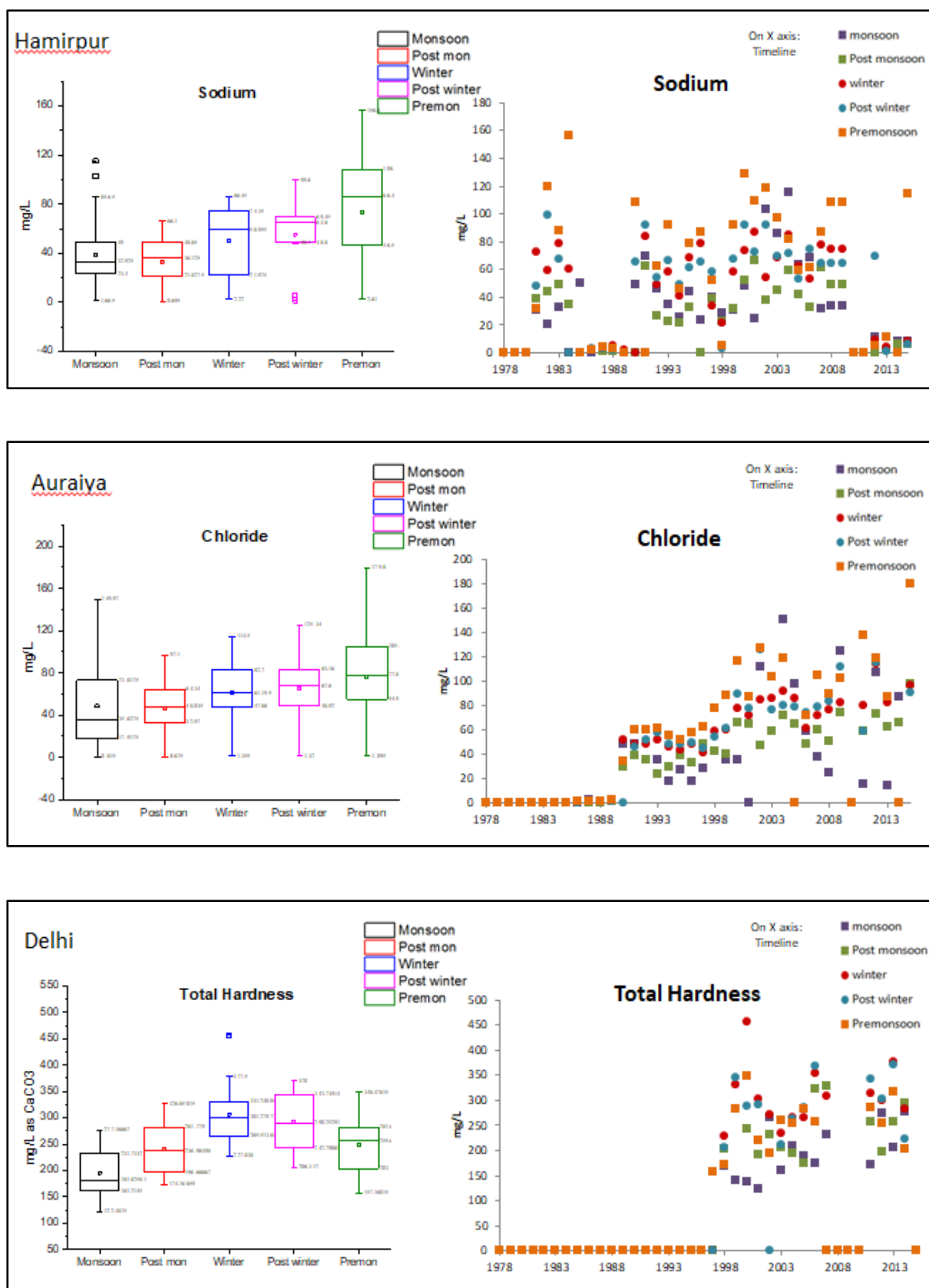


Figure 4.3: Typical Seasonal Variation plots

Seasonal trend analysis was done to understand the overall water quality status over the years. Although the results have been reported as trends during monsoon and non-monsoon, the actual analysis has been performed on 5 seasons, so it is possible to trace back whether the increasing or decreasing trends in non-monsoon seasons are associated to winter, post winter or pre-monsoon months. A comparative 2 season trend analysis was also done for flow, concentration of chemical parameters in mg/L and pollution load due to it in kg/day. This has aided in understanding whether the real cause in river water quality trends could be attributed to natural flow variation or anthropogenic activities.

The correlation between various water quality parameters was looked at for all stations individually with the aim of checking the consistency of data as well as to report any unexpected significant correlation between two parameters.

4.5. Tools used for Analysis

4.5.1. One Way ANOVA

ANOVA basically means analysis of variance. One way ANOVA is a statistical tool to conclude whether the two means of a particular dataset are significantly different from each other or not. It gives a statistical base to conclude about the change as against mere visual representation. The null hypothesis indicates significant variation between the mean values whereas the alternate hypothesis indicates nearly similar mean values of two data sets under consideration. The analysis being carried out for 95% confidence interval, a significance value of 0.05 was considered.

4.5.2. Mann Kendall Trend Test and Theil-Sen Slope Estimator

In general, water quality data is not normalized. The dataset had missing values for certain years. Hence the non-parametric Mann Kendall trend test was used which accounts for missing values. The univariate test was done, where the null hypothesis indicated a monotonic trend in the variables over the time and the alternate hypothesis indicated randomly ordered observations. A significance value of 0.05 was considered. The MK statistic is defined as:

$$S = (\text{for } i < j) \sum \text{sgn}(X_j - X_i) \quad (1)$$

Table 4.3: Definition of Signum Function

Value of x	$x > 0$	$x = 0$	$x < 0$
Sgn (x)	(+) 1	0	(-) 1

negative correlation means increase in one parameter causes decrease in the other. Greater value of correlation coefficient indicates stronger correlation between the two variables.

Correlation analysis for every parameter was done against every other parameter in the cluster. For better visual interpretation, the correlation plots were also plotted in R. Typical results are presented in Figure 4.5.

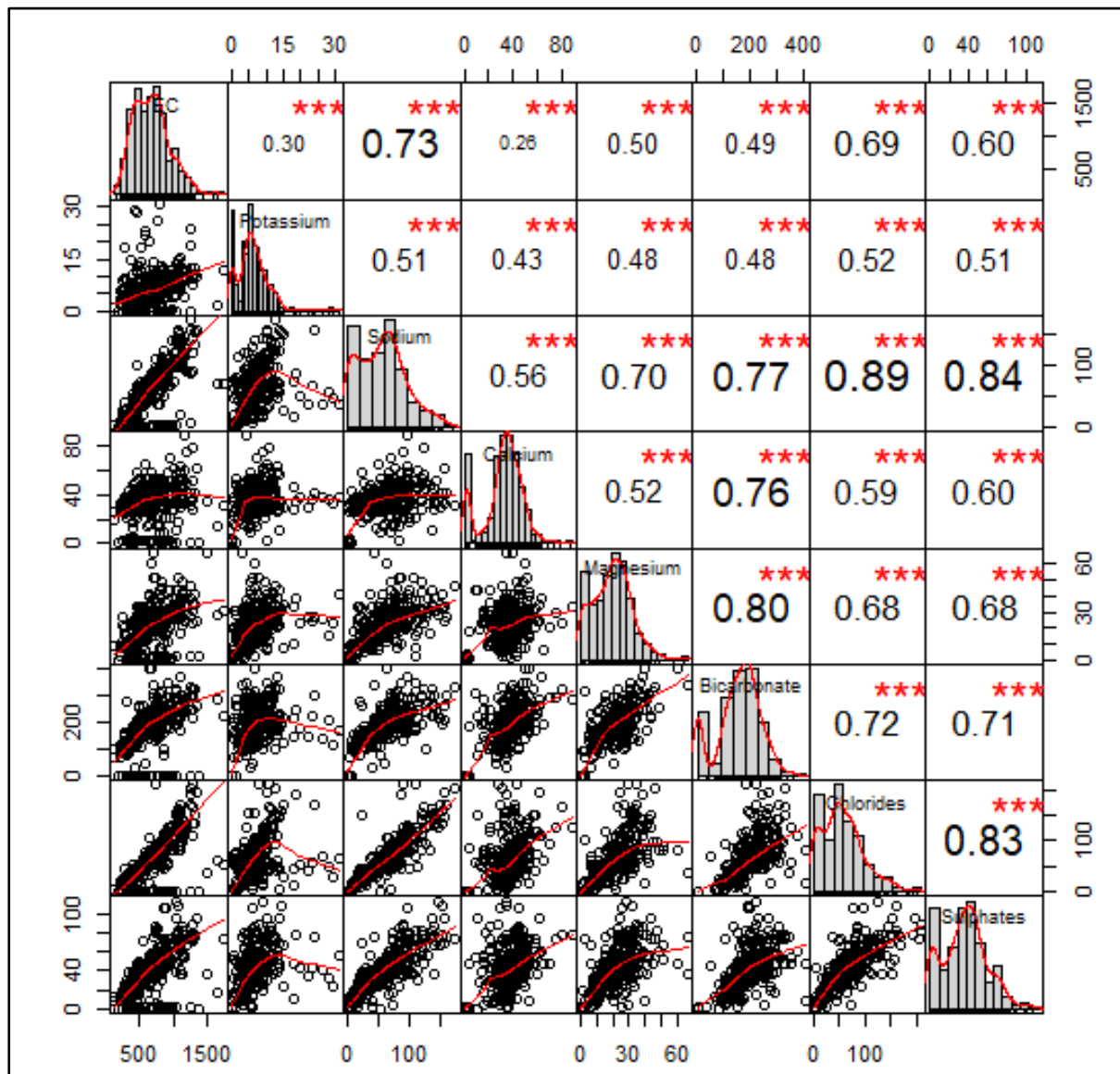


Figure 4.5: Sample Output from R (Correlation results for Auraiya Cluster 4)

5. Results and Discussion

5.1. Analysis of Flow Variation

5.1.1. Effect of Structural Intervention on Guage of River

Figure 5.1 shows the temporal variation of minimum, maximum and average guage at a particular station during a particular season.

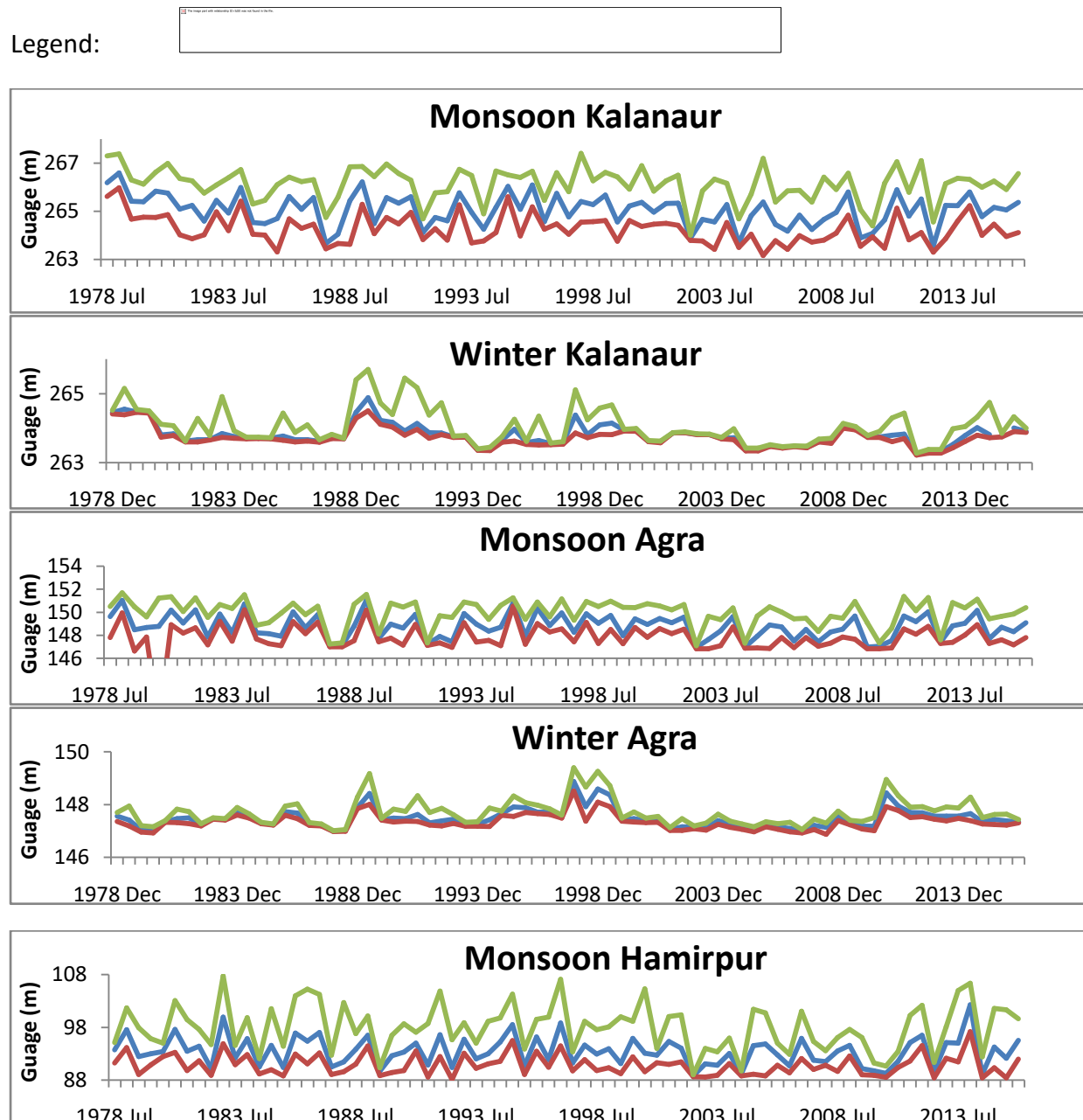


Figure 5.1: Guage Variation at Places of Structural Intervention

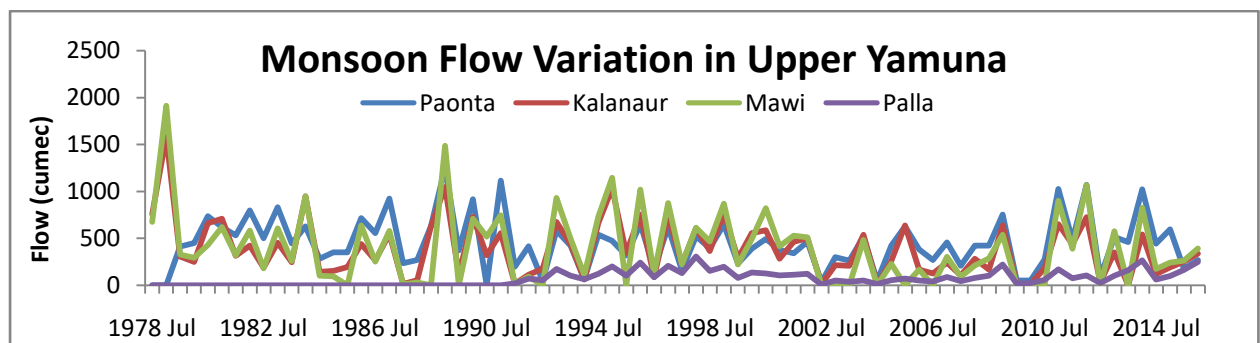
Significant variation between minimum, maximum and average guage is observed only during monsoon period and at those times during lean flow period when monsoon showers have been observed. The range of guage is around 5 m for upper and middle Yamuna stretches but after Chambal joins this range varies up to 20 m. This indicates that the range of flow is immensely affected by joining of Chambal river.

Significant structural changes have been taking place on the river whose effects can be observed on the guage after the period of completion of that particular river training work. The rapidity at which the natural flow of river is being stopped, diverted and altered has a severe impact on the ecology and biodiversity of the downstream river as well as the riparian corridor. Hathnikund barrage was constructed on Yamuna river between 1996 to 1999 for meeting the irrigation demand. This barrage, which lies on the border of Haryana and Himachal Pradesh has been the origin of water disputes between the states. This barrage is located between the CWC stations Paonata and Kalanaur. Hence the effect of flow obstruction at Hathnikund is visible at the downstream station Kalanaur. As observed from the above figure, winter and pre-monsoon guage values at Kalanaur have been observed to reduce from 1999.

During the timeline of the study, flood warning years in Yamuna have been reported as 1978, 1998 and 2010. This is depicted in the monsoon guage levels of stations under consideration.

5.1.2. Temporal and Seasonal Variation of Flow

Flow variation has been studied for a period of 38 years from 1978 to 2015. In the temporal variation plots for flow, the x-axis shows the timeline and the y-axis represents the flow in m^3/sec . Average monthly flows have been analysed stretch wise at four stations in each season, which are presented in Figure 5.2 to 5.5.



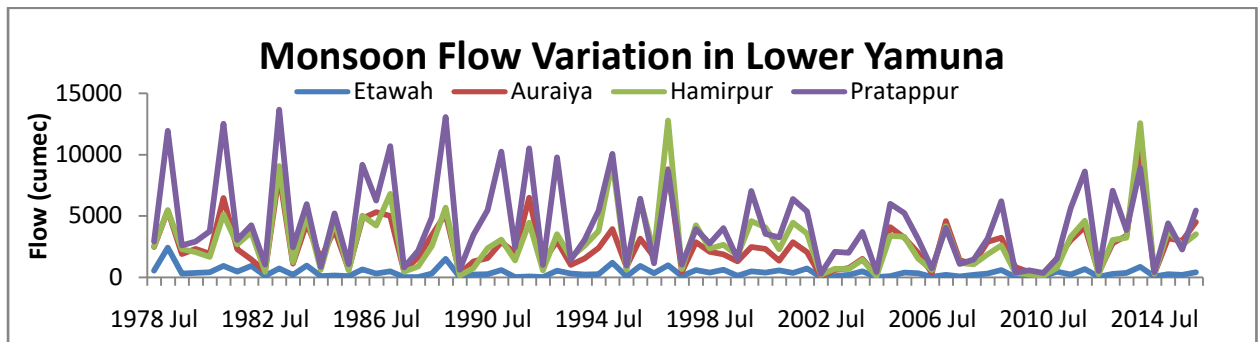
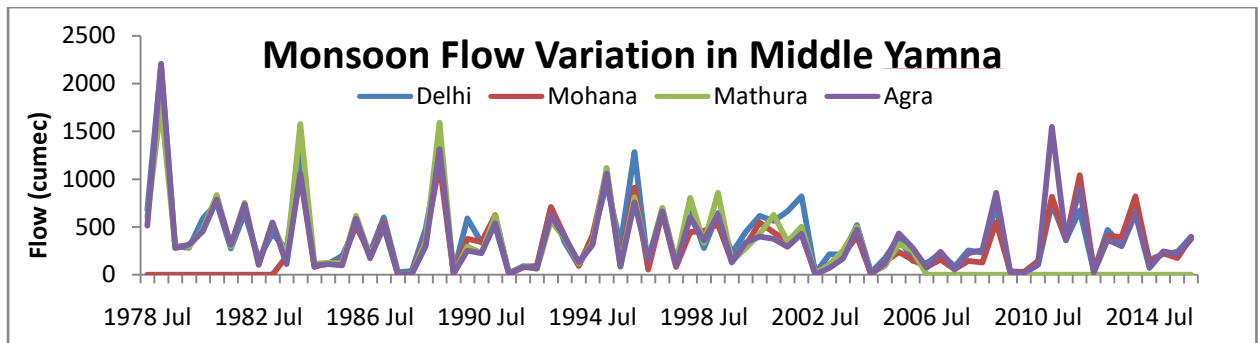
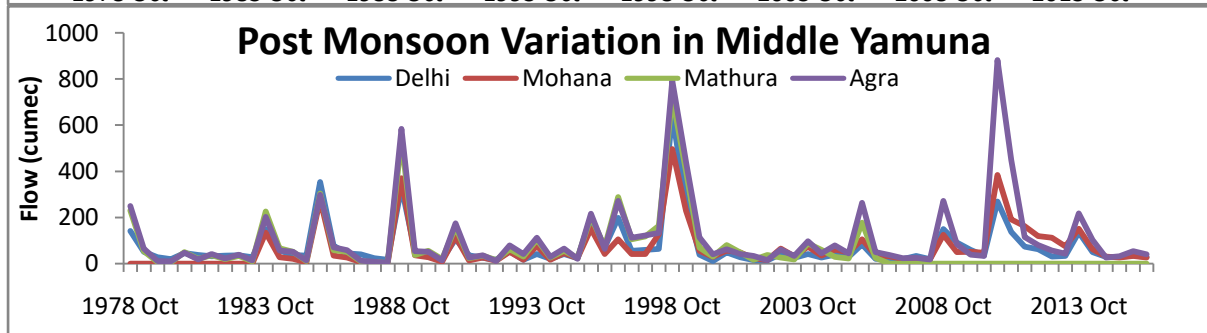
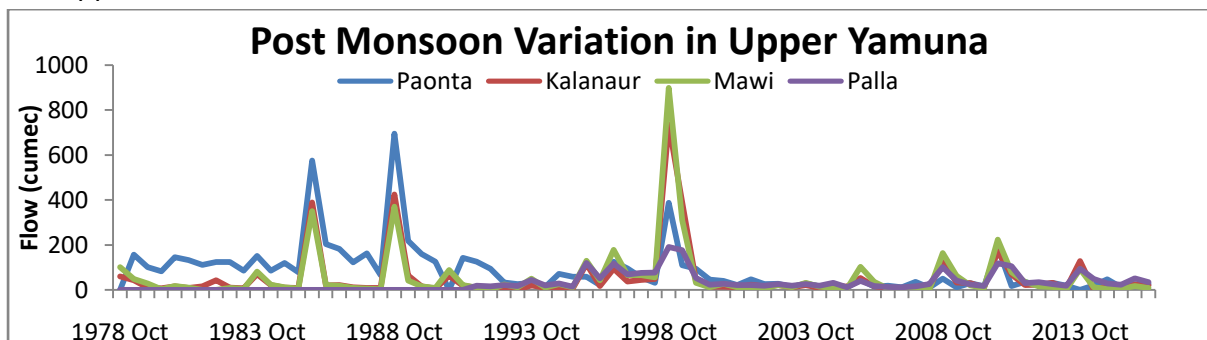


Figure 5.2: Temporal Variation of Flow in Monsoon

Stretch wise flow variation during monsoon follows a particular trend, as seen in Figure 5.2. In upper Yamuna stretch, the flow reduces from Paonta to Palla as no significant tributary joins Yamuna in between. It is only abstraction of water that is taking place in the form of barrages and canals. Almost constant flow is observed in middle Yamuna in monsoon indicating that abstraction of freshwater is comparable to disposal of wastewater. In lower Yamuna, Etawah has the lowest flow and subsequent tributaries add to the flow till Pratappur.



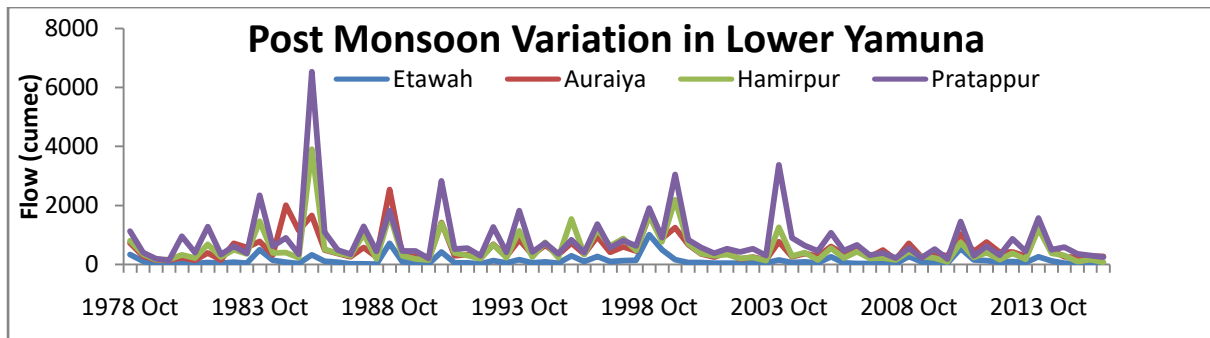


Figure 5.3: Temporal Variation of Flow in Post-Monsoon

During post monsoon, as observed in Figure 5.3, significant peaks are observed in 1985, 1988 and 1998 but no significant peaks are observed after 2000 indicating narrowing of monsoon showers in recent years to just two months namely July and August. Post monsoon peaks in upper and middle Yamuna are observed to be consistent except for the sudden increase in middle Yamuna during 2009-11. This can possibly be due to localised agricultural runoff flow from the surrounding catchment area.

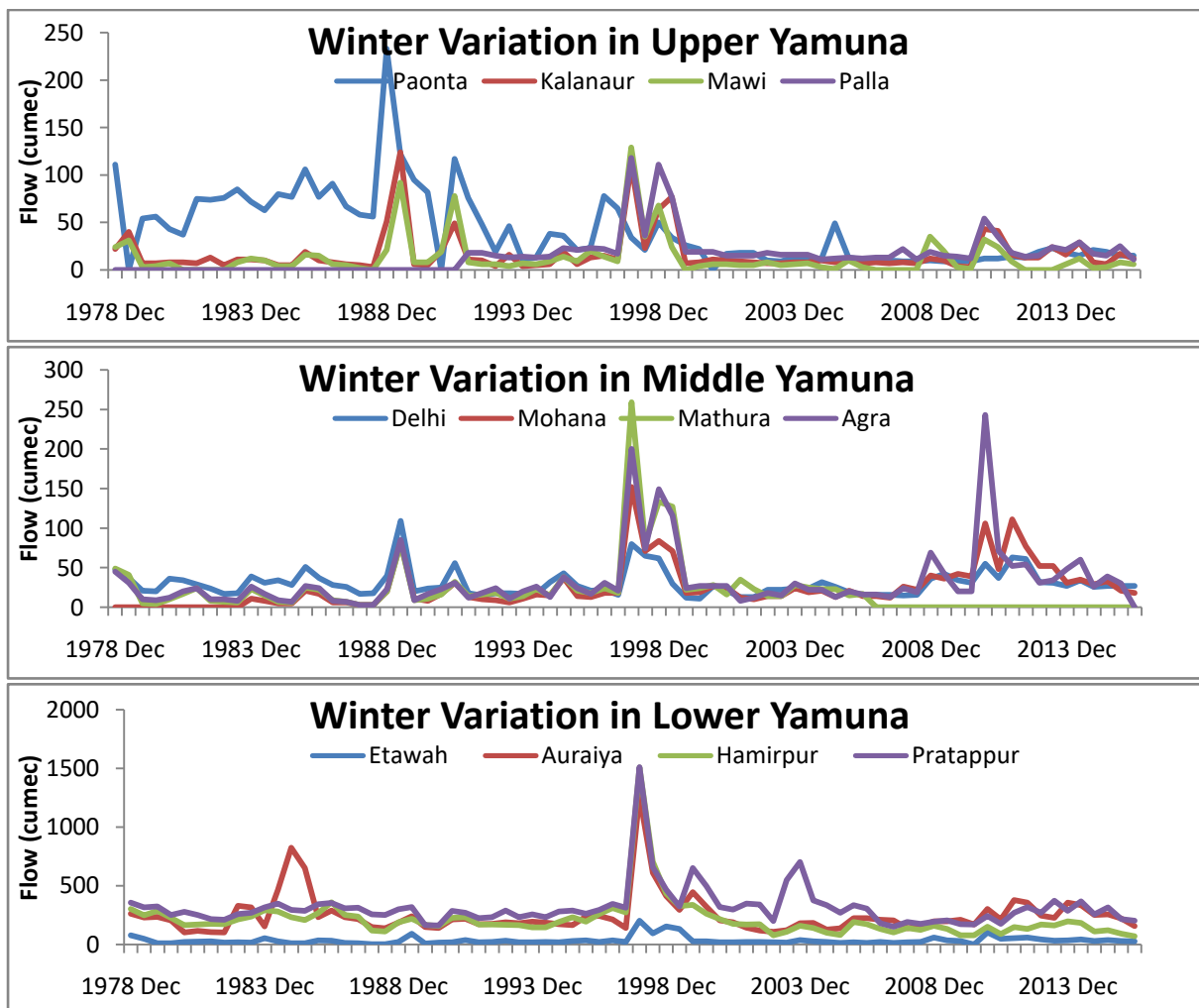


Figure 5.4: Temporal Variation of Flow in Winter

As observed in Figure 5.4, winter flows in Paonata are higher in 1978-88 but rest stations have lower flows, possibly due to obstruction of flow at Hathnikund barrage. From 2000 onwards, all four stations of upper Yamuna stretch are observed to have comparable flows. Winter peak is observed only at Auraiya during 1983-84 while rest three stations show similar trend. This might be due to some anthropogenic activity like wastewater dumping localized to this area during that time. In post winter as well, Paonata shows higher values than the rest of the three stations, indicating continuous abstraction of water.

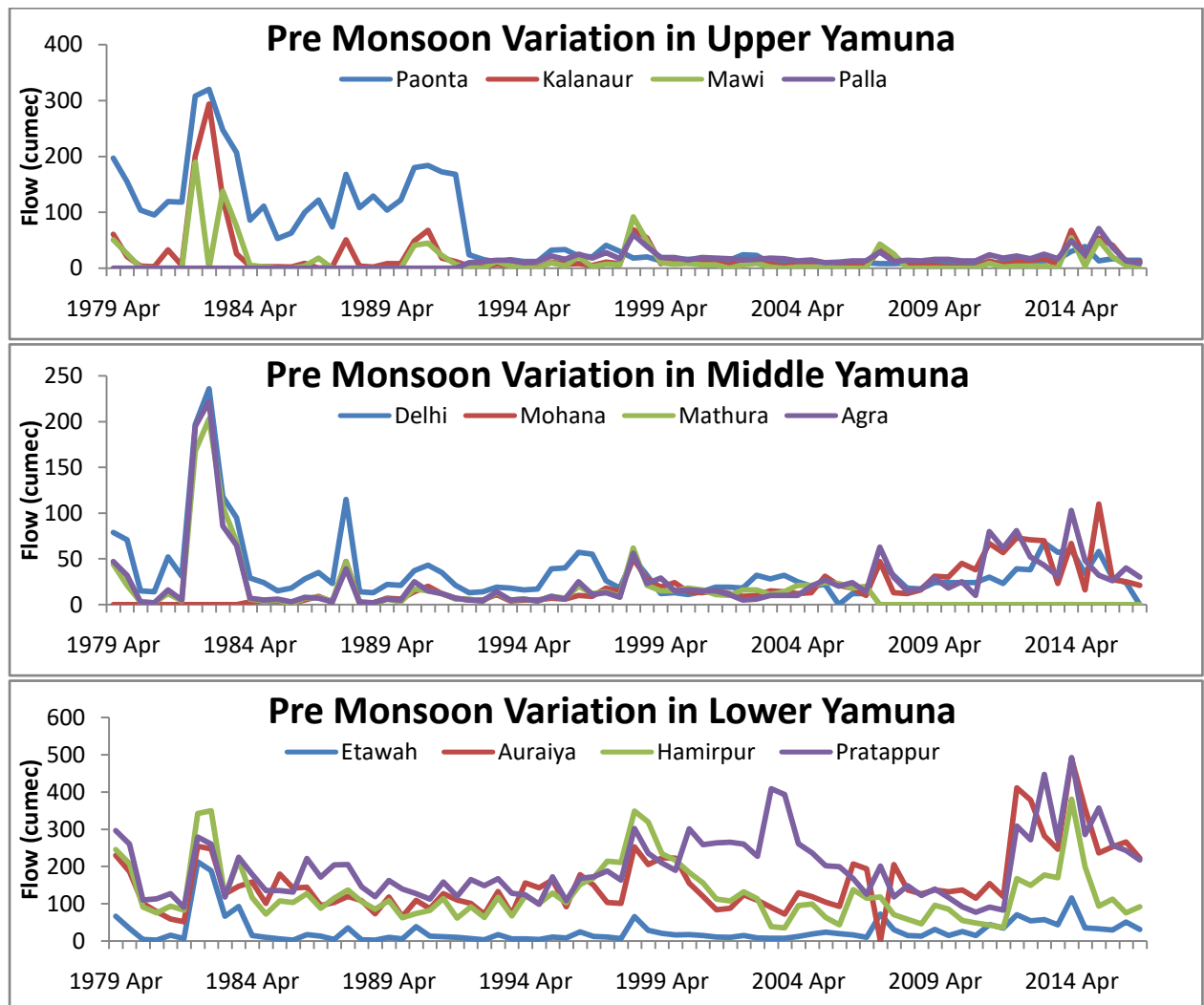


Figure 5.5: Temporal Variation of Flow in Pre-Monsoon

As observed in Figure 5.5, drastic reduction in peaks from 1990 is observed in pre-monsoon. Till 1990's, early showers have been observed frequently in May and June. This indicates delayed arrival of monsoons lately. In lower Yamuna, increased flow observed from 1998 to 2004 and from 2010 to 2014 might be possibly due to severe wastewater dumping in the periods of low flow conditions.

5.1.3. Confluence of Tributaries Chambal and Betwa

The flow in any river is significantly affected by the tributaries joining the river. In the lower Yamuna stretch, four important tributaries join the river, which are schematically represented in the block diagram below. Figure 5.6 also shows the confluence of tributaries Chambal and Betwa, along with their corresponding upstream and downstream stations.



Figure 5.6: Block Diagram of Tributaries in Lower Yamuna Stretch

Table 5.1: Effect of Contribution of Chambal to Yamuna during Various Seasons

Season	Monsoon	Post monsoon	Winter	Post winter	Pre monsoon
Factor	6.5	7	6.5	4	1.7

The factor by which flow in Yamuna is observed to increase after the confluence of Chambal is listed in Table 5.1. This is observed from the relative magnitude of flows at Auraiya and Etawah between which the major tributary Chambal joins. The increase in factor from 6.5 in monsoon to a maximum of 7 in post monsoon can be attributed to the runoff from catchment area which is contributing to river flow. The drastic reduction in this factor to 1.7 in pre monsoon indicates the negligible contribution of Chambal flow to the Yamuna.

Table 5.2: Season Wise Contribution of Tributary to River Flow

Season	% Flow of Chambal to Confluence	Ratio of Chambal to Upstream	% Flow of Betwa to Confluence	Ratio of Betwa to Upstream
Monsoon	81.4	4.4	30.5	0.4
Post monsoon	61.2	1.6	22.3	0.3
Winter	73.4	2.9	21.5	0.3
Post winter	84.1	5.2	23	0.3
Pre monsoon	71.8	2.5	23.3	0.3

From the table it is observed that Chambal tributary constitutes almost upto 70-80% whereas Betwa constitutes upto 20-30% of the flow at the confluence. The Chambal flow is almost 4.4 times whereas Betwa flow is 0.4 times the monsoon flow in mainstream Yamuna. In spite of Chambal being a tributary, at its confluence, it is the tributary which contributes to majority of the mainstream flow. The figures clearly indicate that Chambal is mainly responsible for rejuvenating the dead stretch of middle Yamuna. Knowing the flow

values at corresponding stations on the tributaries, a water balance of tributary and upstream flow was done to find out the flow at the point of confluence. This variation was studied for five seasons, out of which typical plot for Pre-Monsoon is presented in Figure 5.7 below.

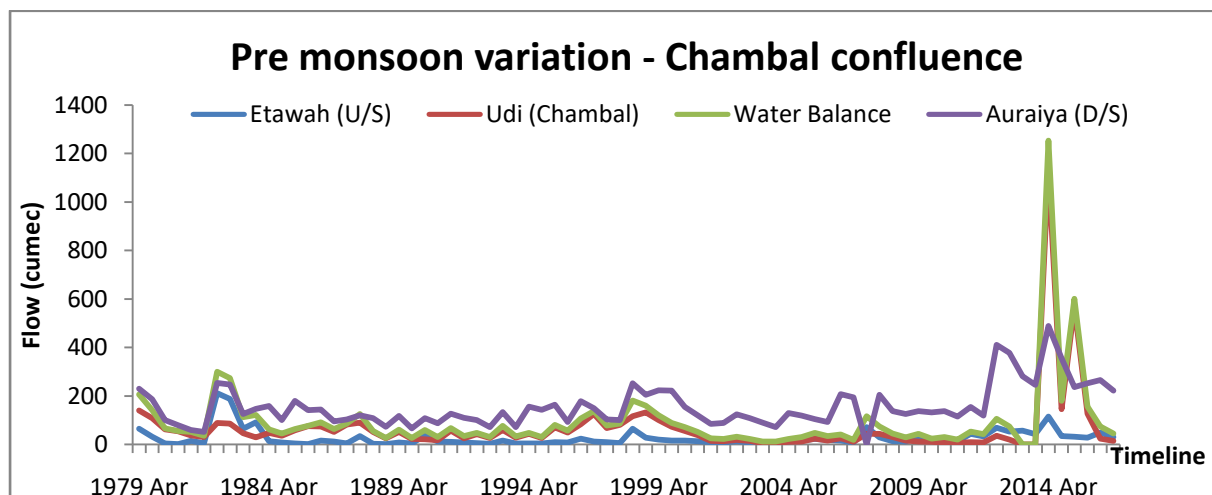
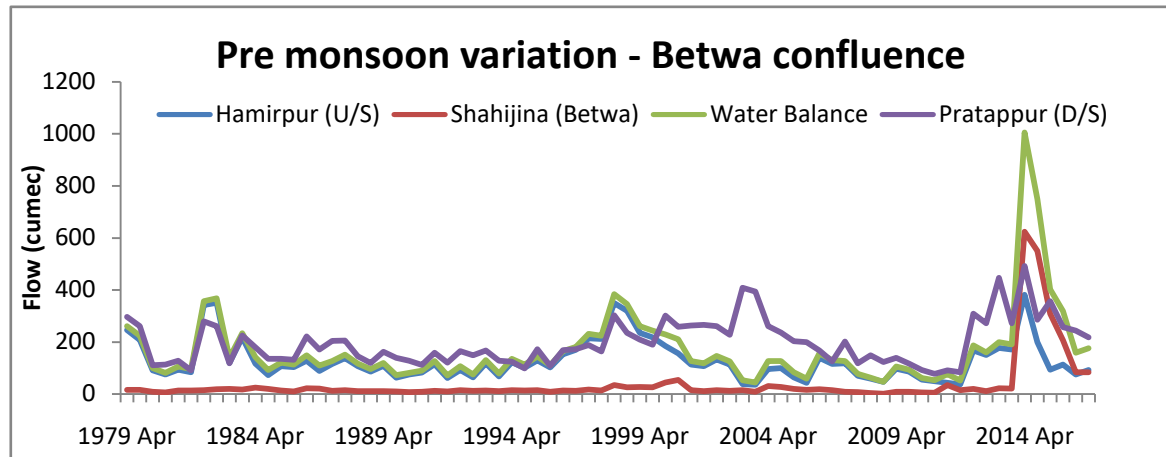


Figure 5.7: Effect of Confluence of Chambal and Betwa Tributaries

2013 onwards, serious abstraction of flow is observed during winter. Actual water balance values are greater than those plotted because the relatively insignificant tributaries namely Sind (before Auraiya) and Ken (before Pratappur) have not been included. In spite of this, observed flow values from 2012 onwards during lean season (post winter – pre monsoon) in downstream stations is much less than those showed by water balance, indicating unchecked water abstraction for anthropogenic activities.

5.1.4. Trend Analysis of Flow

The results of M.K. trend tests for flow have been summarized in Figure 5.8.

Increasing Trend			No Trend	Decreasing Trend		
0<p<0.001	0.001<p<0.01	0.01<p<0.05	p>0.05	0.01<p<0.05	0.001<p<0.01	0<p<0.001

Legend:

FLOW	Station	Paonta	Kalanaur	Mawi	Palla	Delhi	Mohana	Mathura	Agra	Etawah	Auraiya	Hamirpur	Pratappur
Season	Value	1	2	3	4	5	6	7	8	9	10	11	12
	Min												
Monsoon	Max												
	Avg												
Non	Min												
Monsoon	Max												
	Avg												

Figure 5.8: Trend Analysis of Flow

Overall trend in minimum, maximum and average flow is observed to be the same. Wherever trend is observed for monsoon flows, it is decreasing. Minimum as well as maximum flow is seen to be reducing over the years at Paonata. This might be attributed to overall reduction in precipitation over the years. Reducing average flow is observed at the first station Paonata and the stations after the confluence with Chambal. These stations are the ones which are relatively free from anthropogenic activities in comparison to the middle stretch stations. From Kalanaur to Delhi, no trend is observed, indicating that the flow has remained constant over the years. This might be due to the human intervention through river training works which has led to a controlled flow throughout the years. Increasing non-monsoon flows from Mohana to Auraiya are indicative of wastewater additions during the lean flow period. Reducing non-monsoon flow is observed at Hamirpur. Among upper Yamuna stations, Kalanaur is the only station where maximum flow during non-monsoon is observed to increase. This might be due to the growing industrial belt near the station.

Milleret *al.* (2012) report glaciers to be one of the prime sources of freshwater in streams and rivers in Yamuna basin. But global warming has led to increased temperatures, which being the parameter to which glaciers are most sensitive to, has led to continuous melting of glaciers. Though this meltdown means initial increase in meltwater contributing to increased flow, this effect is temporary as it is followed by subsequent decline in the flows due to reduced glacier mass. (Milleret *al.*, 2012) This is probably the reason associated with reducing monsoon maximum flow levels in the basin.

5.1.5. Spatial Variation of Flow during Monsoon and Non-Monsoon

The variation of flow in monsoon and non-monsoon has been presented as a function of space in Figures 5.9 and 5.10 below. The x-axis corresponds to the distance of station from the source of Yamuna whereas the y-axis represents the flow in cumec.

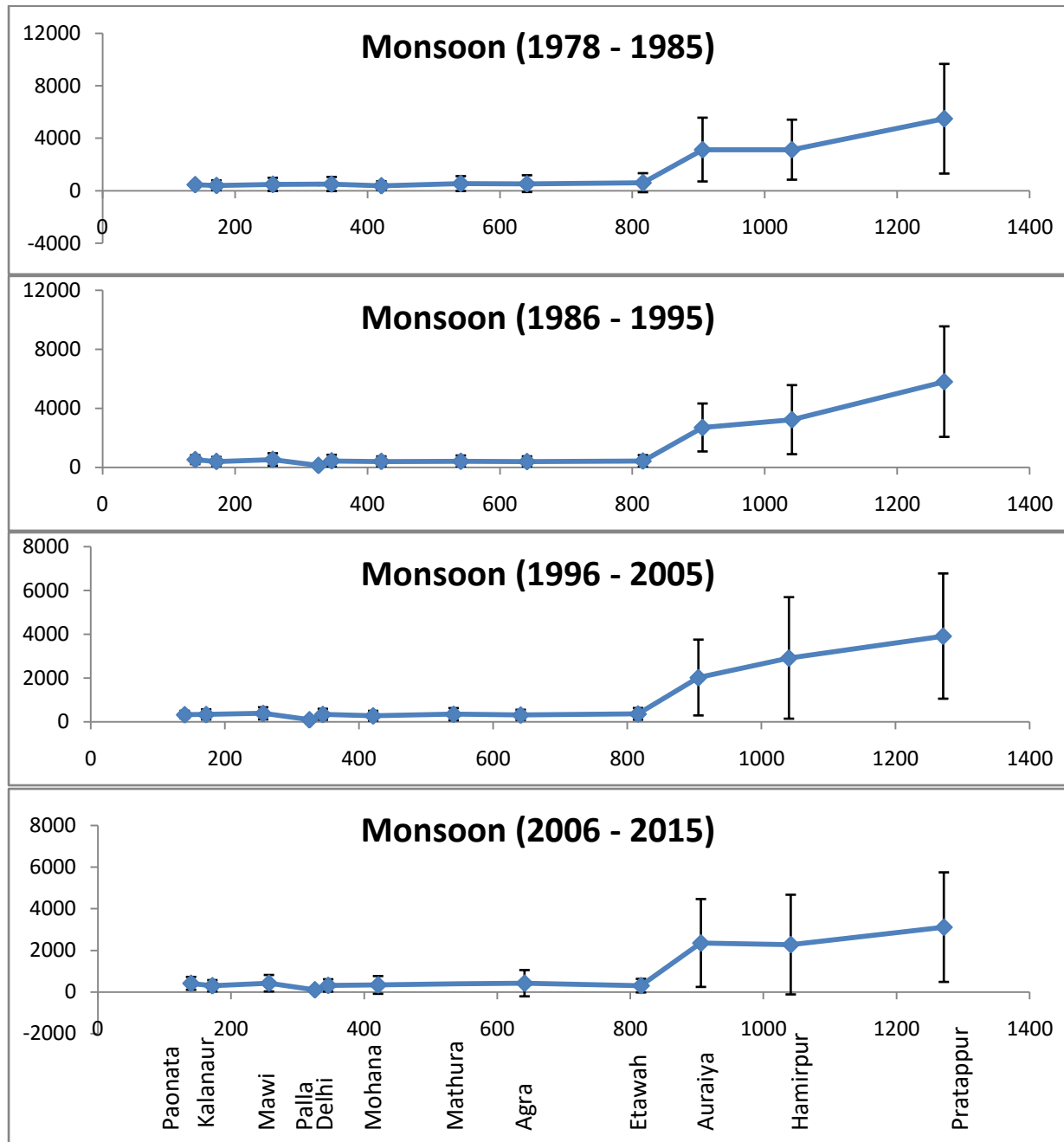


Figure 5.9: Spatial Variation of Monsoon Flow

The sudden increase in flow at Auraiya during monsoon is attributed to Chambal. The magnitude of flow from Auraiya to Hamirpur is observed to be almost constant. It further increases from Hamirpur to Pratappur due to addition of Betwa and Ken tributaries. As

observed from the graphs, the flow rise from Hamirpur to Pratappur during monsoon is decreasing over the years as indicated by the reduction in slope with every time zone.

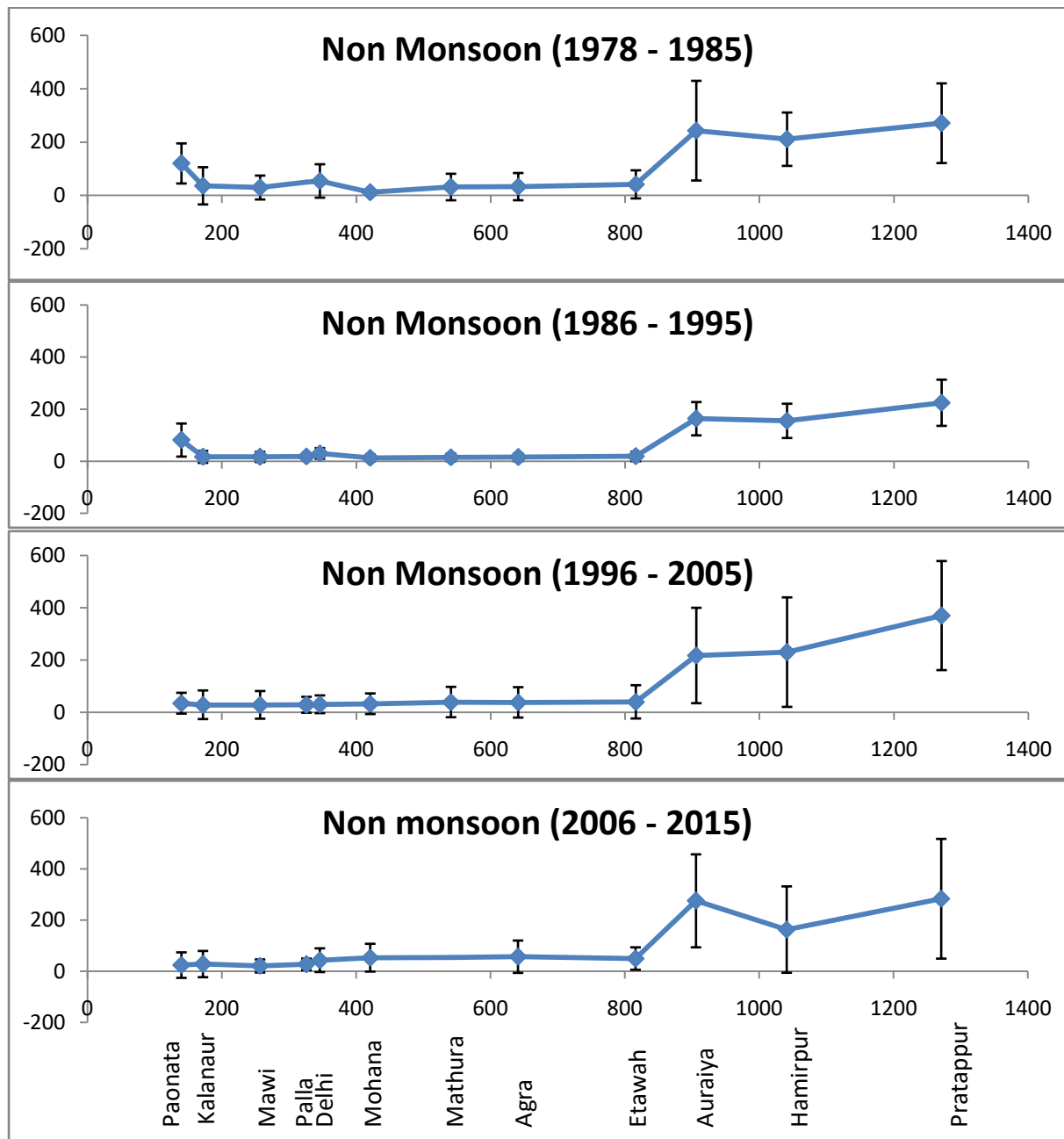


Figure 5.10: Spatial Variation of Non-Monsoon Flow

Trends of monsoon and non-monsoon flows are not similar in lower Yamuna stretch. Flow between Auraiya and Hamirpur is observed to be nearly constant except in recent years where non-monsoon flow at Hamirpur has reduced. Between Hamirpur and Pratappur, slope of non-monsoon flows is slightly increasing over the years.

5.2. Seasonal Variation of Water Quality Parameters

Out of all water quality parameters, some showed significant seasonal variation whereas some are unaffected by seasonal variation. These have been listed in Table 5.3.

Table 5.3: Seasonal Variation based on One Way ANOVA

Change	Parameters
Yes	Q, Temp, EC
No	Iron, nitrate, nitrite, Boron, DO, COD, Coliform

5.2.1. Seasonal Variation based on One Way ANOVA

Discharge, temperature and electrical conductivity are parameters showing significant seasonal variation for all stations. It is obvious for discharge and temperature to show variation as the seasons have been fixed on the basis of flow and temperature itself. Apart from that, EC is the major parameter showing seasonal variation throughout the year.

Iron is mainly derived from the soil in the catchment areas and the corresponding bedrock. During monsoon, the materials from the catchment areas are wiped away by the water and enter the rivers so ideally higher iron concentration would have been expected during monsoon. But these high concentrations come with high flows as well hence result in overall dilution. Moreover the range of iron as detected in rivers is not much to show significant variations in seasonal averages. Nitrate, nitrite, DO, COD and even coliform are indicators of organic pollution which are not seen to vary significantly with seasons. This can be due to the fact that domestic wastes are being discharged in the rivers on a regular basis.

The results for other parameters have been summarized in the Figure 5.11.

Station/Parameter	pH	Bicarbonate	Sodium	Calcium	Magnesium	Chloride	Sulphate	Calcium hardness	Total hardness
Paonata	Yes								
Kalanaur		No	No		No				No
Mawi				No		No	No		
Palla			Yes				Yes	Yes	
Delhi							No		Yes
Mohana			No				Yes		No
Mathura		Yes	Yes	Yes	Yes	Yes			Yes
Agra								No	No
Etawah	No	No	No	No	No	No	No		
Auraiya				Yes					
Hamirpur				No	Yes		Yes	Yes	
Pratappur	Yes	Yes	Yes	Yes	No	Yes	No		Yes

Figure 5.11: Summarized Results of Seasonal Variation by One Way ANOVA

Paonata, Kalanaur, Agra and Etawah are the stations at which no chemical parameter is seen to be undergoing any significant seasonal variation. It might be due to the fact that the

first two stations Paonata and Kalanaur, being the stations in the initial stretch of Yamuna and relatively free from organic and industrial pollution till lately that the chemical composition of river near its source remains almost the same throughout the year. Agra and Etawah are the stations subjected to maximum pollutant load from the urban cities and nearby industries. So the fact that no seasonal variation is shown by any chemical and biological parameter shows that the river is in the constant state of deterioration throughout the year at these two stations.

pH is seen to show seasonal variation at only Paonata, Auraiya, Hamirpur and Pratappur stations which can be said to be the relatively less affected stations in the river stretch. Rainwater is slightly acidic so the pH of river is expected to decrease slightly during monsoon. But the bicarbonate alkalinity in the remaining stations apparently seems sufficient to act as a buffer during monsoon to maintain the pH.

All cations except potassium are seen to be affected by seasonal variation at nearly half the stations i.e. from Mawi to Mathura and from Auraiya to Pratappur after joining of Chambal. Among the anions, bicarbonate and chloride are seen to be subjected to seasonal variation. It is mainly through domestic wastes that chloride finds its way in the surface water. Domestic waste discharge is continuous throughout the year which shows that chloride concentration must be getting affected by dilution due to flow variation.

Sulphate is showing seasonal variation at only Palla, Mohana, Auraiya and Hamirpur. It is possible that some sulphate emitting industry or presence of abandoned mines is common in the catchment areas of these four stations, whose timely discharges are responsible for modifying the sulphate concentration occasionally. Among the nutrients, only phosphate is showing seasonal variation at three stations of middle Yamuna stretch.

Table 5.4: Season Pair Number and Seasons Considered for Pair Wise Variation

Pair no	1	2	3	4	5
Season Pair	Monsoon	Post monsoon	Winter	Post Winter	Pre monsoon
	Post monsoon	Winter	Post winter	Pre monsoon	Monsoon

Some parameters have been found to undergo significant seasonal variation at only particular stations and for a single season pair. The reasons for this variation may not be generalised as this variation might be due to some localised factor. These are denoted in the Table 5.5.

Table 5.5: Parameters Showing Non-Uniform Seasonal Variation

Parameter	Season Pair	Station
Potassium	2	Mathura
T-Alkalinity	1,4	Palla
Carbonate	5	Mathura, Auraiya
Fluoride	1	Auraiya
Phosphate	2	Delhi, Mathura
Silicate	4	Pratappur
BOD	5	Delhi

Figure 5.12 below shows the results of paired seasonal variation for eight parameters in which the highlighted cells in pink denote significant seasonal variation for the season pair.

pH	Mon-PM	PM-Win	W-Pwin	PW-Prem	Pre-Mon	Sulphate	Mon-PM	PM-Win	W-Pwin	PW-Prem	Pre-Mon
Paonata						Palla					
Auraiya						Mohana					
Hamirpur						Auraiya					
Pratappur						Hamirpur					

Sodium	Mon-PM	PM-Win	W-Pwin	PW-Prem	Pre-Mon	Calcium	Mon-PM	PM-Win	W-Pwin	PW-Prem	Pre-Mon
Mawi						Palla					
Palla						Delhi					
Mathura						Mohana					
Auraiya						Mathura					
Hamirpur						Auraiya					
Pratappur						Pratappur					

Magnesium	Mon-PM	PM-Win	W-Pwin	PW-Prem	Pre-Mon	Chloride	Mon-PM	PM-Win	W-Pwin	PW-Prem	Pre-Mon
Mawi						Palla					
Palla						Delhi					
Delhi						Mohana					
Mohana						Mathura					
Mathura						Auraiya					
Auraiya						Hamirpur					
Hamirpur						Pratappur					

Bicarbonate	Mon-PM	PM-Win	W-Pwin	PW-Prem	Pre-Mon	Total Hardness	Mon-PM	PM-Win	W-Pwin	PW-Prem	Pre-Mon
Mawi						Palla					
Palla						Delhi					
Delhi						Mathura					
Mohana						Etawah					
Mathura						Auraiya					
Auraiya						Hamirpur					
Hamirpur						Pratappur					
Pratappur											

Figure 5.12: Paired Season Results for Significant Parameters

5.2.2. Paired Seasonal Variation for Significant Parameters

EC is observed to show variation mainly between season pairs 2, 4 and 5. EC values are seen to gradually increase from monsoon to winter and then again reducing till pre monsoon. Hence winter is the critical season for the stations up to Delhi. From Mohana onwards, the critical season is observed to change from winter to pre monsoon, with monsoon and post monsoon still being the seasons with lowest EC values. The shift in critical season from winter in upper stations to pre monsoon in lower stations can be attributed to the pre-monsoon showers which must be diluting the EC values. However for the lower Yamuna stations, the river is almost devoid of fresh water which results in pre-monsoon being the most critical season. Maximum variation in the range of EC values is observed in pre-monsoon for Palla, post-winter for Mawi, post-monsoon for Palla and monsoon for Delhi. All stations after Mohana seem to have a wide range of EC values per season, indicating slight fluctuations within the season as well.

The critical season pair which is observed to undergo seasonal variation in pH is pre-monsoon and monsoon. The obvious reason being the precipitation which, being of acidic nature tends to change the pH levels of surface water bodies. Apart from this Paonata is observed to have variation in post-monsoon and winter, where the pH has suddenly been observed to increase from a median value of 7.51 in post monsoon to that of 8 in winter. Auraiya observes a pH variation from 8.32 in post winter to 8.6 in pre monsoon. In general the lowest pH values are observed to have occurred in monsoon.

For bicarbonate, post-winter is observed to be the critical season for Mawi and Palla whereas winter for Delhi, Mohana Auraiya, Hamirpur and Pratappur. For Mathura, pre monsoon is noted to be the critical season for carbonate and bicarbonate.

For Mawi, the median value of sodium is gradually seen to increase from 11.1 mg/L in monsoon to 19 mg/L in pre-monsoon. The general trend observed at all stations except Palla is that monsoon or post-monsoon observe the lowest sodium concentration, winter and post-winter have nearly same values whereas pre-monsoon is the critical season for sodium. Winter is the critical season at Palla, where the pre-monsoon concentration is slightly less than post-winter values.

Calcium is mainly undergoing significant seasonal change from Palla to Mathura. At Palla the calcium concentration is seen to increase from 32 mg/L in monsoon to 52 mg/L in post-monsoon while it reduces from 47 mg/L in post winter to 37 mg/L in pre-monsoon. The range of calcium is seen to be the largest in middle Yamuna where concentration as high as 97 mg/L has been observed in Mathura during pre-monsoon. The commonly observed trend is that of increasing calcium concentration from monsoon to winter and reducing concentrations thereafter. Only at Palla, the post-monsoon concentration is observed to exceed that of winter.

Magnesium is observed to show significant seasonal variation within season pairs 1,2 and 5. This indicates that similar concentration levels of magnesium are observed in winter, post winter and pre monsoon as well. From monsoon to winter the magnesium concentration increases at all stations. The median value during critical winter season is around 16 mg/L for upper Yamuna stations, 30-32 mg/L for middle Yamuna stations and it drops to around 25 mg/L for lower Yamuna stations.

The most significant variation for chloride is observed between post-monsoon to winter where the chloride concentration suddenly shows an increase. The next most visible change is when the pre-monsoon concentration is diluted after monsoon showers. The range of chloride is observed to be the maximum at Delhi (~80 mg/L) which is reduced to ~50 mg/L from Mohana to Mathura and is narrowed down from 30 mg/L to 3 mg/L at Hamirpur and Pratappur stations respectively. Lowest values are observed in monsoon, except for Pratappur where post-monsoon records the lowest chloride concentration. The prime source of chloride in surface waters being sewage effluents, the maximum chloride range at Delhi and middle Yamuna can be attributed to the point sources of domestic pollution.

Sulphate shows almost similar concentrations throughout the seasons except at Palla, Mohana, Auraiya and Hamirpur, where the concentration is observed to be changing significantly during some seasonal pair. At Palla, sulphate concentration observes a drastic increase during post-monsoon which can be attributed to the two extremes observed while at Auraiya, the increase from post-monsoon to winter is significant. Mohana, Auraiya and Hamirpur observe a sudden drop in sulphate from pre-monsoon to monsoon.

Fluoride concentration at Auraiya is seen to undergo a reduction from 0.375 mg/L in monsoon to 0.21 mg/L in post monsoon. Silicate concentration at Pratappur is observed to be nearly constant at all seasons with a gradual fall from 19 to 16 mg/L from monsoon to post winter, after which it suddenly rises to 23 mg/L in pre monsoon. Phosphate is seen to vary significantly at Delhi and Mathura where it increases suddenly from post-monsoon to winter. The BOD concentration in pre-monsoon is almost 1.5 times higher than in monsoon. So monsoon does the job of dilution of pre-monsoon BOD levels in monsoon. Calcium hardness shows seasonal variation at Mawi, Palla and Auraiya. The common trend is increasing concentrations from monsoon to post-monsoon and further reducing concentration from post-winter to pre-monsoon. Either of winter or post-winter is observed to be the critical season. Total hardness shows significant seasonal variation at Palla, Delhi and all four lower Yamuna stations for all four season pairs. The common seasonal trend of all parameters is also observed in total hardness, where the values increase from monsoon to a peak in winter and further reduce then after.

Table 5.6: Parameters Showing Significant Variation in the Season Pairs considered

Pair no	1	2	3	4	5
Season Pair	Monsoon	Post monsoon	Winter	Post Winter	Pre monsoon
	Post monsoon	Winter	Post winter	Pre monsoon	Monsoon
Parameters showing variation	EC, Na, Ca, Mg, bicarbonate, chloride, fluoride, sulphate, calcium and total hardness	pH, EC, K, Na, Ca, Mg, bicarbonate, chloride, sulphate, phosphate, total hardness	-	pH, EC, Na, Ca, T-Alkalinity, bicarbonate, chloride, silicate, calcium and total hardness	pH, EC, Na, Ca, Mg, carbonate, bicarbonate, chloride, sulphate, BOD, calcium and total hardness

5.2.3. Concluding Remarks based on Seasonal Variation

As observed, there is no significant variation in winter and post-winter seasons considered. Also from the graphical representation of seasonal variation, it can be seen that the overall range of water quality parameters is almost comparable for the lean season. Hence for further analysis, two seasons namely, monsoon and non-monsoon are adopted.

5.3. Spatio – Temporal Trends in Water Quality Parameters

The variation of water quality parameters over the entire timeline and entire stretch of Yamuna mainstream has been represented in two graphs, pertaining to monsoon and non-monsoon. For every station, the timeline has been divided in four parts of ten years, the median of which has been plotted. The error bars denoting the minimum and maximum values, indicate the range of parameters. The x-axis represents the station whereas the y-axis denoted the magnitude of parameter. Figure 5.13 to 5.18 denote the spatio-temporal variation in the six groups of water quality parameters as listed in Table 5.7.

Table 5.7: Groups of Water Quality Parameters

Group	Category	Parameters
1	Alkalinity	pH and Alkalinity
2	Indicators of Organic Pollution	DO, BOD and COD
3	EC and Hardness	EC, Total hardness, Sodium and Potassium
4	Anions	Chloride, Sulphate and Silicate
5	Nutrients	Ammonical Nitrogen, Nitrate and Phosphate
6	Coliform	Total and Faecal Coliform

5.3.1. Temporal Variation in Group 1 Parameters

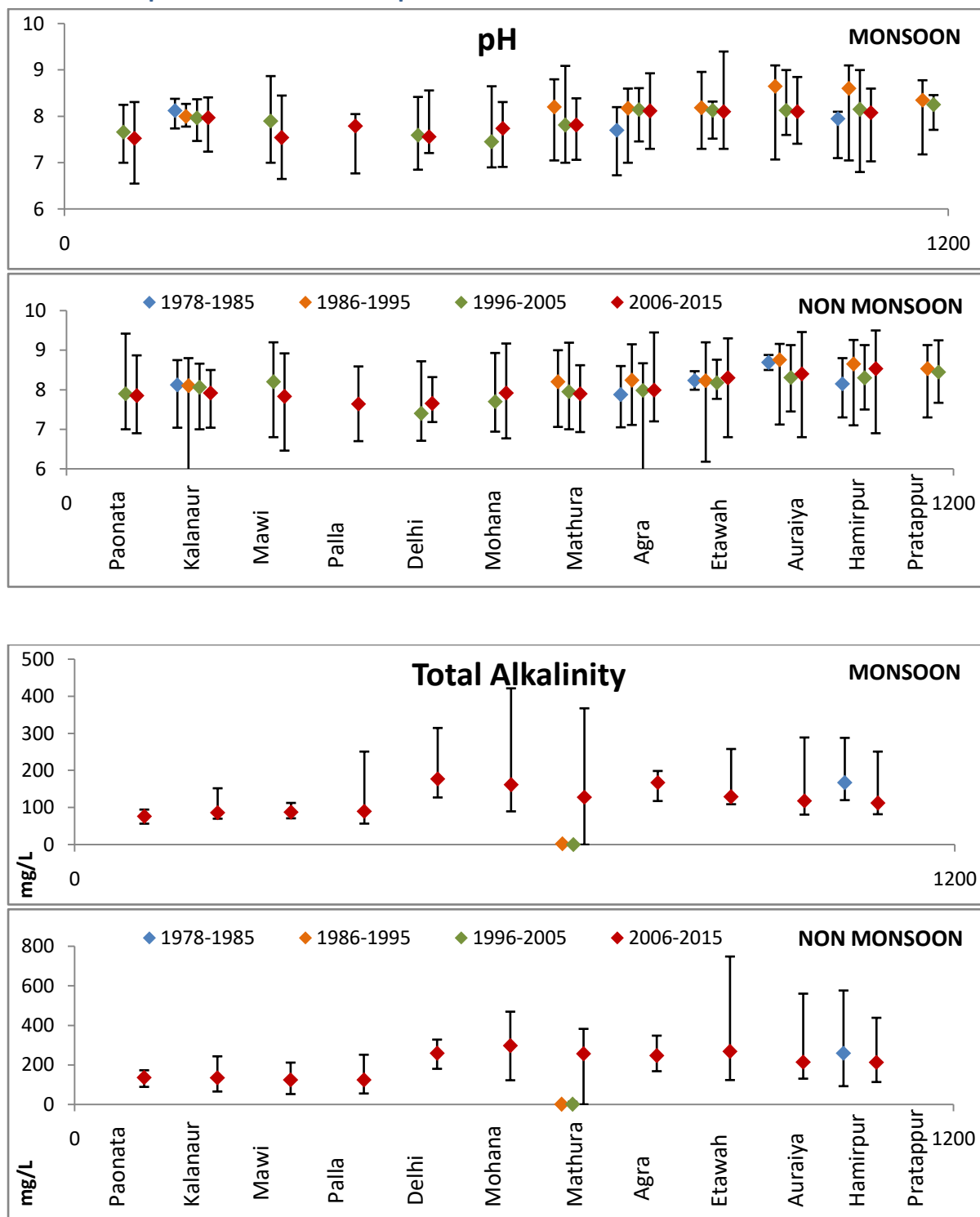


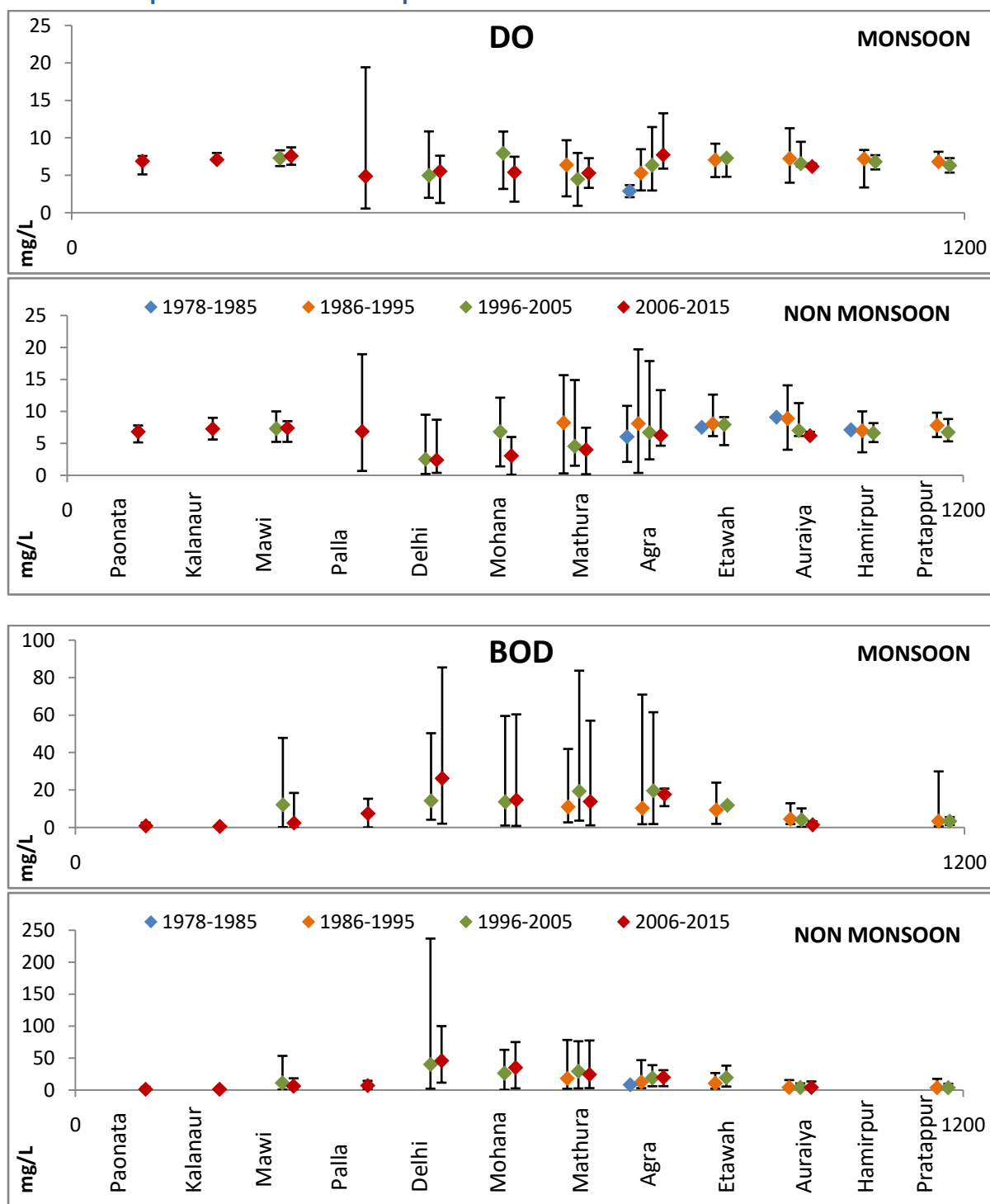
Figure 5.13: Spatio-Temporal Variation of Group 1 Parameters

At all stations, pH is seen to lie in the desirable range. pH values at Kalanaur, Mawi, Palla, Delhi, Mohana, Agra have been found to exceed 8.3 occasionally and it is reflected by the presence of carbonate during those times. pH values even exceeding 9 have been observed at Mathura where carbonate concentrations upto 70 mg/L have been observed during 1992 to 1995. In the stations beyond the confluence of Chambal, the average pH values are

greater than 8.3 so the river is in constant alkaline conditions throughout the year. Carbonate concentrations are seen to lie in the range of 10 to 40 mg/L.

Total alkalinity has been recorded in the recent years only and is observed to lie in a constant range for every station. . The total alkalinity is least in upper Yamuna stations and highest in middle Yamuna stations. The average P-Alkalinity at Auraiya and Hamirpur is around 5 and 20 mg/L.

5.3.2. Temporal Variation in Group 2 Parameters



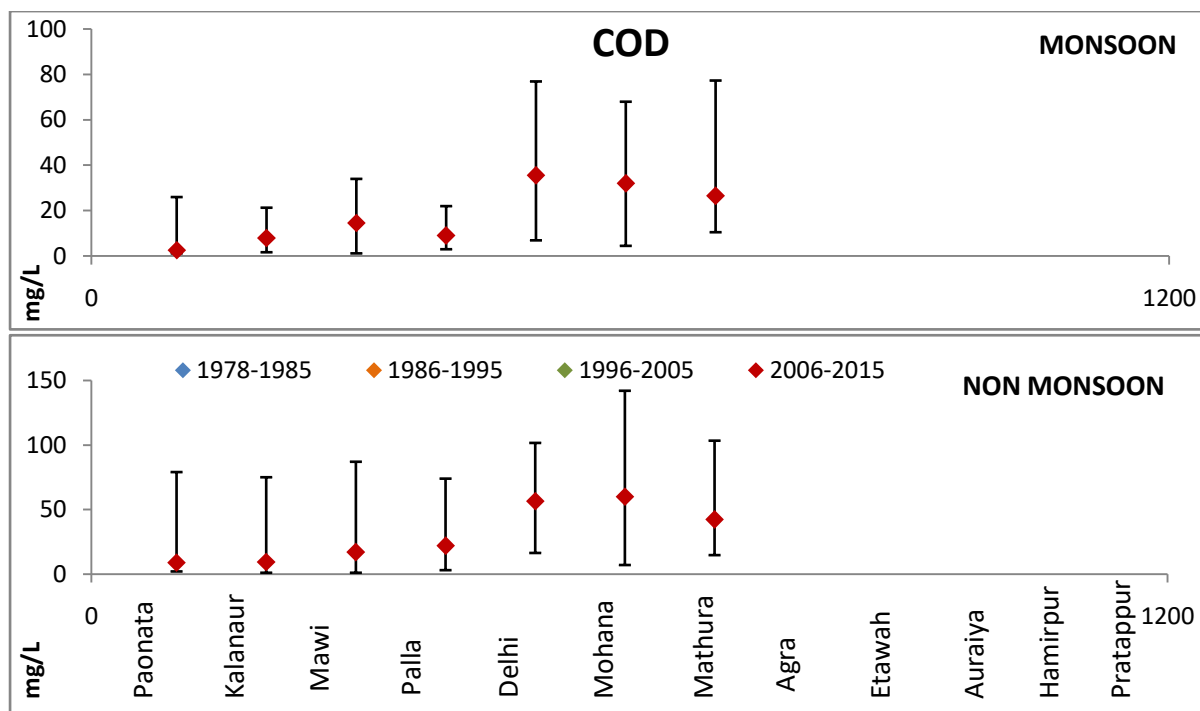


Figure 5.14: Spatio-Temporal Variation of Group 2 Parameters

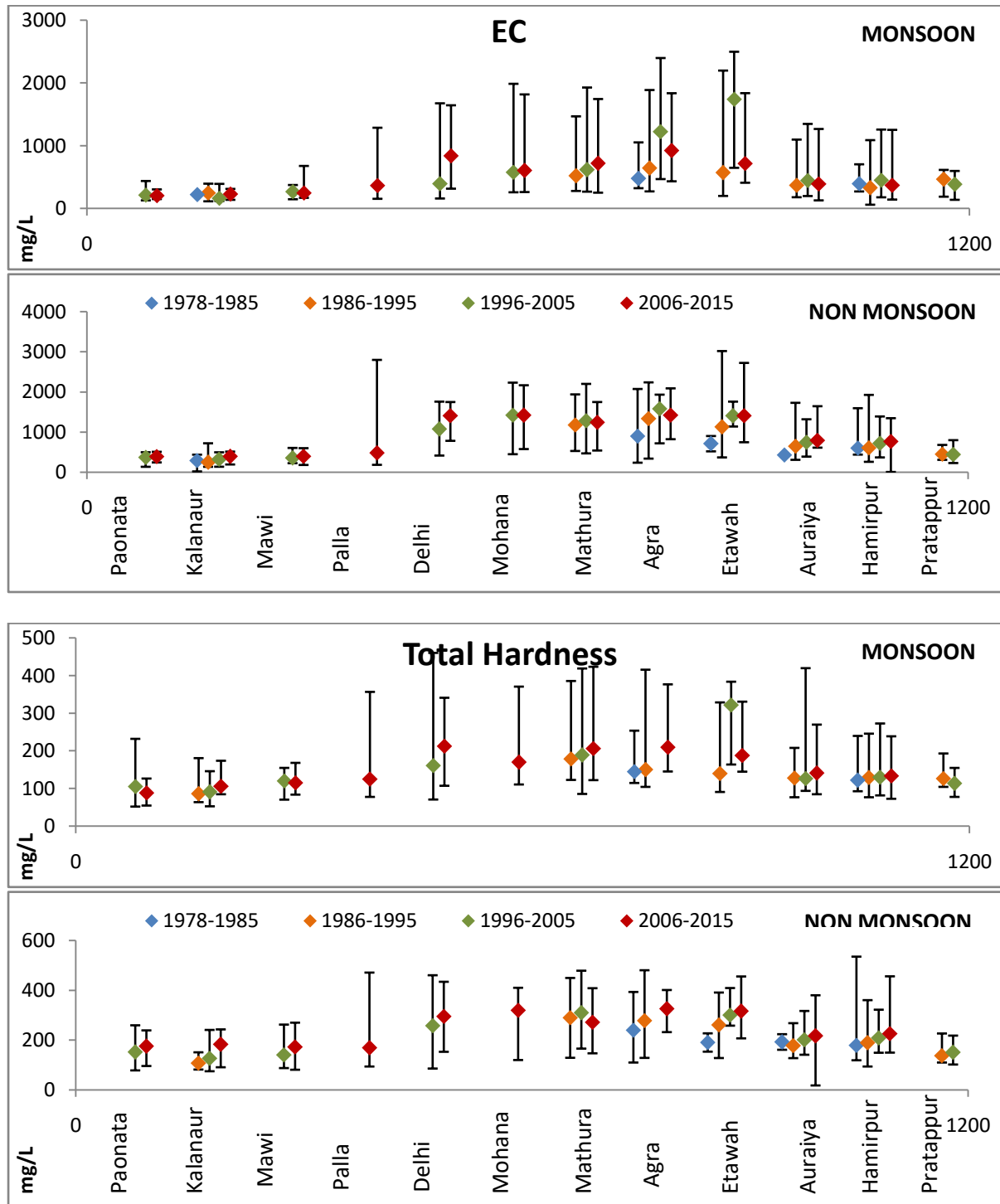
DO values have been observed to lie above 6 mg/L at Paonata and Kalanaur. At Mawi, DO less than 6 mg/L has been observed during 1998 and 2006. At Palla and Delhi, DO has been observed to decrease in the recent years. DO below 5 mg/L has been observed for almost all times between 2011-2013. The deteriorating condition of middle Yamuna is indicated by the drop in DO levels over the years. At Mathura, DO values ranging from 4 to 16 mg/L have commonly been observed during 1990 to 1998 but since 2003 this range has narrowed down to 2-8 mg/L. DO values at Agra have been observed to lie in the range of 5 to 15 mg/L till 2000. Between 1986 and 1995, DO values at Etawah are observed to increase from 6 to 14 mg/L. After 1995, they are monotonically seen to decrease back to 6 mg/L. At Hamirpur and Pratappur, the DO values range from 6-8 mg/L and 6-10 mg/L respectively.

BOD and COD:

The BOD range of 1-3 mg/L at Paonata and Kalanaur is an indication of the upper Yamuna stations being relatively free from organic pollution. The increasing COD values at Paonata from 10 mg/L in 2011 to 30 mg/L in 2015 is possibly due to increasing industrial pollution. Similar instances of high COD values have been observed at Kalanaur and Mawi where COD has rose up to 70 mg/L in past few years. At Mawi, the BOD values have reached up to 50 mg/L during 2000-2001 but after 2004, BOD has not exceeded the permissible limit of 20 mg/L. BOD levels are seen to rise suddenly up to 70 mg/L at Delhi and Mohana. Despite the maximum BOD values slightly reducing with time at Mathura, the BOD levels are way above the surface water standards. COD values have been increasing from 2010 to 2015 in middle Yamuna stations. At Etawah, BOD values are observed to lie in the range of 5 to 25 mg/L during 1988 to 1992, which gets narrowed to 2 to 15 mg/L at Auraiya, possibly due to

confluence with Chambal. Most of the BOD values at Pratappur are seen to lie below 10 mg/L.

5.3.3. Temporal Variation in Group 3 Parameters



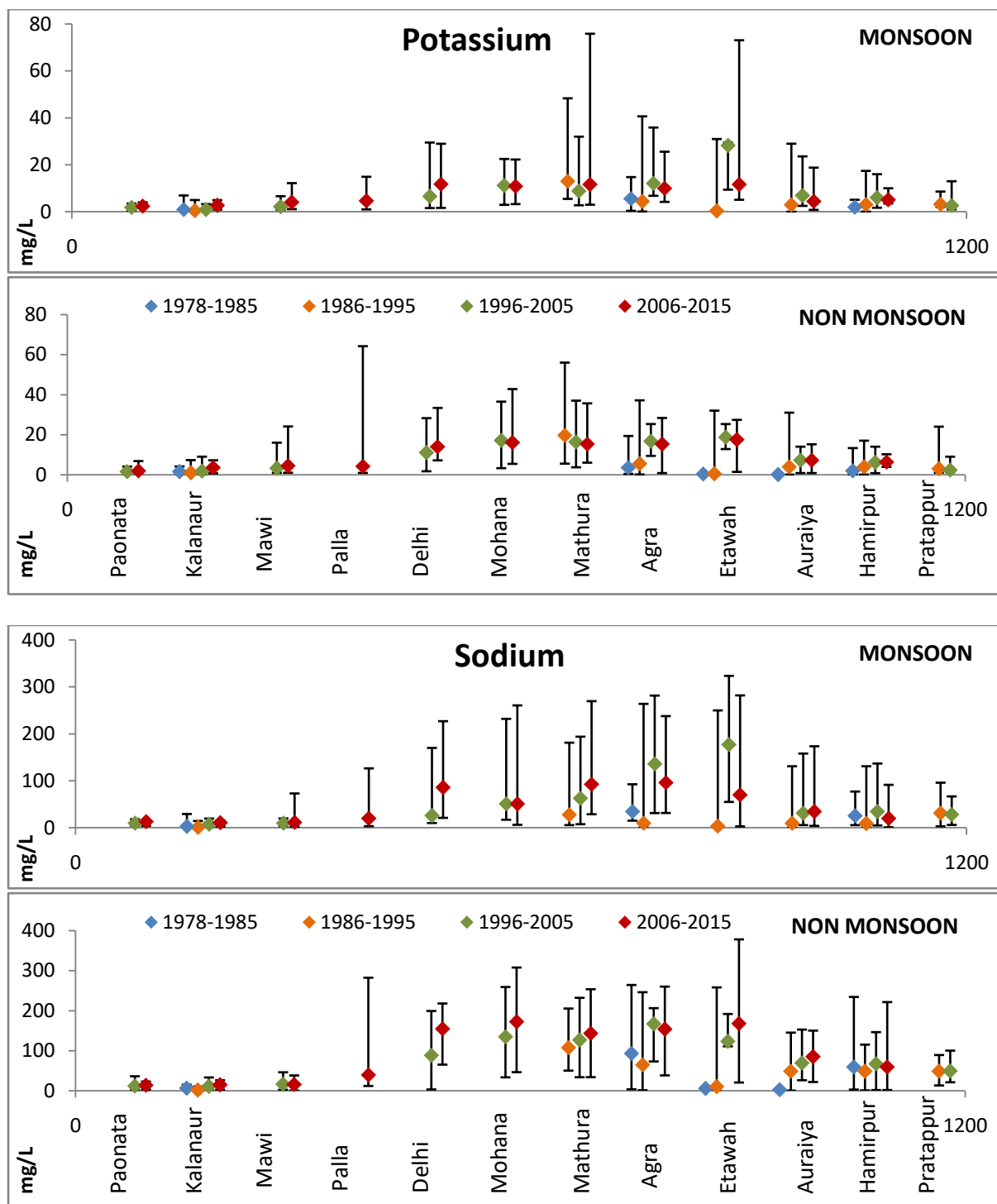


Figure 5.15: Spatio-Temporal Variation of Group 3 Parameters

At Paonata, TDS is showing a peak of 550 mg/L during the intermediate time span in 2002-2003. It drops down to 130 mg/L in 2005 and after that is almost constant to 300 mg/L till 2008. The electrical conductivity values at Paonata and Kalanaur mostly lie in the range from 200 to 400 $\mu\text{S}/\text{cm}$. The maximum value at Kalanaur during 1992-1998 has been observed to be less than 250 $\mu\text{S}/\text{cm}$ whereas during the time span from 2005-2009, it lies within 400-500 $\mu\text{S}/\text{cm}$. At Mawi, the maximum TDS values which have been observed to exceed 400 mg/L during 1998 to 2007, have reduced to 200 mg/L during 2009 to 2011. At Delhi, the EC values

are observed over a wide range from 200 to 1800 $\mu\text{S}/\text{cm}$. The maximum peak of TDS is observed to be increasing over the years, from 600 mg/L in 1998 to 1335 mg/L in 2008. EC values are observed to lie in the range of 500 to 2000 $\mu\text{S}/\text{cm}$ at Mohana, Mathura, Agra and Etawah. No trend is observed at Auraiya. The maximum values are observed to decrease from 1200 $\mu\text{S}/\text{cm}$ in 1989 to 600 $\mu\text{S}/\text{cm}$ in 1998, again rising to over 1300 $\mu\text{S}/\text{cm}$ in 2004, dropping to 800 $\mu\text{S}/\text{cm}$ in 2007 and remaining almost constant up to 1000 $\mu\text{S}/\text{cm}$ in the recent years. EC values are observed to lie in the range of 400 to 1000 $\mu\text{S}/\text{cm}$ at Hamirpur, which is observed to narrow down to 300-600 $\mu\text{S}/\text{cm}$ at Pratappur.

During non-monsoon, the EC values are observed to increase over the years. At Agra and Etawah, EC variation is observed during monsoon over the years. The range of EC values is very wide in the middle Yamuna stretch.

Total Hardness:

Peak values of calcium hardness have been reducing at Paonata during last 4 years. At Kalanaur, the average range of calcium hardness being 70 to 150 mg/L and that of total hardness being 100 to 250 mg/L. Calcium and total hardness at Palla are observed to lie in the range of 60 to 150 and 100 to 250 mg/L respectively. Calcium and total hardness have been observed to lie in a constant range with no exceptional increase or decrease over the years at Mathura, Agra and Etawah. In the lower Yamuna stations, total hardness is observed to increase slightly over the years with values ranging from 100 to 300 mg/L.

Potassium and Sodium:

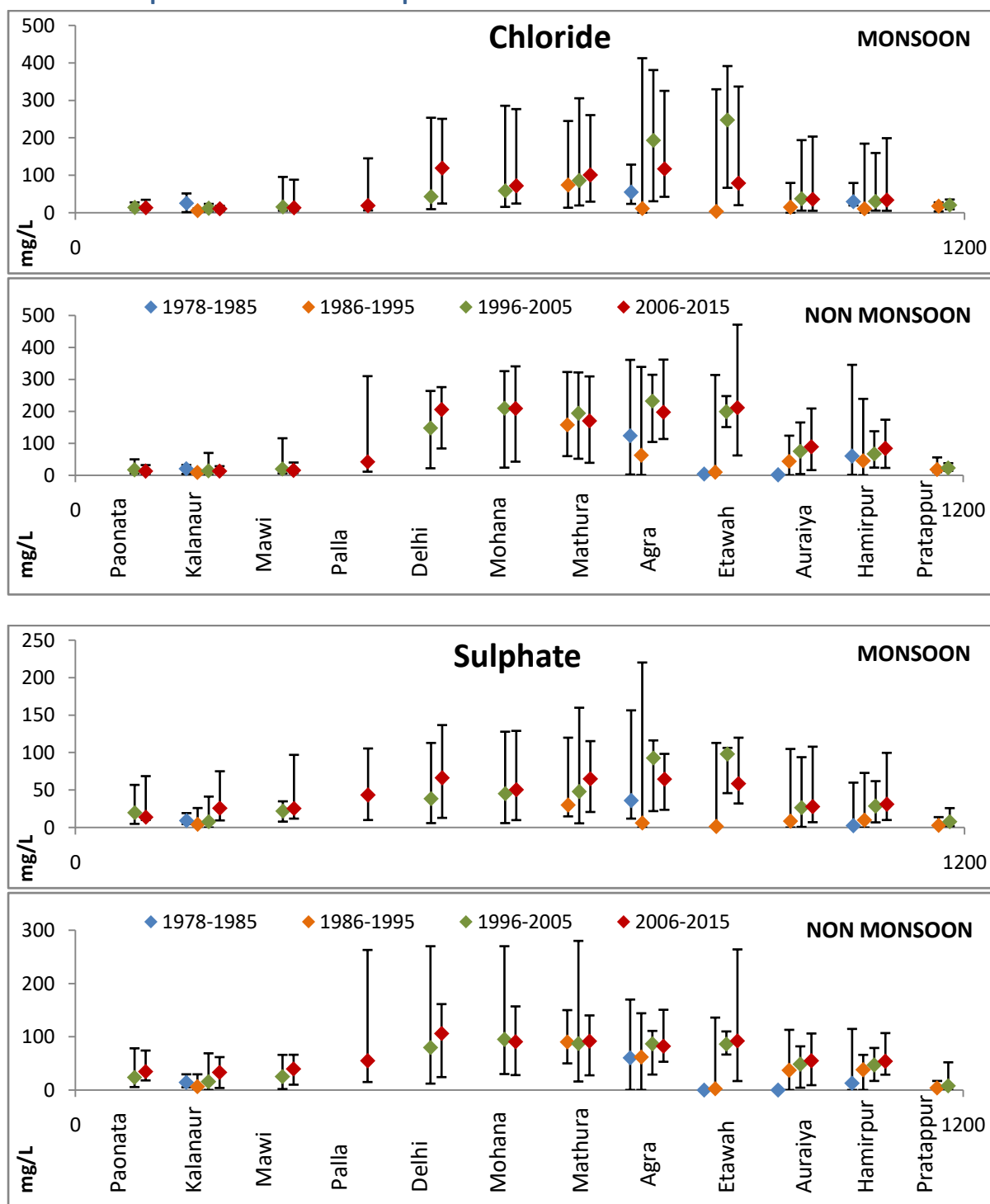
Potassium values at Paonata have been gradually increasing upto 4 mg/L in 2001 and falling to 0.5 mg/L in Aug 2004. In the recent years, it is observed to lie in the range of 2 to 6 mg/L. Sodium has high values in the initial years. Peaks of 35 mg/L have been observed in 2000 and 2003 after which the values are nearly constant between 5-10 mg/L. All cations at Kalanaur have been observed to have high values during 1980 after which the peaks have reduced in time span from 1990 to 1998. But after 2000, the maximum peak values have again seen to be increasing. The ranges observed in these three time periods are 2-4, 0-2 and 2-6 mg/L for potassium and 5-15, 0-5 and 10-30 mg/L for sodium. At Mawi, the average potassium concentration observed in 1998 to 2004 is less than average concentration during recent years 2006 to 2015. Sodium is observed to lie in the range of 10 to 40 mg/L with an extreme peak of 73 mg/L in July'2013. A sudden peak in Nov 2011 is observed for all cations at Palla. Low flow conditions during this winter season coupled with point source pollution might be associated with this sudden increase in all parameters.

At Delhi, the cations are seen to have a monotonically increasing maximum, which has almost doubled during the years 1998 to 2011. Potassium has increased from 15 to 30 mg/L while sodium has increased from 100 to 200 mg/L. No significant peak is observed for cations at Mohana. At Mathura, the potassium values have been observed to decrease from

a maximum of 60 mg/L in 1995 to 30 mg/L during 2000-11. The range of cations is observed to be almost constant at Mathura, Agra and Etawah.

During the three years 1995-1997, potassium concentrations (lying around 20 mg/L) at last three stations are observed to be distinctly higher than the normal range (5-10 mg/L). Sodium is observed to lie in a uniform range of 20-100 mg/L at the last three stations. After 2000, this range has increased to 160 mg/L at Auraiya.

5.3.4. Temporal Variation in Group 4 Parameters



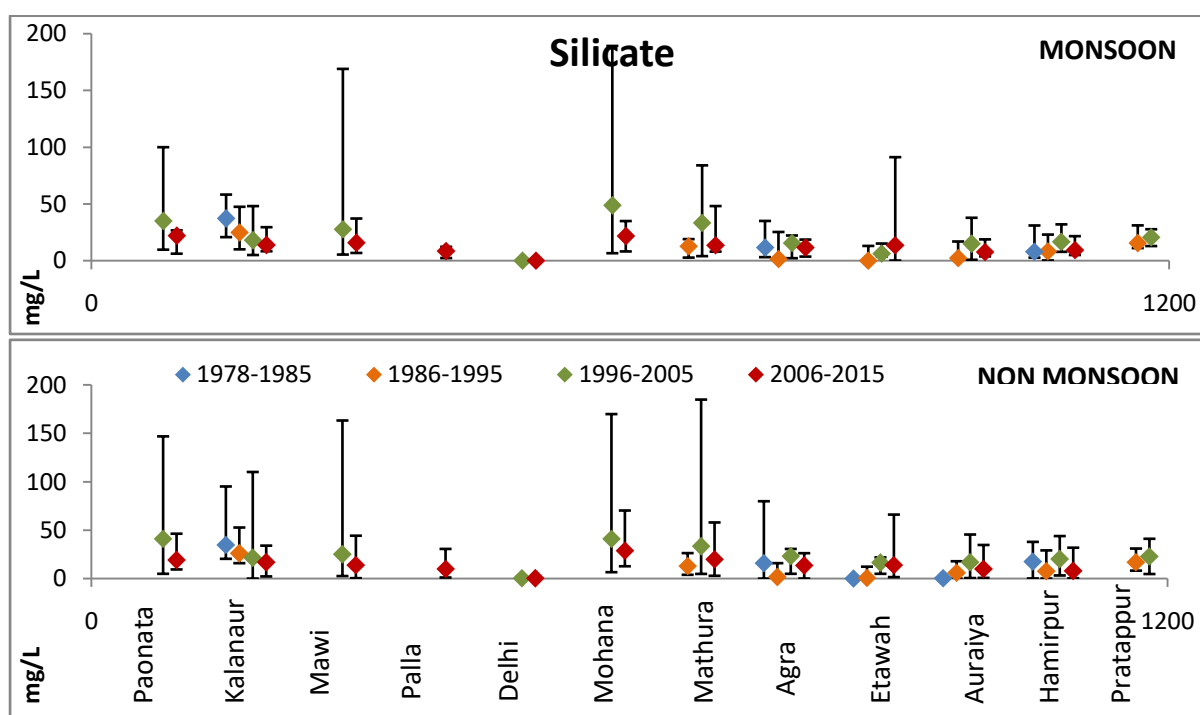


Figure 5.16: Spatio-Temporal Variation of Group 4 Parameters

At Paonata, chloride has reduced in comparison to 1998-2006 and has remained almost constant around 10-15 mg/L in recent years. The time period from 1992 to 1998 is observed to be the time of least range for all anions at Kalanaur. Chloride is generally observed to be lying below 40 mg/L and 100 mg/L at Mawi and Palla respectively. Extreme peaks observed occasionally may be attributed to point sources of pollution occurring close to the event of sampling. The chloride concentration at Delhi is observed to monotonically increase from 100 mg/L during 1998 to 250 mg/L in 2008 after which it has remained almost constant. In the stretch from Mohana to Etawah, the range of chloride has not changed over the years and concentrations lie between 50 to 350 mg/L. At Auraiya, the chloride concentration which was observed to lie around 50 mg/L till 1998 has monotonically increased to 200 mg/L in 2005. At Hamirpur, highest chloride concentrations up to 250 mg/L have been observed during 1993-94. From 1996, chloride values are seen to increase very gradually from around 50 mg/L to 150 mg/L in 2015. Chloride is seen to lie in the narrow range of 20 to 40 mg/L at Pratappur.

Sulphate:

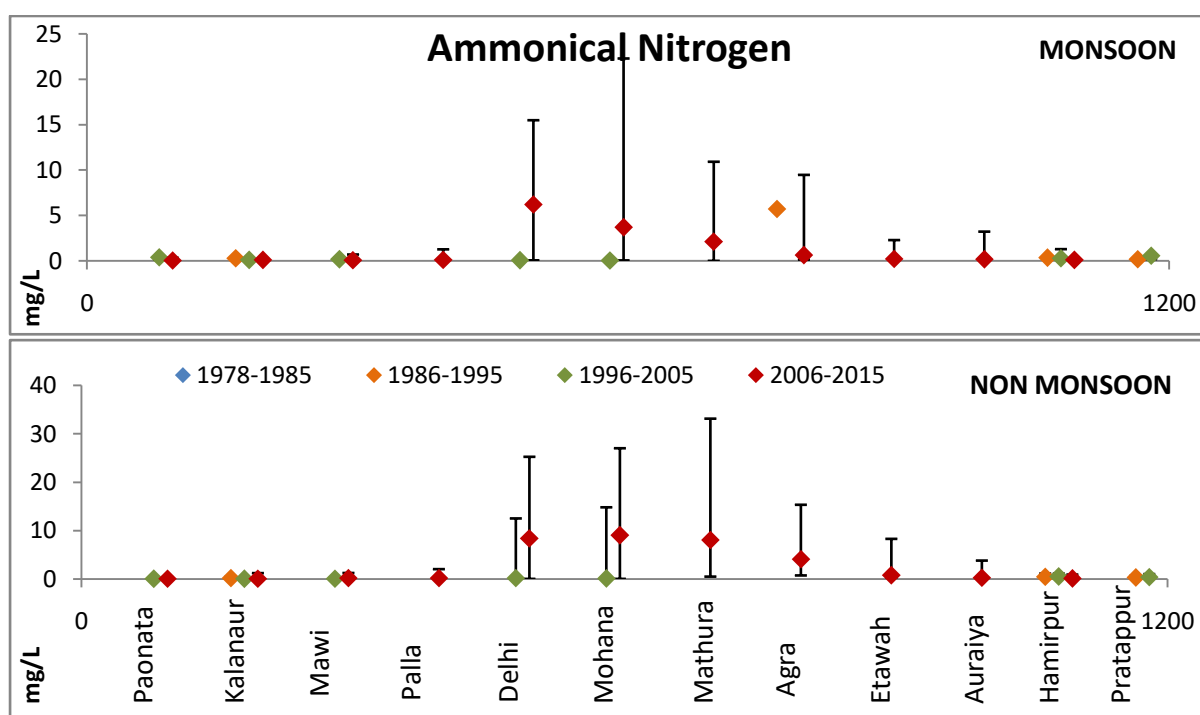
Peaks exceeding 40 mg/L have been occasionally observed at Paonata except during the time span of 2002 to 2006. At Kalanaur, the range of sulphate concentration has been observed to change from 10 to 20 mg/L during initial years upto 1988 to less than 10 mg/L from 1994-1998. However an increase in sulphate concentration upto 60 mg/L has been observed from 2000 onwards. Sulphate concentrations at Mawi and Palla have not shown any significant changes and the seasonal variation over the years is observed to be almost

the same. At Delhi, except for a peak of 270 mg/L in April 1999, sulphate concentration has been observed to gradually increase over the years from 60 mg/L in Nov 2001 to around 150 mg/L in recent years. Sulphate concentration is observed to be fairly constant ranging from 30 to 150 mg/L at Mohana, Mathura and Agra. At Etawah, a monotonically increasing trend is observed for sulphate from 2013 to 2015 where it is gradually rising to 150 mg/L from 50 mg/L. Sulphates are observed to uniformly lie in the range of 20 to 80 mg/L all over the years at the last three stations beyond confluence with Chambal.

Silicate:

Over the years, silicate has been observed to reduce at Paonata, Kalanaur, Mawi and Mohana. It is nearly constant at Palla, Delhi and Agra. At Mathura, silicate is observed to lie between 10 to 20 mg/L during 1991-98. His range has increased to 20 to 100 mg/L during 2001-06. 2008 onwards silicate values are observed below 50 mg/L. At Agra, silicate ranges between 0-40 mg/L. At Etawah, where silicate is observed to lie in the range of 0-20 mg/L is suddenly seen to increase to 80 mg/L in 2012. Mixed trends are observed for silicate variation in Auraiya and Hamirpur. Silicate at Auraiya is observed to gradually increase from 15 mg/L during early 90's to 45 mg/L in 2004 and again decrease gradually to 15 mg/L till 2009. In early years from 1981-85, at Hamirpur, silicate has been observed to lie in range of 10 to 35 mg/L. Silicate is observed to gradually increase from 15 mg/L during early 1995 to 45 mg/L in 2004 and again decrease gradually to 15 mg/L till 2007. At Pratappur, the maximum silicate has been observed to be 20 mg/L during 1991-94. This has gradually increased to 30 mg/L by 2005.

5.3.5. Temporal Variation in Group 5 Parameters



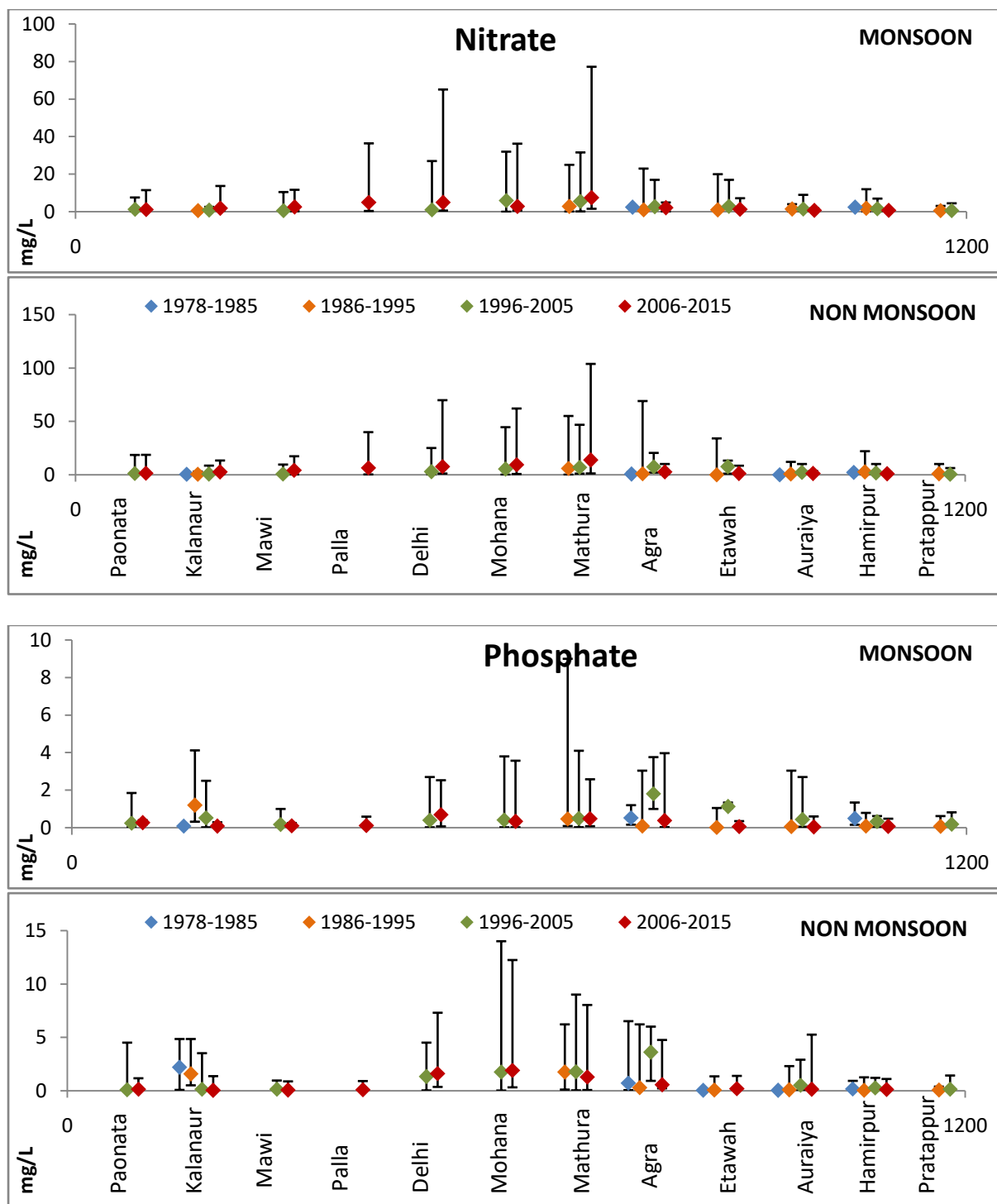


Figure 5.17: Spatio-Temporal Variation of Group 5 Parameters

At Mawi, The peaks in measurement of ammonical nitrogen are seen to be increasing monotonically from 1998 to 2014. At Palla, ammonical nitrogen values have remained almost constant throughout the years. Rising values at Delhi and Mohana indicate increased pollution levels. At Mathura, ammonical nitrogen has been observed to reduce from 2009 to 2015. Although ammonical nitrogen at Etawah is seen to lie in the range of 0 to 2 mg/L, peaks up to 8 mg/L have also been observed. At Pratappur, ammonia concentrations up to 0.8 mg/L are observed.

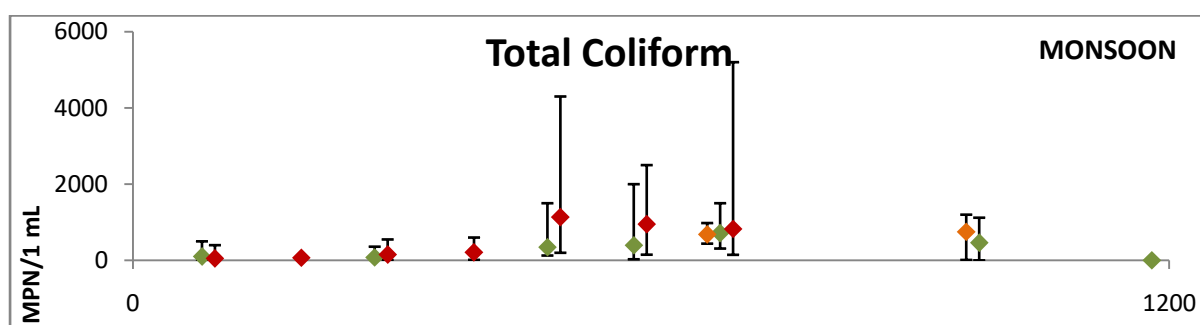
Nitrate:

At Paonata, nitrate peaks of around 14 to 18 mg/L have been observed during 2000, 2005 and 2012, apart from which nitrates are observed below 10 mg/L. The nitrate concentration is seen to reduce from over 15 mg/L in 2012 to 3 mg/L in 2015. Nitrate concentration at Kalanaur has been continuously increasing from 2 mg/L in 1991-2004 to 8 mg/L in 2015. Extreme values from 28 to 32 mg/L have been observed during 2012. The nitrate peaks at Mawi have reduced from an average of 6 mg/L (2000) to 1 mg/L (2001 to 2004). 2005 onwards, it is generally observed to lie in a range of 1-10 mg/L. Nitrate concentration at Palla has undergone a reduction after 2012. At Delhi, Mohana and Mathura, nitrate concentrations have been found to increase over the years, especially after 2011. High peaks of ammonical nitrogen and nitrate have been observed at Agra during 1991-1992. Relatively, nitrate is seen to be gradually decreasing at Agra. In general, nitrate has been observed to lie in the range of 0-35, 0-10 and 0-20 mg/L during 90's at Etawah, Auraiya and Hamirpur respectively. But over the years, nitrate has been observed to reduce and in the recent years, nitrate has not been observed to cross 10, 4 and 5 mg/L at the same stations.

Phosphorus:

At Paonata, Kalanaur, Delhi, Mathura and Agra, phosphate is clearly seen to reduce with time. At Kalanaur, phosphate concentration has been observed to have dropped from a range of 1-2.5 mg/L in 1985 to 1998 to less than 1 mg/L from 2000 onwards. Peaks exceeding 4 mg/L have been commonly observed at Mathura during 1990 to 2003 but from 2008, phosphate concentration has been observed to lie below 3 mg/L. At Etawah, phosphate is observed to increase gradually from 0.4 to 1.2 mg/L during 1990-1992 and from 0.2 to 0.6 mg/L in last four years. Phosphate values at Hamirpur have increased from around 0.5 mg/L in 1990 to 1.2 mg/L in 2005 and are seen to reduce then after. In the recent years, phosphate is observed to lie below 0.4 mg/L.

5.3.6 Temporal Variation in Group 6 Parameters



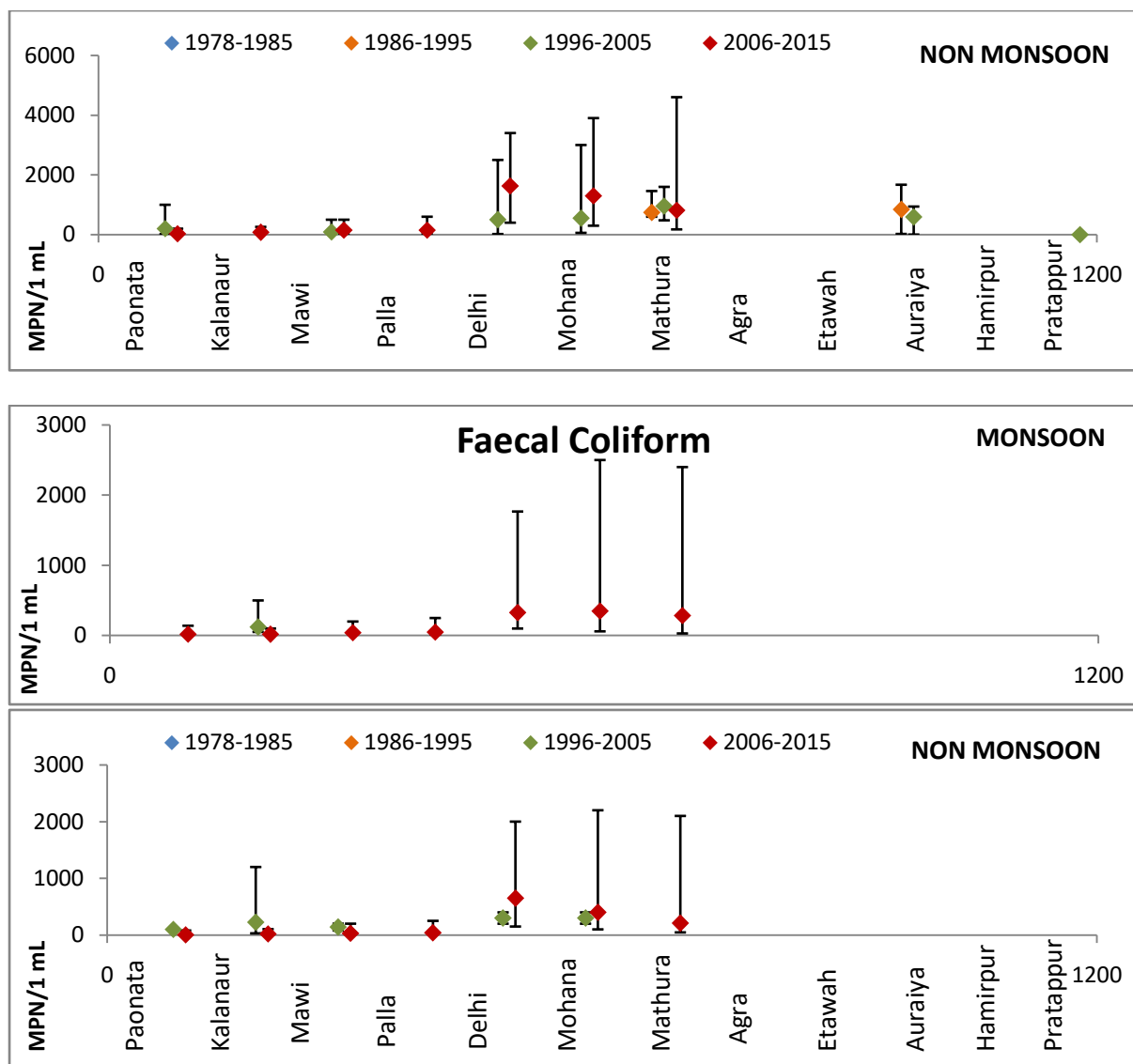


Figure 5.18: Spatio-Temporal Variation of Group 6 Parameters

Total and faecal coliform are observed to decrease at upper Yamuna stations namely Paonata and Mawi. From Palla to Mathura, coliform counts have been observed to increase over the years. The maximum coliform counts in monsoon are observed to be higher, which might be possible due to a higher death rate of coliform in summer as reported in studies.

5.3.6. Summarizing points for Spatial Variation

From the graphs of spatial variation, the middle Yamuna stretch with lowest DO values and highest BOD, COD values can easily be identified as the critical stretch. Similar variation is observed for all other parameters where highest values of parameters are observed in the middle Yamuna stretch. Also the range of parameters is least for upper and lower Yamuna stations but is maximum for middle Yamuna. This might be due to point sources of pollution contributing to the extreme values. It is observed that DO values in non-monsoon period have been reducing with time. The median values and the range of parameters are observed to increase in the non-monsoon period for all parameters.

5.3.7. Effect of Tributaries on Water Quality of Yamuna

The effect of confluence of Chambal is observed at the downstream station, Auraiya. Etawah is the upstream station under consideration. CPCB data for station Udi was used to find the water quality at the confluence of Chambal and Yamuna using the dilution technique as per following equation. The ratios at confluence to upstream and that of downstream to confluence have been evaluated to understand the proportionate changes in water quality due to tributary. Similarly for Betwa, upstream and downstream stations considered are Hamirpur and Pratappur. CWC data for Shahijina station lying on Betwa was used for analysis.

$$P_{\text{confluence}} = [Q_{\text{upstream}} * P_{\text{upstream}} + Q_{\text{tributary}} * P_{\text{tributary}}] / [Q_{\text{upstream}} + Q_{\text{tributary}}]$$

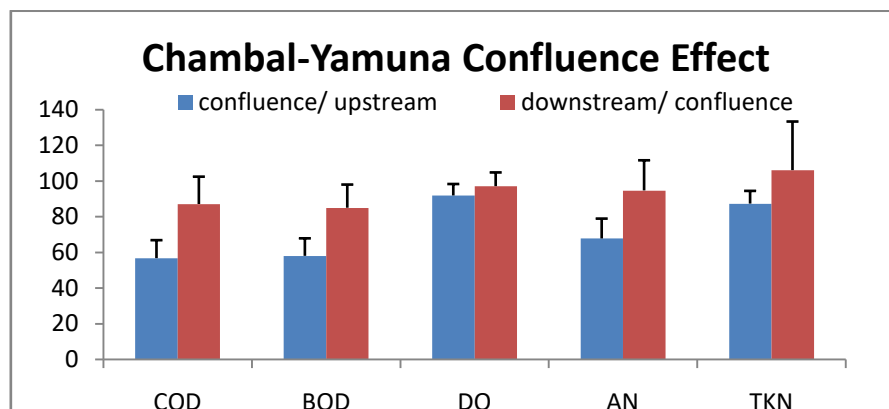


Figure 5.19: Effect of Chambal-Yamuna Confluence on Water Quality

It is observed from Figure 5.19 that almost 50-60% reduction of BOD, COD and ammonical nitrogen is occurring at the confluence in comparison to the upstream. The downstream parameters are almost comparable to those at confluence (80-90%) due to the short river stretch of 15 km between the two points.

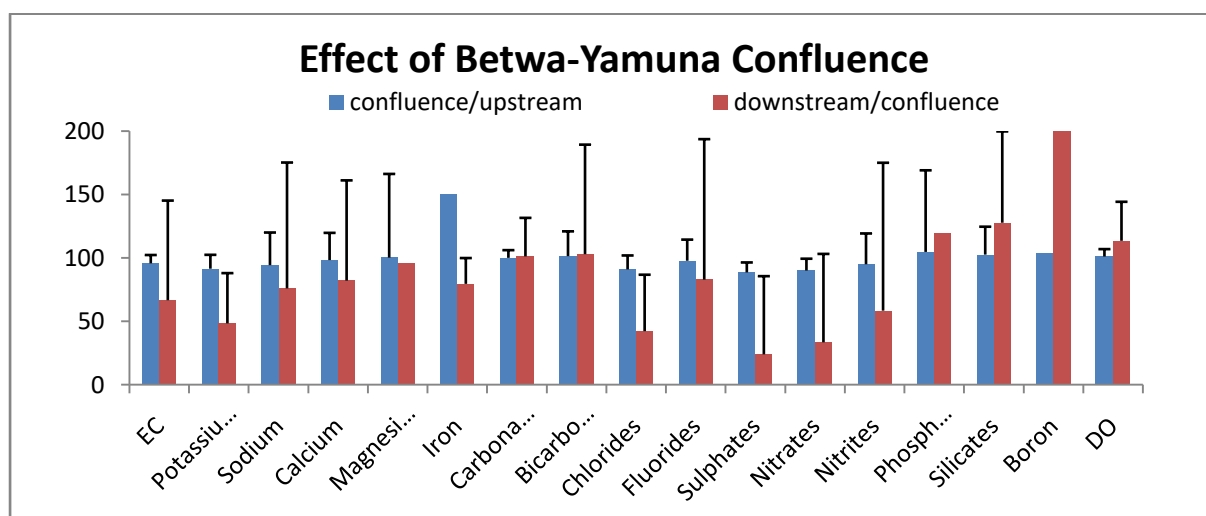


Figure 5.20: Effect of Betwa-Yamuna Confluence on Water Quality

It is observed from Figure 5.20 that confluence and upstream values are almost comparable. At most 10% reduction is observed for chemical parameters like potassium, sodium, sulphate and nitrate. This is mainly because of the insignificant contribution of flow by tributary Betwa to Yamuna. Betwa is not seen to improve the river water quality significantly. However the downstream values are significantly different from that of confluence and this can primarily be attributed to the distance of 220 km and confluence of Ken amidst the two locations. There seems to be change in land use pattern in the catchment area between the two stations. 70% reduction in nitrate and 20% increase in phosphate is possibly due to change in agricultural land. 60% and 80% reduction in chloride and sulphate is observed at Pratappur, indicating relatively less domestic pollution in the downstream stretch. The geology of catchment area is seen to differ as well, which is reflected by the significant change in parameters like iron, silicate and boron.

5.4 Correlation among Water Quality Parameters

The water quality parameters were divided in four clusters for plotting the correlation plots which are described in Table 5.8. Cluster wise correlation plots have been studied for all stations, and the results of pairs of parameters showing significant variation have been listed in Figure 5.21.

Table 5.8: Clusters of Water Quality Parameters for Correlation Analysis

Sr	Cluster	Parameters
1	Alkalinity – hardness	pH, carbonate, bicarbonate, P-Alkalinity, T-Alkalinity, Ca, Mg, Ca hardness, Total hardness
2	Nutrients and biological	pH, nitrate, nitrite, phosphate, Temp, DO, BOD, COD
3	Hardness and it's constituents	T-Hardness, carbonate hardness, Non-carbonate hardness, T- Alkalinity, sulphate, bicarbonate, nitrate, silicate
4	EC, TDS and it's constituents	EC, TDS, K, Na, Ca, Mg, bicarbonate, Cl, sulphate

Legend:

$p > 0.05$	$0 < r < 0.5$	$0.5 < r < 0.7$	$0.7 < r < 1$

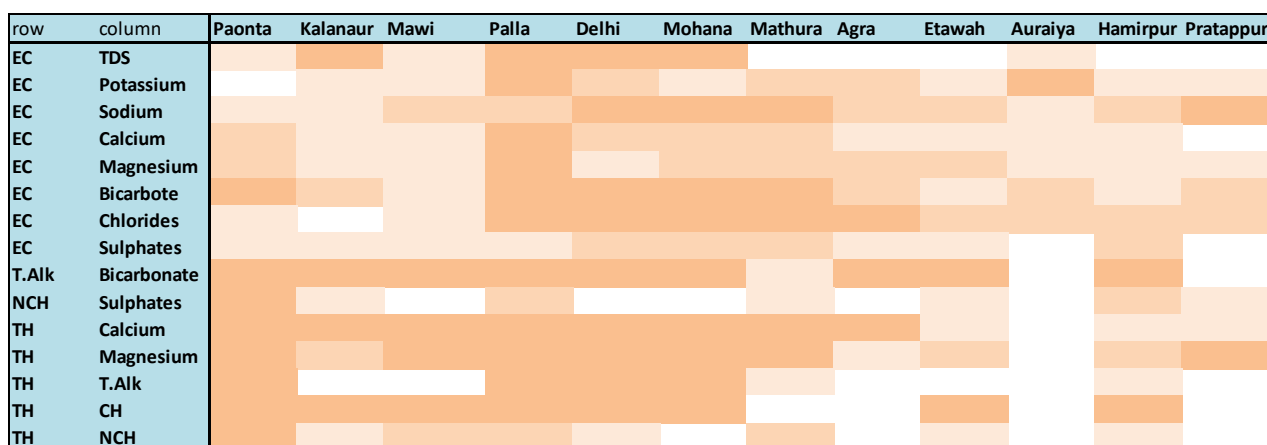


Figure 5.21: Water Quality Parameter Pairs Showing Significant Correlation

5.4.1 Group 1 Cluster

Figure 5.21 shows how total hardness is correlated with various parameters. Total alkalinity and bicarbonate are strongly correlated at almost all the stations. At Paonata, TH shows a strong correlation with both cations Ca, Mg as well as both types of hardness CH, NCH. Ca and CH are observed to have a strong correlation with TH from Paonata to Agra and Mathura respectively. Magnesium also shows a strong correlation with TH from Mawi to Mathura. CH shows a strong correlation with TH at Etawah and Hamirpur. Apart from that TH doesn't show a strong correlation with any parameter in the Lower Yamuna stretch.

pH is not even moderately correlated with any of the parameters at almost all stations. At Kalanaur, pH shows a strong negative correlation with P-Alkalinity and at Etawah it shows a weak positive correlation between carbonate. P-Alkalinity and carbonate are seen to show a positive uphill correlation throughout the stretch of the river. In general, calcium and magnesium are moderately correlated with each other and with T-Alkalinity as well. Yamuna receives water at Kalanaur mainly through groundwater and Ca being a significant groundwater component explains the strong correlation between Ca and hardness at this station. A strong correlation of calcium with both Ca and total hardness indicates the calcium dominance in constituting hardness. Agra and Kalanaur are the stations where calcium shows a strong correlation with calcium hardness. At Mohana, both divalent cations Ca and Mg show a strong correlation with calcium hardness.

5.4.2 Group 2 Cluster

The parameters in this cluster were chosen with a view to understand which nutrient or indicator of organic pollution, affects DO severely. A negative correlation of DO with BOD, COD is expected. Nutrients like nitrate and phosphate facilitate photosynthetic activity and

algal blooms thereby depleting the DO levels in surface water bodies. Since the solubility of oxygen is reduced with higher temperatures, an inverse relation is expected between the two. But hardly any of the expected correlations were observed in the correlation plots of cluster 2. Even if some correlation was observed, it was localised to some station so no result can be generalised. At some places, weak but significant correlations were observed while at others strong but insignificant correlations were observed.

Temperature and DO are observed to have a weak inverse relation at only the first and last station namely Paonata and Pratappur. Strong but less significant correlation is observed between phosphate and COD at Paonata. Nitrate and phosphate observed to follow a weak inverse relation at Kalanaur whereas significant moderate correlation at Etawah. Nitrate and nitrite are seen to have weak significant correlation at Palla and Hamirpur whereas moderate correlation at Agra. In the absence of inorganic pollution, BOD and COD must be strongly correlated. But a moderate correlation between BOD and COD at Mawi, Delhi and Mohana possibly indicates dominance of industrial pollution in comparison to organic pollution in these areas. In Delhi, phosphate is observed to be moderately correlated with COD. Soaps and detergents being an important source of phosphate, this correlation is indicative of the urban areas responsible for emitting phosphate in the river at Delhi.

5.4.3 Group 3 Cluster

The parameters considered in this cluster were mainly types of hardness and the anions which commonly constitute NCH. Non carbonate hardness was calculated from Total Alkalinity and Total hardness data using the formulae:

$$CH = \min \{TA, TH\}$$

$$NCH = TH - CH$$

CH and TH are observed to have a strong correlation at Paonata, Kalanur, Etawah and Hamirpur. Total Alkalinity and CH showed positive uphill correlation at Mawi and Palla. This absence of NCH indicates that the river water which is used as a source of drinking water supply in this stretch is soft. In general, NCH was not significantly correlated with TH. Out of all anions, NCH shows a strong correlation with sulphate at Paonata and a moderate correlation at Palla. It indicates that wherever NCH is present, sulphate is the prime anion constituting it.

5.4.4 Group 4 Cluster

Fig shows how EC is correlated with other cations and anions. It is obvious for EC and TDS to be strongly correlated with each other but this is observed at only four stations, namely Kalanaur, Palla, Delhi and Mohana. At Palla, almost all cations and anions are strongly correlated with EC. In the middle Yamuna stations from Delhi to Mathura, sodium and bicarbonate is observed to be strongly correlated with EC. Strong correlation of chloride

with EC in the polluted stretch of middle Yamuna is obvious due to large amount of domestic wastes being dumped in the river. Apart from that, magnesium is moderately correlated with EC in middle Yamuna stretch whereas bicarbonate is moderately correlated with EC in the lower Yamuna stretch.

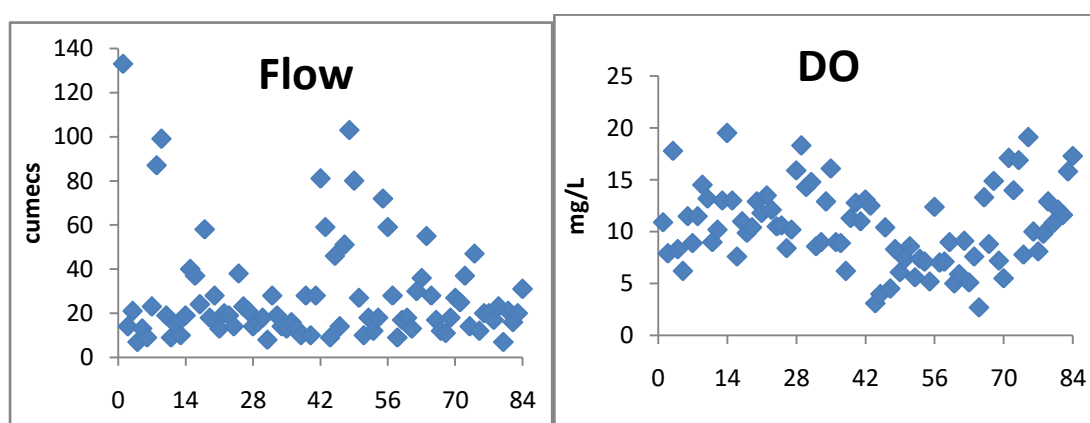
All the cations and anions are moderately correlated with each other at Paonata, Mawi and Hamirpur whereas a strong correlation is observed between them at Palla and Agra. Calcium and sulphate show a strong correlation at Paonata. The cations calcium and magnesium are observed to have moderate correlation with anions bicarbonate and sulphate at most stations. Sodium and chloride are moderately correlated with each other at Mawi while strongly correlated at Agra and Auraiya. This strong correlation is a possible indication of marine contamination in the lower stretches of the river. Chloride and sulphate show a strong correlation at Palla and Auraiya. Chloride is also strongly correlated with Magnesium at Palla and Mathura. Sodium is observed to be strongly correlated with almost all other ions at Palla and Auraiya. At Auraiya, bicarbonate is showing a strong relation with all cations except potassium.

5.5 Study of Biological parameters and Factors Contributing to Organic Pollution

5.5.1 Seasonal Variation of BOD, COD and Pollution Load

0-14	Jan-Feb	43-56	Jul-Aug
15-28	Mar-Apr	57-70	Sep-Oct
29-42	May-Jun	71-84	Nov-Dec

Legend:



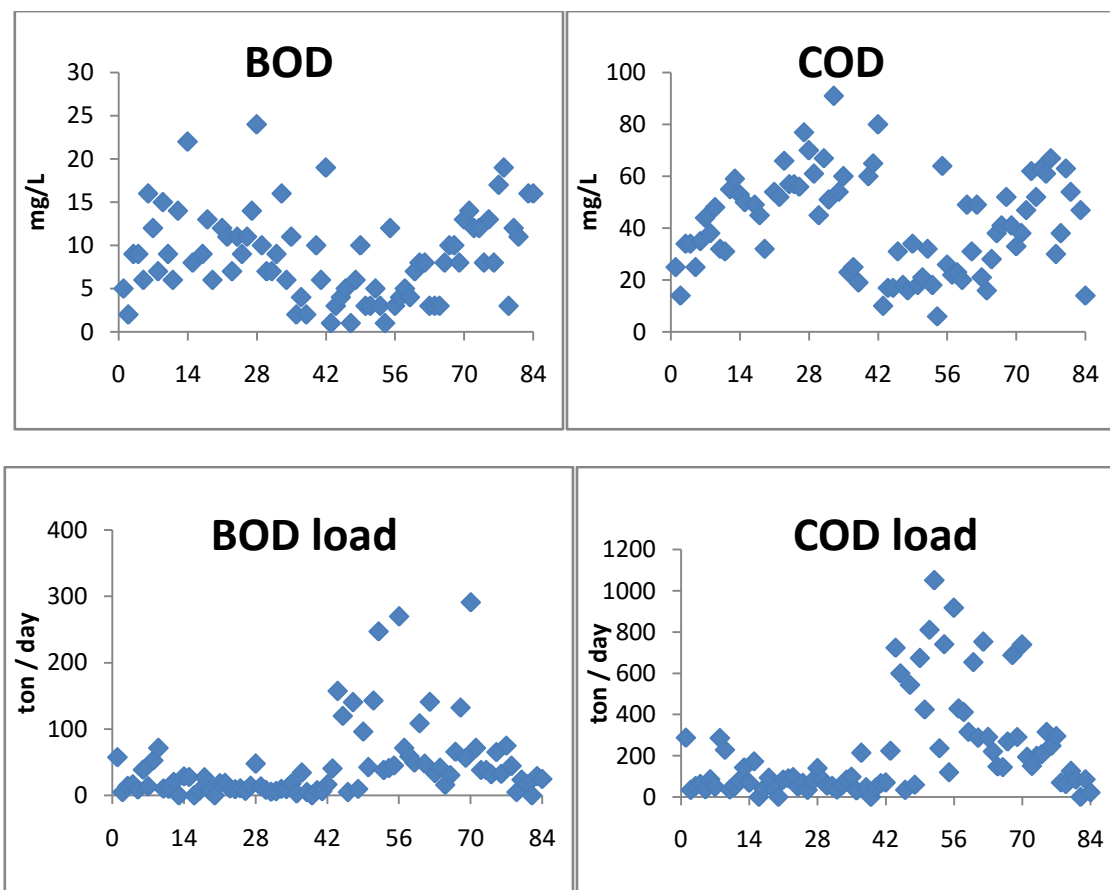


Figure 5.22:Typical Time Series Plots (for Station Etawah)

As observed in Figure 5.22, during the period from July to October, a drop in DO levels is observed. Similar variation is seen at all the stations. At Mathura, no difference between the U/S and D/S levels of DO is observed whereas at Agra, the D/S values are consistently lower than the U/S values. BOD levels are observed to be almost constant in the upper Yamuna stations with values lying between 1-4 mg/L. At Mazawali, Bateswar, Delhi, Agra canal and Etawah, seasonal variation is observed in BOD values, as dilution effect during monsoon might possibly be contributing to the reduced BOD levels. At Mathura, no variation between U/S and D/S BOD is observed while at Agra, D/S values are observed to be consistently higher than the U/S values.

As far as pollution load is considered, sudden increase in BOD and COD load is observed during the months of July-Oct which might be attributed to the increased flow during monsoon. The wastes generated by open defecation and those in the partially flowing drains are unable to reach the river basin during non-monsoon. All the organic load like leaves, vegetation remains accumulated during the non-monsoon period are flushed in the surface water bodies with the monsoon showers. Also, industries which are not allowed to dispose their wastes in rivers during low flow periods store their wastes in huge lagoons and dispose the same in the river bodies at the onset of monsoon. It is due to all these reasons that both BOD and COD load values are affected by flow variation.

High DO values ranging almost up to 20 to 25 mg/L have been reported in the Yamuna river. The high DO values and absence of fish in the middle stretch of river is actually an indication of supersaturated conditions prevailing in the river. It is the presence of photosynthetic activity occurring in the river that is responsible for release of oxygen during the working hours of daytime when DO is actually being measured. Had diurnal sampling being conducted for measuring DO, very low values would have been obtained in the absence of sunlight at night, when algae would emit carbon dioxide in large amounts. So the one time sampling of DO fails to capture the actual state of the river.

Although studies pertaining to photosynthetic activity or diurnal DO variation have not been carried out in the stretch of Yamuna, Tare *et al.* (2003) has analysed the same in Kannauj to Kanpur stretch of river Ganga. Diurnal variation of DO has reported DO concentrations up to 12 mg/L at 4 pm whereas concentrations as low as 4 mg/L at 4 am. The rates of oxygen production in the river have been found to exceed the respiration in the river. So inspite of increased organic loadings received over the years, the river has the potential to maintain fairly constant levels of DO.

BOD is calculated on the basis of how much DO is depleted during a fixed time of five days. It is basically a measure of the oxidation demand exerted by the organic matter present in the sample. BOD is the basis of the biological treatments used in most of the sewage treatment plants. So influent BOD becomes a parameter of great significance in the context of view of choosing a particular source of water for drinking water supply.

However measurement of BOD in a surface water body and judging the condition of river solely on the basis of BOD does not make sense. High values of BOD do not necessarily mean that the river is in a deteriorated state. The micro organisms like algae and bacteria which are responsible for carrying out decomposition of organic wastes also constitute BOD. So BOD is not always toxic. On the contrary, it supports the food chain in river. The surface runoff carried away during monsoon constitutes leaves and vegetation matter which is not harmful but is actually responsible for initiating life forms in river which aid in achieving the self-purification capacity of the river.

5.5.2 Temporal Variation of Coliform

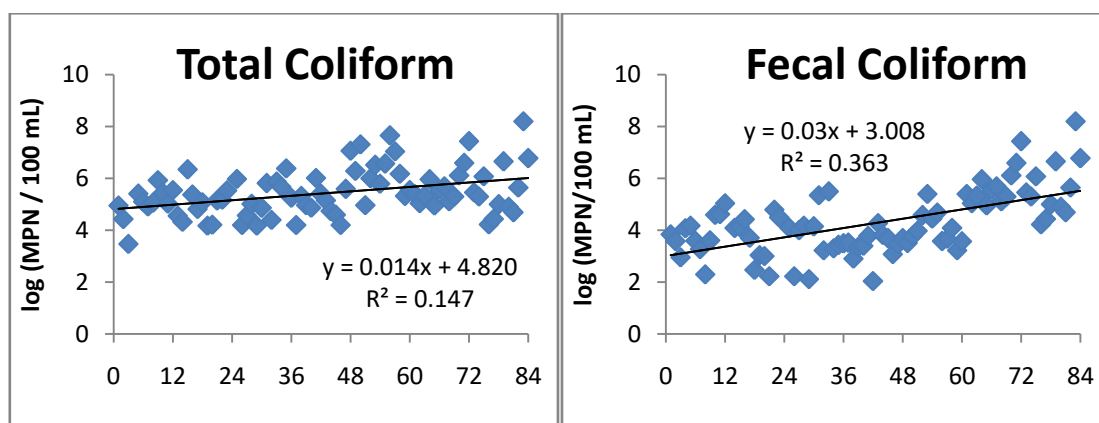


Figure 5.23: Month Wise Time Series Plots of Biological Indicators on Log Scale

The coliform counts are observed to lie in a huge range from hundreds to lakhs. The positive slope of regression line as seen in Figure 5.23 indicates that the coliform count in river has been increasing continuously over the period of seven years. Similar trend has been observed for all other stations. If compared to the standards, total coliform are found to exceed the maximum permissible limit of 5000 MPN per 100 mL in all the stations. 85% of the data points are found to exceed the limit in the upper stretch up to Palla whereas 100% data points lie above the limit from Delhi to Agra. Even after dilution of Chambal, 96% data is observed to exceed the standards at Auraiya. These figures indicate that Yamuna river is not fit for bathing as far as coliform standards are considered. If the standards for faecal coliform are considered, 25-40% data points are observed to exceed the maximum permissible limit of 2500 MPN per 100 mL in the upper stretch of Yamuna. 85-100% faecal coliform outliers are observed in the polluted stretch of Delhi to Agra and after confluence with Chambal, the % outliers drop to 50% at Auraiya. In spite of various human interventions taking place to restore the water quality of the river, there has been a monotonic rise in the coliform count in rivers over the years. This indicates that the action plans have not been successful in achieving the reduction of coliforms.

5.5.3 Spatial Variation of DO, BOD and COD

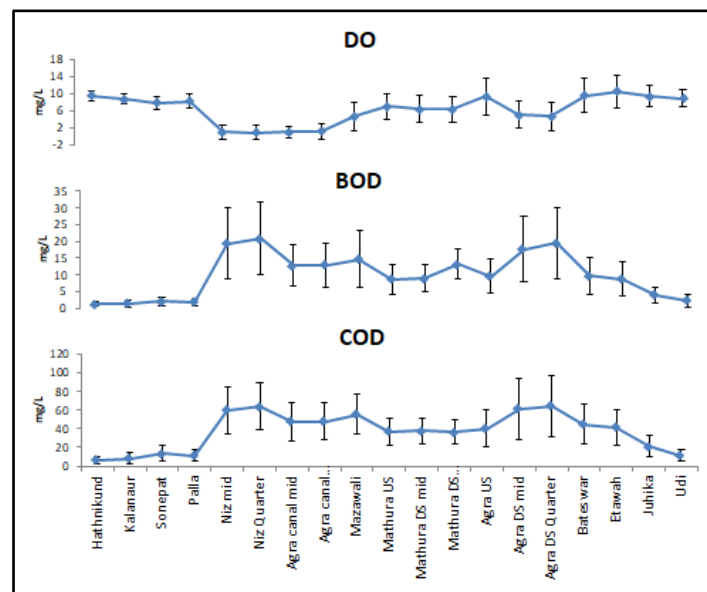


Figure 5.24: Spatial Variation of DO, BOD and COD

The polluted stretch from Delhi to Agra is clearly visible from Fig 5.24. In the middle stretch, the DO values are almost zero and the corresponding BOD values are observed to increase from 3 to 15 mg/L whereas COD values are seen to be rising from around 5 to 60 mg/L as the river enters Delhi after Palla. So if the condition of the river is to be restored, it is this critical stretch between Delhi to Agra which needs to be addressed for policy making.

5.5.4 Trend Analysis

Increasing Trend			No Trend	Decreasing Trend		
0<p<0.001	0.001<p<0.01	0.01<p<0.05	p>0.05	0.01<p<0.05	0.001<p<0.01	0<p<0.001

Legend:

Monsoon						Non Monsoon					
Station	Flow	BOD	BOD load	COD	COD load	Station	Flow	BOD	BOD load	COD	COD load
Kalanaur						Kalanaur					
Palla						Palla					
Niz mid						Niz mid					
Niz Quarter						Niz Quarter					
Mathura US						Mathura US					
Mathura DS mid						Mathura DS mid					
Mathura DS Quarter						Mathura DS Quarter					
Agra US						Agra US					
Agra DS mid						Agra DS mid					
Agra DS Quarter						Agra DS Quarter					
Etawah						Etawah					
Juhika						Juhika					
Udi						Udi					

Figure 5.25: Trend Analysis Results

Monsoon flow is observed to reduce over the span of seven years from 1999-2005. There is no change in BOD concentration as well as BOD load during monsoon. The reduced flow in lean season from Mathura onwards is reflected in reduced BOD load. From Mathura onwards, COD concentration is following a decreasing trend in monsoon whereas an increasing trend is observed in non-monsoon. COD load is mostly showing no significant change except for a reducing trend in lean season from Agra to Auraiya . As load is significantly affected by flow values, reducing flow should have resulted in reducing BOD load. No change indicates slight increase in BOD concentration, but that is not reflected in the BOD trend. From Mathura to Juhika, an increase in COD concentration is observed during the lean season, which might be attributed to the increasing industrial pollution from the industrial sectors in the urban areas of Delhi, Mathura and Agra

5.5.5 Correlation of DO vs BOD

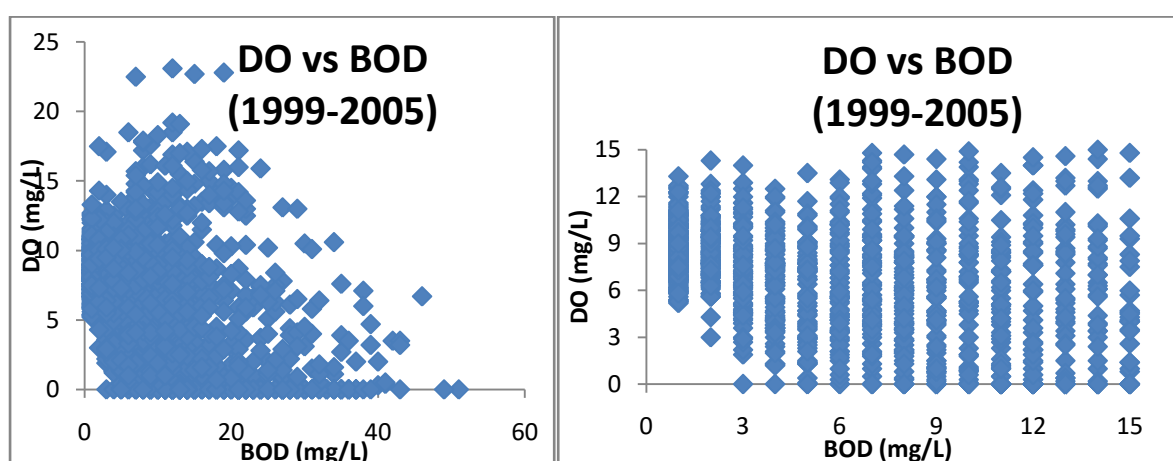


Figure 5.26: Correlation Plots of DO vs BOD (different scales)

Table 5.9: No. of Samples and Correlation Coefficients for DO vs BOD Paired Data

LEGEND	Sr	Station	n	r	Sr	Station	n	r
	1	Hathnikund	84		10	Mathura US	82	
$p > 0.05$	2	Kalanaur	84		11	Mathura DS mid	80	
$0 < r < 0.5$	3	Sonepat	83		12	Mathura DS Quarter	80	
$0.5 < r < 0.7$	4	Palla	83		13	Agra US	81	
$0.7 < r < 1$	5	Niz mid	68		14	Agra DS mid	82	
	6	Niz Quarter	80		15	Agra DS Quarter	81	
$p > 0.05$	7	Mazawali	81		16	Bateswar	83	
$0 < r < 0.5$	8	Agra canal mid	80		17	Etawah	79	
$0.5 < r < 0.7$	9	Agra canal Quarter	81		18	Juhika	82	
$0.7 < r < 1$								

At Palla, Mathura, Agra, Bateswar and Etawah, DO-BOD show a positive but weak correlation. Only at Nizamuddin and Agra, inverse weak correlation is observed between DO-BOD. It is observed that throughout the stretch of river, no uniformity is observed in the nature of correlation between DO and BOD values. This lack of correlation shows that BOD removal does not ensure increase in DO

levels. Poor DO levels might be attributed to other water quality parameters such as nitrates or phosphates prevalent in the surface water.

5.5.6 Correlation of TC vs FC

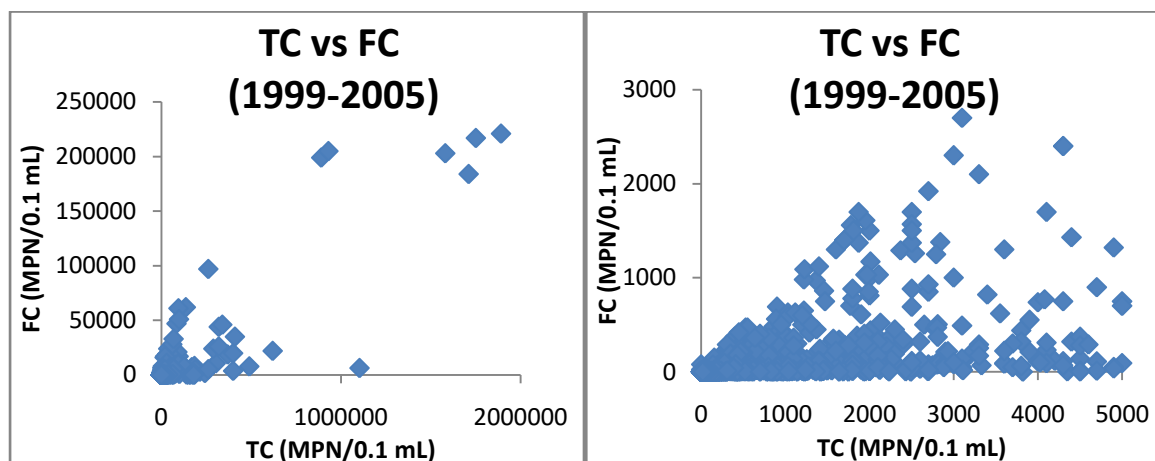


Figure 5.27: Correlation Plots of TC vs FC (different scales)

Table 5.10: Number of Samples and Correlation Coefficients for TC vs FC Paired Data

LEGEND	Sr	Station	n	r	Sr	Station	n	r
	1	Hathnikund	79		10	Mathura US	82	
$p > 0.05$	2	Kalanaur	78		11	Mathura DS mid	82	
$0 < r < 0.5$	3	Sonepat	80		12	Mathura DS Quarter	82	
$0.5 < r < 0.7$	4	Palla	82		13	Agra US	82	
$0.7 < r < 1$	5	Niz mid	69		14	Agra DS mid	81	
	6	Niz Quarter	81		15	Agra DS Quarter	81	
$p > 0.05$	7	Mazawali	82		16	Bateswar	82	
$0 < r < 0.5$	8	Agra canal mid	83		17	Etawah	81	
$0.5 < r < 0.7$	9	Agra canal Quarter	83		18	Juhika	81	
$0.7 < r < 1$								

With the exception of Hathnikund, all areas upstream of Delhi and downstream of Agra show an insignificant correlation between TC and FC, indicating the absence of faecal coliform in TC. So TC might mainly be constituted by other natural sources such as animal wastes in these stretches. A strong correlation between TC and FC in Delhi to Agra stretch indicates that it is FC which mainly constitutes TC. The highest correlation is observed at Delhi ($0.92 < r < 0.94$) which is gradually reduced from Delhi to Agra. This high correlation of TC and FC is undesirable for any beneficiary use of water. It is important to take measures to reduce the coliform counts. The focus of treatment should be shifted from BOD to coliform in this highly polluted stretch.

5.5.7 Correlation of Coliform vs BOD

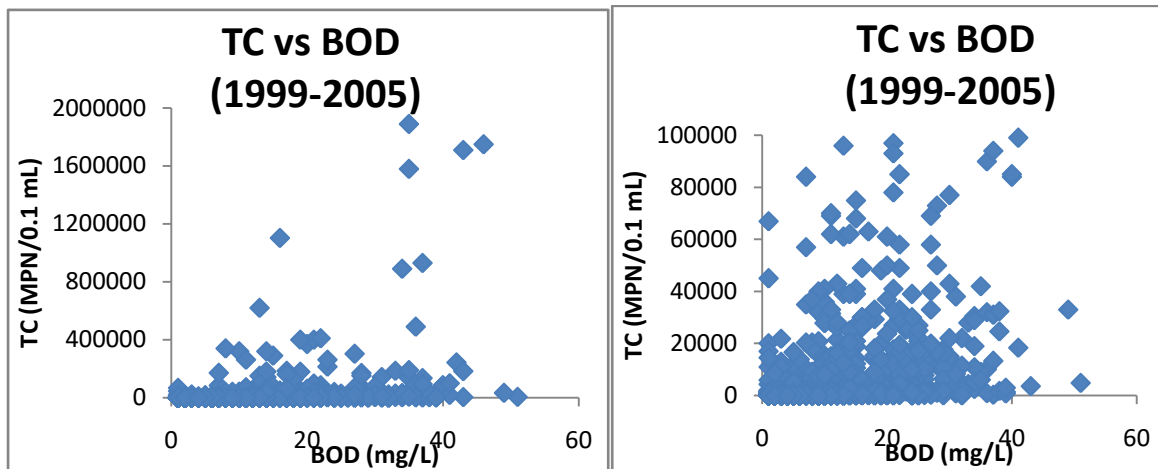


Figure 5.28: Correlation Plots of TC vs BOD (different scales)

Table 5.11: No. of Samples and Correlation Coefficients for TC vs BOD Paired Data

LEGEND		Sr	Station	n	r	Sr	Station	n	r
	$p > 0.05$	1	Hathnikund	80		10	Mathura US	81	
	$0 < r < 0.5$	2	Kalanaur	79		11	Mathura DS mid	80	
	$0.5 < r < 0.7$	3	Sonepat	81		12	Mathura DS Quarter	82	
	$0.7 < r < 1$	4	Palla	83		13	Agra US	80	
		5	Niz mid	68		14	Agra DS mid	82	
	$p > 0.05$	6	Niz Quarter	80		15	Agra DS Quarter	82	
	$0 < r < 0.5$	7	Mazawali	82		16	Bateswar	83	
	$0.5 < r < 0.7$	8	Agra canal mid	83		17	Etawah	77	
	$0.7 < r < 1$	9	Agra canal Quarter	83		18	Juhika	82	

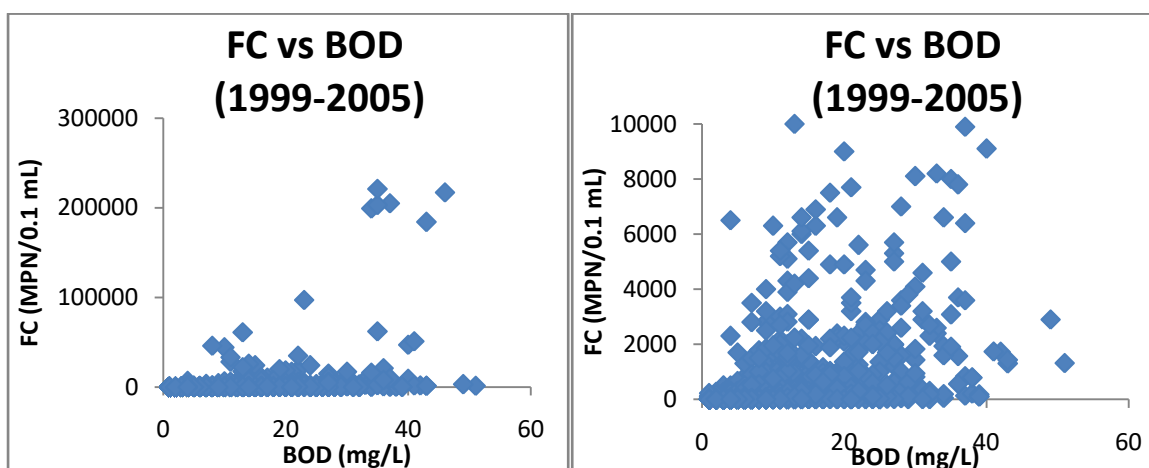


Figure 5.29: Correlation Plots of FC vs BOD (different scales)

Table 5.12: No. of Samples and Correlation Coefficients for FC vs BOD Paired Data

LEGEND	Sr	Station	n	r	Sr	Station	n	r
	1	Hathnikund	80		10	Mathura US	82	
$p > 0.05$	2	Kalanaur	79		11	Mathura DS mid	80	
$0 < r < 0.5$	3	Sonepat	80		12	Mathura DS Quarter	82	
$0.5 < r < 0.7$	4	Palla	81		13	Agra US	81	
$0.7 < r < 1$	5	Niz mid	67		14	Agra DS mid	82	
	6	Niz Quarter	79		15	Agra DS Quarter	81	
$p > 0.05$	7	Mazawali	81		16	Bateswar	82	
$0 < r < 0.5$	8	Agra canal mid	82		17	Etawah	77	
$0.5 < r < 0.7$	9	Agra canal Quarter	82		18	Juhika	82	
$0.7 < r < 1$								

In general, as depicted from Table 5.11 and 5.12, BOD is not significantly correlated with either TC or FC. Only at Hathnikund, Agra Canal and Agra downstream, a weak but significant correlation is observed. This indicates that, neither do coliforms affect the BOD in any manner nor the reduction of BOD ensures reduction in coliform counts. These are two independent parameters which must be dealt independently.

5.5.8 Correlation Results of CWC Data

Similar correlation was studied between the four pairs based on CWC data which are presented in Figure 5.30 below.

LEGEND		CWC Data		DO vs BOD		TC vs FC		TC vs BOD		FC vs BOD	
		Sr	Station	n	r	n	r	n	r	n	r
	p > 0.05	1	Paonata	Insufficient data		26		Insufficient data		Insufficient data	
	0 < r < 0.5	2	Kalanaur	Insufficient data		42		Insufficient data		Insufficient data	
	0.5 < r < 0.7	3	Mawi	150		70		72		60	
	0.7 < r < 1	4	Palla	75		70		58		58	
		5	Delhi	79		54		122		54	
		6	Mohana	135		45		89		48	
		7	Mathura	274		65		207		65	
	p > 0.05	8	Agra	Insufficient data		Coliform data not available					
	0 < r < 0.5	9	Etawah	54							
	0.5 < r < 0.7	10	Auraiya	225							
	0.7 < r < 1	11	Hamirpur	Insufficient data							
		12	Pratappur	92							

Figure 5.30: Correlation Results Based on CWC Data

Similar results are observed in both cases. Only at Delhi, Mohana and Mathura stations, significant but weak inverse correlation exists between DO and BOD. Insignificant correlation is observed between DO and BOD at all other stations. TC vs FC show strong correlation, of high significance at all stations. At upper Yamuna stations namely Kalanaur and Palla, CPCB data has not shown significant correlation between TC and FC whereas CWC data shows strong positive correlation. This might be due to the different timelines for both data sets. It might be possible that till 2005, FC did not constitute TC in the upper Yamuna stations whereas recently the increasing pollution has reported increasing FC as part of TC. BOD is not significantly correlated with either of TC or FC, except

at Mathura, where they are weakly associated. This indicates that though BOD concentrations are to an extent responsible for depleting the DO levels in the river, it is NOT the only parameter affecting DO. Biological parameters especially faecal coliform is important from the point of view of pollution.

5.6 Effect of Anthropogenic Influence on River Yamuna

5.6.1 Trend Analysis Discussion on Load vs Concentration

Increasing Trend			No Trend	Decreasing Trend		
0<p<0.001	0.001<p<0.01	0.01<p<0.05	p>0.05	0.01<p<0.05	0.001<p<0.01	0<p<0.001

The results of M.K. trend tests are represented on the basis of their significance values. The increasing and decreasing trends are represented by warm and cool colours, the intensity of colour being proportional to the level of significance.

	Paonata				Kalanaur				Mawi				Palla			
Season	Monsoon		Non monsoon		Monsoon		Non monsoon		Monsoon		Non monsoon		Monsoon		Non monsoon	
Type	conc	load	conc	load	conc	load	conc	load	conc	load	conc	load	conc	load	conc	load
Flow																
Potassium																
Sodium																
Calcium																
Magnesium																
Bicarbonate																
Chloride																
Fluoride																
Sulphate																
Nitrate																
Phosphate																
Silicate																
Boron																

Figure 5.31: Trend Analysis of Load vs Concentration for Upper Yamuna

Monsoon flow is observed to increase only at Paonata but no change is observed at further stations. Non-monsoon flow is observed to reduce at Paonata but increase at Palla. Magnesium, bicarbonate, chloride, phosphate and silicate are seen to reduce in almost the entire upper Yamuna stretch. Nitrate concentration at Kalanaur is seen to have an increasing trend throughout the year. The non-monsoon load at Palla is showing an increasing trend for all parameters, which might possibly be attributed to increased wastewater flow discharged in the river during lean season. Boron concentration at Kalanaur is observed to increase throughout the year, which might possibly be due to mining activities carried out in the nearby areas.

	Delhi				Mohana				Mathura				Agra			
Season	Monsoon		Non monsoon		Monsoon		Non monsoon		Monsoon		Non monsoon		Monsoon		Non monsoon	
Type	conc	load	conc	load	conc	load	conc	load	conc	load	conc	load	conc	load	conc	load
Flow																
Potassium																
Sodium																
Calcium																
Magnesium																
Bicarbonate																
Chloride																
Fluoride																
Sulphate																
Nitrate																
Phosphate																
Silicate																
Boron																

Figure 5.32: Trend Analysis of Load vs Concentration for Middle Yamuna

It can clearly be observed that for the entire middle stretch, non-monsoon flows are increasing. Moreover, these increased flows are not contributing to reduced concentration or loads indicating absence of dilution effect. Hence it is wastewater finding its way in the river during non-monsoon period that is showing an increase in flow. For majority cases, trends in concentration and loads are observed to be the same, indicating that it is concentration which is affecting the pollution load. Relatively, Delhi and Agra are the stations where almost all parameters show an increase in concentration and pollution load during non-monsoon season.

	Etawah				Auraiya				Hamirpur				Pratapapur			
Season	Monsoon		Non monsoon		Monsoon		Non monsoon		Monsoon		Non monsoon		Monsoon		Non monsoon	
Type	conc	load	conc	load	conc	load	conc	load	conc	load	conc	load	conc	load	conc	load
Flow																
Potassium																
Sodium																
Calcium																
Magnesium																
Bicarbonate																
Chloride																
Fluoride																
Sulphate																
Nitrate																
Phosphate																
Silicate																
Boron																

Figure 5.33: Trend Analysis of Load vs Concentration for Lower Yamuna

Etawah and Auraiya are the worst affected stations as far as pollution load of all chemical parameters is considered. It is only after the Yamuna traverses a significant distance after its confluence with Chambal that its dilution effect is visible. This is because the nutrient loads are observed to reduce only at Hamirpur, and not Auraiya. Monsoon flow is observed to decrease at Pratappur.

5.6.2 Temporal Variation of Heavy Metals

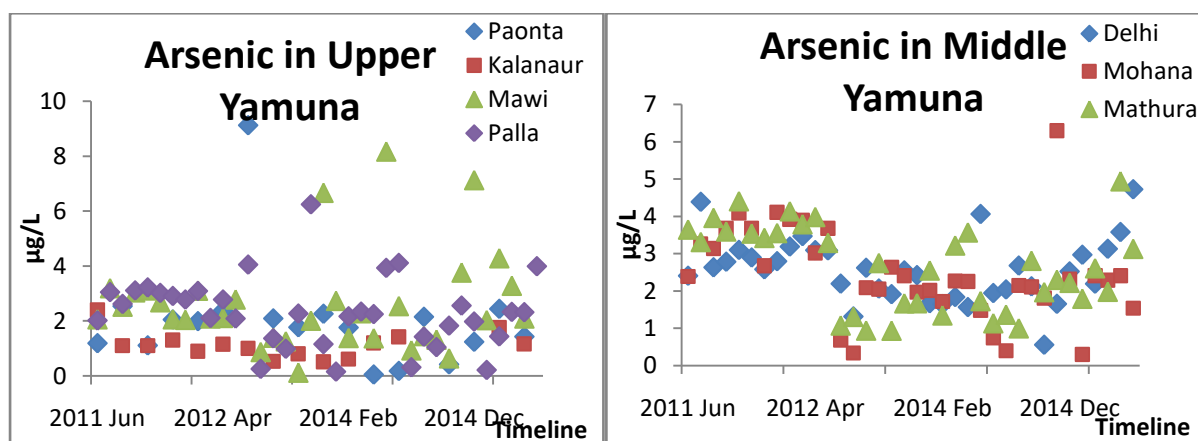


Figure 5.44: Temporal Variation of Heavy Metals (Arsenic)

- Relatively, arsenic pollution is observed to increase in Mawi and Palla from 2014. Temporal variation of arsenic concentration is seen to follow similar trends in all three middle Yamuna stations.
- Cadmium concentrations are found to be below 5 µg/L in all seven stations. High cadmium concentrations up to 35 µg/L are observed at Kalanaur, possibly due to the presence of electroplating industries in the catchment area of Kalanaur. In the middle Yamuna stretch, cadmium concentrations are observed to rise suddenly to 8 µg/L during two specific times (May-July 2013 and 2014).
- The average chromium concentration at Kalanaur (6-7 µg/L) is almost thrice the average concentration at Palla (1-2 µg/L). In the middle Yamuna stretch, similar trend is observed for all stations, with chromium concentrations lying between 2-6 µg/L.
- The copper concentrations at Mawi and Palla in upper Yamuna stretch from 2013 are seen to be increasing beyond 5 µg/L. Copper concentrations in middle Yamuna till 2013 are observed to be clustered around 5 µg/L. However since Oct 2013, copper concentrations going up to 15 µg/L are observed in the river stretch.
- Mercury concentrations are mainly monitored during the monsoon year 2015-16 and it is observed to lie in the range of 1 to 15 µg/L.
- Lead concentrations are found in negligible amounts, generally below 5 µg/L. However some outliers are observed from Mawi to Mathura during lean flow season of winter in 2013 and 2014.
- For the upper Yamuna stretch, zinc concentrations are observed to be increasing continuously over the short span of 4 years. From 1 µg/L in 2011, concentrations up to 25 µg/L are reached till 2015. For the middle Yamuna stretch, zinc concentrations are observed to lie below 5 µg/L till 2013 after which, they are found to increase.

5.6.3 Concluding Remarks on Heavy Metal Contamination

Maximum concentrations of heavy metals in the middle Yamuna stretch are found to occur in Mohana. If the entire stretch is considered, upper Yamuna stations especially Kalanaur, is found to have metal concentrations greater than Mohana. This indicates the rise of industrial belts in upper Yamuna catchment areas as well.

In general, there is a great variability in the occurrence of heavy metals in the river basin. But nowhere the concentrations are found to exceed the permissible limits for drinking water. They are well within the limits. As stated in the report (CPCB, 1978), no trace of heavy metals was observed in Yamuna basin in 1978. The point of concern is that within a span of 35 years, heavy metals are observed in detectable ranges and are even observed to increase with time. This calls for preventive and control measures which need to be taken to avoid the heavy metal concentrations crossing the permissible limits in the coming years.

5.6.4 Seasonal Variation of Heavy Metals

Parameter/Station	Paonta	Kalanaur	Mawi	Palla	Delhi	Mohana	Mathura
Arsenic			No	No	No	No	No
Cadmium			Yes	No	No	Yes	No
Chromium			No	No	No	No	No
Copper			No	No	No	No	No
Lead			No	No	No	No	No
Mercury				Yes	Yes	Yes	No
Zinc				No	No	No	No

Figure 5.55: Seasonal Variation by One Way ANOVA for Heavy Metals

One way ANOVA analysis was done for heavy metals based on 5 season variation. The results show insignificant variation among seasons. Bhardwaj *et al.* (2017) has studied the seasonal variation for three seasons and reported the order in which heavy metals vary as:

Pre monsoon > Monsoon > Post monsoon

Seasonal variation considering the same three seasons as above was also studied for CWC data. Mercury concentrations in pre-monsoon were observed to be higher than post-monsoon always, but the monsoon values are observed to be the least at Palla and greatest in Delhi and Mohana. For all other parameters no critical season was observed in particular. This indicates the random occurrence of heavy metals in the river and that the concentrations are not affected by seasonal flows. This is a clear sign of anthropogenic pollution.

5.6.5 Correlation between Heavy Metals

Heavy	Metal	Pairs	Paonata	Kalanaur	Mawi	Palla	Delhi	Mohana	Mathura
moderate	0.5-0.7	+		Cd-Cu	Cd,Cu-Cr; As-Pb	Cd-Cr,Zn	As-Hg	Cr-Hg	
strong	0.7-1	+	Cr,Cu-Hg	Pb-Hg-Zn				Cd-Hg	
moderate	0.5-0.7	-					Cd,Zn-Hg; Cr-Zn		As-Zn

Figure 5.56: Correlation between Heavy Metals

Cadmium chromium show moderate correlation in Kalanaur, Mawi and Palla. Arsenic and zinc are moderately correlated at Mathura. Cadmium and mercury show inverse moderate correlation with each other in Delhi but show strong positive correlation in Mohana. Chromium and mercury show strong and moderate correlation at Paonata and Mohana. Zinc and mercury show inverse moderate correlation with each other in Delhi but show strong positive correlation in Kalanaur. No pair of heavy metal showing is showing uniform correlation throughout a particular stretch which indicates a variation in the sources of heavy metals at all stations.

Based on the results of Pearson correlation and principal component analysis, two main groups namely Ni, Zn, Cd, Fe, Cd and Cu, Cr have been reported to have the same sources but CWC data for Delhi does not report a significant correlation. Cadmium and zinc show a significant correlation of 0.521 (Bhardwaj *et al.*, 2017) and 0.404 (CWC). Lead is seen to be moderately and weakly correlated to zinc and cadmium (Bhardwaj *et al.*, 2017) but CWC data reports insignificant correlation between the two pairs.

Since copper, chromium, cadmium and zinc are associated with electroplating industries, significant correlation between these metals from Kalanaur to Delhi indicate the presence of electroplating industries in these regions. The significant correlation between cadmium and chromium at Mawi and Delhi can be traced back to manufacture of paints.

5.6.6 State of Yamuna as a River for Beneficiary Uses

Table 5.9 Classes of Water Use

Class	Classes of Water Use
A	Drinking water source without conventional treatment but after disinfection
B	Outdoor bathing
C	Drinking water source with conventional treatment but after disinfection
D	Propagation of wild life, fisheries
E	Irrigation, industrial cooling, controlled waste disposal

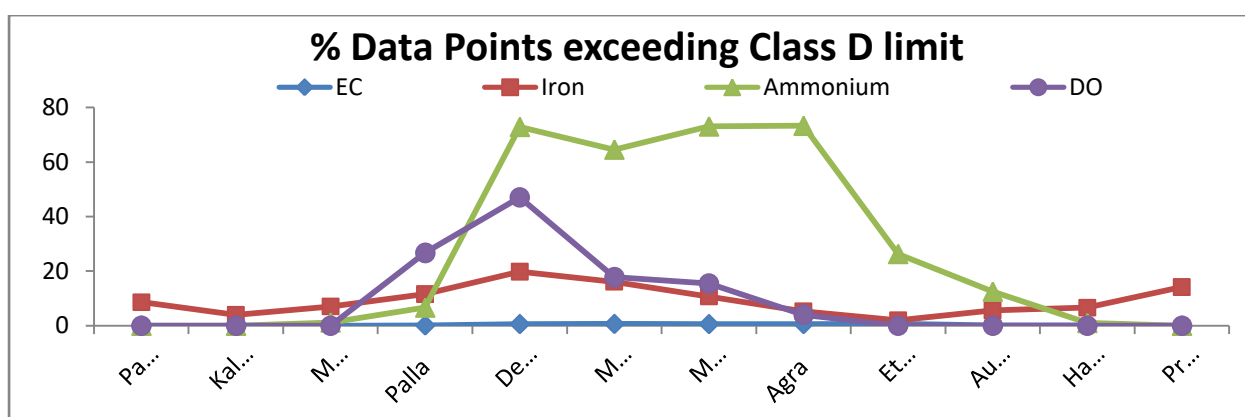
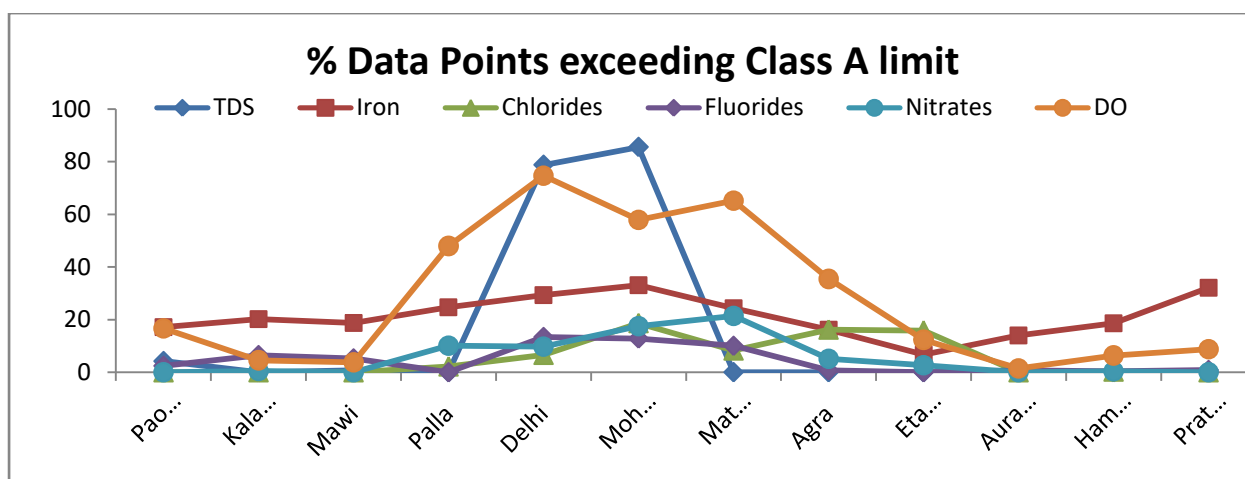


Figure 5.57: % Data Points Exceeding Permissible Limits for Classes A and D

Table 5.10: % Data Points exceeding Surface Water Standards for DO

DO	Delhi	Mohana	Mathura	Agra
% Outliers	54	37	32	0.1

From Figure 5.57 it is clearly seen that the middle stretch of Yamuna has maximum number of outliers as far as the parameters DO and TDS are concerned. River at Palla is used as drinking water supply for capital city of Delhi, but for the further cities Agra and Mathura, river downstream of Delhi becomes the raw water supply source. This is not suitable for use as far as class A is considered. Even if class C limits are considered, significant outliers are observed for the parameter DO. This means that even after conventional treatment is resorted to, the water is not suitable for consumption. The water quality is deteriorated to an extent that bringing it to desirable state of consumption has become highly uneconomical. If Class D is considered, the middle stretch is highly critical from the point of view of DO and ammoniacal nitrogen. The survival of fish is very critical with respect to ammonia concentrations in rivers. Almost up to 70% data points are found to exceed the permissible limit for fisheries indicating that survival of fish is difficult in this middle stretch.

BOD is observed to be the parameter which is found to exceed the permissible limit of surface standards very often. Except for Agra, around 96% data points exceed 3 mg/L in Delhi to Etawah stretch. The average BOD concentration is nearly 12 times higher than the limit in Agra, 8-9 times higher in Mohana and Mathura and 4-5 times higher in Agra and Etawah. The river condition at Delhi is also critical w.r.t. DO where the average concentration is less than 4 mg/L and 54% data points lie below the limit.

5.6.7 Effect of Yamuna Action Plan on Four Parameters DO, BOD, Nitrate and Phosphate

The Yamuna Action Plan, which was initiated in 1993 mainly targeted at trapping and cleaning the open drains and setting up decentralized sewage treatment plants in order to clean the sub drains. Dredging was carried out in the 22 km of polluted stretch of Yamuna bed. Laying of sewers was undertaken in the un-sewered areas to facilitate a better infrastructure. With a view of developing the polluted stretch of drains into recreational public spaces, bioremediation techniques were adopted. These mainly included storm water management and practicing rain water harvesting, facilitating aquatic biodiversity wetlands and slope stabilization techniques to reduce siltation along the river. BOD was the parameter targeted in action plans to restore the condition of the river.

Table 5.11: Timeline of Yamuna Action Plan

Time Zone	Years considered	Significance
1	1978 to 1993	Prior to Implementation of YAP
2	1994 to 2003	YAP Phase 1
3	2004 to 2012	Completion of YAP Phase 1 and Phase 2 in progress
4	2013 to 2015	Completion of YAP Phase 2 and Phase 3 in progress

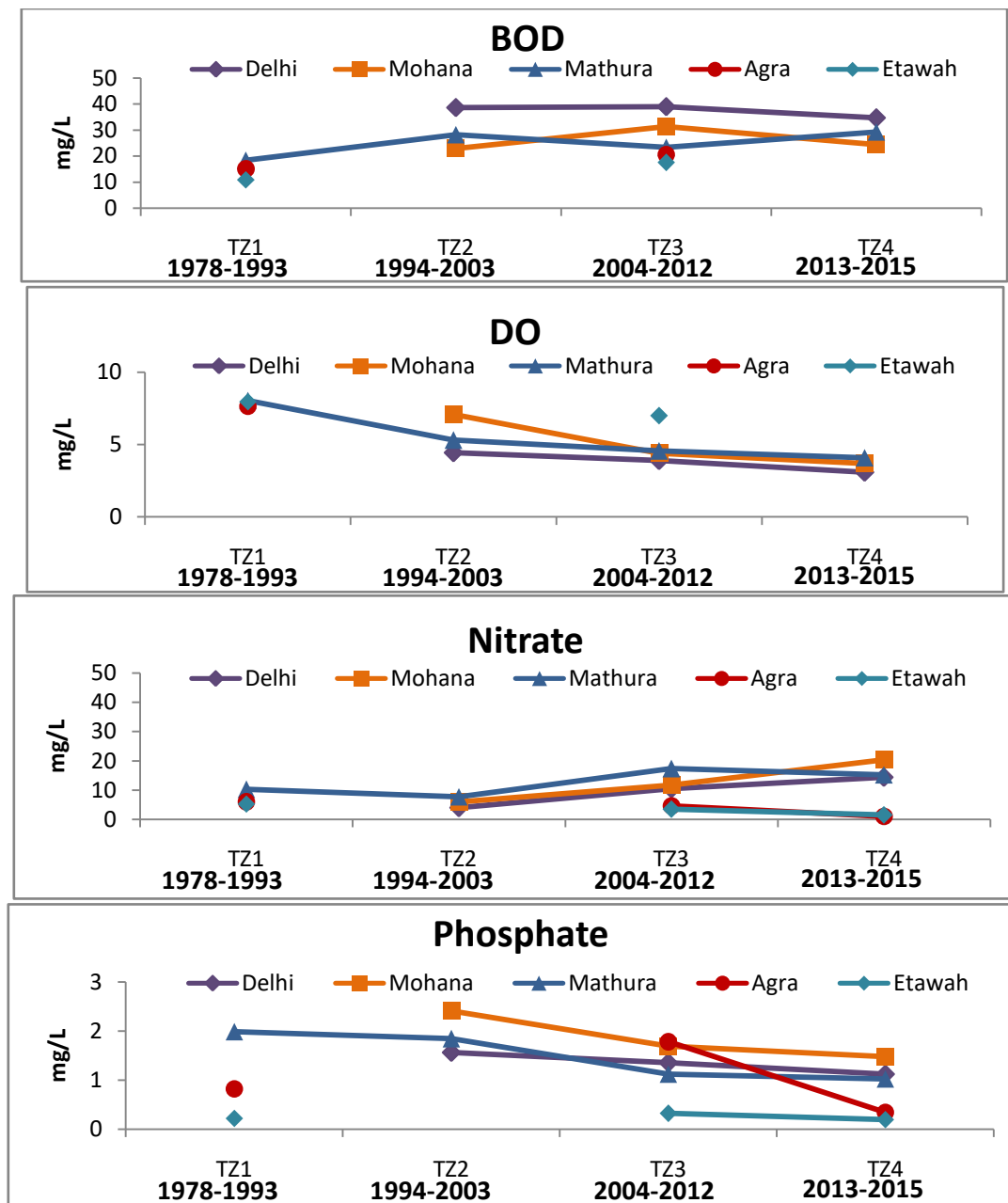


Figure 5.58: Effect of Yamuna Action Plan on Parameters DO, BOD, N and P

Inspite of BOD being the targeted parameter for all action plans, it remains to be the most violating parameter as far as permissible limits for surface water are considered. YAP has targeted removal of BOD, which is seen to have reduced, but still it does not meet the surface water standards. The important question is whether BOD should actually be the basis for deciding the condition of river. DO levels in Delhi to Mathura are poor so along with BOD, the focus should also be to improve the DO levels in surface water which will ensure life in this stretch of dead river. It should be realized that if increased DO levels are achieved, it will ensure reduced concentrations of BOD, nitrate and phosphate.

- Literature reporting BOD not basis of surface water bodies in foreign countries

YAP has not been completely successful in its objective of improving the water quality of the river mainly because it has targeted a single and possibly the wrong parameter in framing the policies. Since water quality is a complex phenomenon which is interdependent on many parameters, it is actually the combined interaction of parameters like DO, BOD and various forms of nitrogen that decide the condition of river. It is observed that the condition of river between Delhi to Agra remains worst affected in terms of the two parameters – nitrate and DO. Nitrate concentration is seen to be increasing whereas DO levels continue to drop low in spite of the implementation of Yamuna Action Plan.

Presence of nitrates in surface water body is actually good as it is an indication of autotrophic condition of river. In the absence of autotrophic conditions, there would be no life in the river. It is increasing ammonical nitrogen that is actually responsible for heterotrophic condition of the river. So increasing nitrate is favourable as long as the river is in an active state i.e. it has significant amount of flow which is free from algal blooms and water hyacinth.

But the point of concern is that the stretch of river from Delhi to Agra is devoid of fresh water in the lean season. The river is almost in a stagnant state throughout the year. In these circumstances, even slight increase in nitrate and phosphate concentrations might be responsible for causing eutrophication. So the nutrient standards need to be revised to shift the treatment focus to nitrate and phosphate, especially in the stretch of no flow conditions.

6. CONCLUSION

6.1 Significance of Study

In March 2003, Delhi High Court ordered government bodies to clear banks of river Yamuna. Action was taken against dairy industries and electroplating and dye units. But they protested that it is not industrial waste but the cluster of 22 slums which was primarily contributing to domestic water pollution in Yamuna. Even though activists came up with statistics showing that pollution from slums constitutes even less than 1% of the domestic wastewater, it resulted in the clearance of slums. (Sharan, 2016) This incident shows that, in order to frame policies, it is important to correctly identify the main cause of pollution. Accurate source apportionment based on a holistic approach is the need of the day.

- The basis of all treatment initiated in Yamuna Action plan was based on BOD removal. (Sharma & Kansal, 2010) All efforts have been taken and money has been spent with the focus of achieving high BOD removal efficiency. But BOD solely is not the parameter that constitutes the water quality of rivers. It is not one parameter which decides the fate of water quality but the overall interaction between various

water quality parameters that governs the ultimate quality of water. So surface water bodies must be studied from this broad perspective for effective policy making.

- DO should be the parameter targeted for river action plans in order to restore life in the dead stretch of middle Yamuna. Diurnal measurement of DO should be practiced instead of single daytime measurement, which will help in understanding the actual state of the river.
- There are many outfalls letting in domestic sewage and industrial effluents directly in the river. The Najafgarh and Shahdara drains are the primary contributors to the deteriorated condition of Yamuna in Delhi. These drains must be targeted for improving the condition of river. Responsibility of ensuring clean drains must be taken by organizations.
- Structural interventions abstracting freshwater from the river have obstructed the natural flow of the river, resulting in the middle Yamuna stretch being almost devoid of freshwater. So policies should be made to reduce the amounts of freshwater abstracted from rivers directly. This will ultimately force the industries to reuse and recycle the generated wastewater. It will ensure adequate flows in rivers thereby improving condition of river near the capital city.
- The stagnant condition of river from Delhi to Agra makes it prone to eutrophication. Excess of nutrients act like drugs to a stagnant river. Once algal blooms especially water hyacinth finds its way in the river, it becomes very difficult and highly uneconomical to remove it due to their exponential increase. Economics of nutrient removal in wastewater vs costs incurred in removal of algal blooms should be studied. This will provide an economic basis to initiate tertiary treatment.
- Decentralized wastewater treatment plants must be set up in the 22 km polluted stretch of Delhi. This will ensure reduced pollution load in river.

6.2 Limitations of Study

- Lot of intermittency was observed in the data available. This is a major limitation of a huge dataset. Had the data been continuous, the trend test results would have been more accurate.
- The outliers were observed manually and removed. There might be a chance of omission of actual data or retention of false data due to this.

6.3 Comments on CWC Data

- Absence of uniformity in maintaining the data results in errors in handling the data. A standard format should be devised and used by all laboratories for entering the experimental observations and final calculations. This will also make the analysis very efficient and nearly free from manual errors.

- Coliform and heavy metal data is not available for lower Yamuna stations. These parameters being of prime importance must be monitored regularly.

6.4 Future Scope

- Having the critical stretches been identified, high frequency sampling must be resorted to in the stretch from Delhi to Agra. This will help in understanding the diurnal variations in water quality and will bring out the real sources of pollution.
- Diurnal DO variation studies have not been conducted in Yamuna. These must be adopted in middle Yamuna stretch.
- The detailed water quality analysis of tributaries must be done. The analysis of the entire river basin as a whole will help in better interpreting the causes of pollution.
- CPCB measures only AN and TKN whereas CWC measures nitrate, nitrite and occasionally AN and TN. The pollution status of river can better be understood if all forms of nitrogen are measured.
- Yamuna river has become a victim of sand mining. Analysis of water quality parameters like turbidity and suspended solids must be done to understand effects of sand mining on suitability of river for irrigation.
- To prevent eutrophication conditions, it is important to limit the nutrients coming in the river. Fertilisers and manures used in agriculture and synthetic detergents being the major source of nitrates and phosphates, it is important to frame policies to reduce the nitrogen and phosphorus used in manufacturing these products.