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WATER QUALITY PARAMETERS OF RIVER YAMUNA IN DELHI AFTER 20 YEARS OF THE YAMUNA ACTION PLAN

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ABSTRACT
The present study was conducted to evaluate selected water quality parameters of the river Yamuna along the Delhi segment. The samples were collected from 12 selected locations at three different periods, *viz*., pre-monsoon (June), post-monsoon (October), spring (February) in 2013 and 2014 and were analysed for pH, dissolved oxygen (DO), biochemical oxygen demand (BOD) and chemical oxygen demand (COD). The pH was in the range of 7.17 to 8.30. The highest DO was 8.55 mg/l at site 1 while it was nil for most of the studied locations. The BOD and COD were 2 mg/l and 20 mg/l respectively for site 1 where as the maximum values were 58.2 mg/l and 260 mg/l respectively for site 5. The surface water quality was better in the sites where the river enters into the Delhi stretch before the Wazirabad barrage while the river becomes severely polluted after the discharge of Najafgarh drain into it. Overall the level of pollution was slightly lower after the monsoon. Correlations regression study revealed strong correlation between pH, DO, BOD and COD.

KEYWORDS: Correlations Regression, Pollution, Seasonal variations, Water quality, Yamuna River.

INTRODUCTION
The river Yamuna originates from the Yamunotri glacier, situated near Banderpoonch peak ($38^0 59'$ N, $78^0 27'$ E) in the Mussorrie range of lower Himalayas at an elevation of 6,320 msl in the Uttarkashi district of Uttarakhand. It is a major tributary of river Ganga and travels through 7 states covering a distance of 1376 kilometers before merging. It is considered that approximately 57 million people depend on the river for their regular basic needs (CPCB, 2006). Delhi constitutes less than 1% of the total catchment of Yamuna but contributes more than 50% of the total pollutant load which is discharged into the river over the urban stretch of 22 km between Wazirabad and Okhla barrages (MOEF, 2013). Quite frequently the rivers and streams have been treated as a convenient dumping and discharge site for various industrial and municipal wastes degrading water quality status that adversely affects the human health and aquatic biota to a great extent (Singh *et al.,* 2007; Paul *et al.,* 2014). The industrial effluents, domestic wastes, urban and agriculture runoff are full of suspended solids, coloured wastes, toxic substances and organic matter (Kaushik *et al.,* 2008; Suthar *et al.,* 2009; Mishra *et al.*, 2010). Due to enrichment of organic and biological matter in river water and rapid decomposition of biodegradable organic matter, increasing biological oxygen demand, depleting dissolved oxygen and changing pH, making the water not usable for drinking, irrigation and fish culture (Hur and Cho, 2012).
Indian government has strong environmental regulations to control water pollution empowered under the Water (Prevention and Control of Pollution) Act, 1974 (amended in 1988), The Environment (Protection) Act, 1986 (with Rules 1986 and 1987) (E.P.A.) and other acts related indirectly. There are also legal provisions for the punishments and penalties but failing of the enforcing agencies, legal framework and lack of education and awareness among the citizens is adding to the problem of environmental crisis. In a study, industrialization, irrigation intensity and fertilizer use were shown to be in negative relationship while rainfall to be in positive relationship with the river water quality. Also the level of educated people was significantly positively related to the water quality in rivers flowing through that particular district (Goldar and Banerjee, 2004). Water quality parameters of river are dynamic that varies spatially and temporally. Assessment of pollution load in river flowing in urban areas and its continuous monitoring is an important tool to manage and protect precious fresh water resources. The water quality parameters of Yamuna and other river waters have been evaluated from time to time at different places by many workers (Singh *et al.,* 2005; Singh *et al.*, 2008; Suthar *et al.*, 2010). Today Yamuna is one of the most polluted rivers in the world, especially along the Delhi segment, where about 22 drains discharge waste water into the river (CPCB, 2006; MOEF, 2013; Paul *et al.,* 2014). Therefore, present study has been designed to investigate selected water quality parameters in different sites along river Yamuna in Delhi region and investigate temporal variations during three different time periods, viz. summer pre-monsoon (June), post-monsoon (October) and spring (February) in the year 2013 to 2014.

MATERIAL & METHODS
Sampling area
The study included about 32.5 km of the river Yamuna stretch through Delhi, the national capital of India. The study area varies from latitude of 28°46'17.30"N to 28°32'9.84"N and longitude of 77°13'25.16"E to 77° 19' 29.16"E. A total of 12 sampling sites were selected approximately 2.5 to 3.5 km apart from each other. Table 1 summarizes the details of the investigated sites.

TABLE 1: Locations of the sampling sites

Site no.	Latitude	Longitude	Location
Site 1	28°46'17.30"N	77°13'25.16"E	9 km upstream from Wazirabad barrage
Site 2	28°45'46.98"N	77°14'12.12"E	6.5 km upstream from Wazirabad barrage
Site 3	28°44'16.61"N	77°13'53.43"E	3.5 km upstream from Wazirabad barrage, opposite Jagarpur kadar village
Site 4	28°43'8.88"N	77°14'27.36"E	1 km upstream from Wazirabad barrage
Site 5	28°41'55.44"N	77°13'46.62"E	Majnu ka Tila, at a distance of about 0.9 km downstream from Najafgarh drain
Site 6	28°40'13.26"N	77°14'1.44"E	Near ISBT bridge
Site 7	28°39'1.92"N	77°15'51.00"E	Near Geeta colony
Site 8	28°37'39.18"N	77°15'30.00"E	Near ITO flyover and Delhi Jal Board
Site 9	28°35'59.70"N	77°15'44.82"E	Near Nizamuudin bridge
Site 10	28°34'37.62"N	77°17'14.94"E	Near Delhi Noida flyover
Site 11	28°32'54.28"N	77°18'23.53"E	Okhla
Site 12	28°32'9.84"N	77°19'29.16"E	1.6 km downstream to Okhla

Sample collections

The water samples were collected in triplicate from all the sampling sites in the month of June (pre-monsoon), October (post-monsoon) and February (Spring) in the year 2013 to 2014. The samples were collected from the bank of the river to the highest possible depth in high grade polyethylene bottles and labelled properly. The samples were brought to the laboratory with necessary precautions and further processed within 24hrs of the sampling.

Water Quality Analysis

The pH was measured on the site itself with the help of portable pH meter (Hanna). All the reagents used for the analysis were of analytical reagent grade. The dissolved oxygen (DO) was calculated by Winkler's titration. Biochemical oxygen demand (BOD) was calculated by the 5-day BOD test while chemical oxygen demand (COD) was calculated by using open reflux method. The detailed methodology adopted was according to the standard methods of APHA (1995, 2005).

RESULTS & DISCUSSION

The pH was found to be in the range of 7.17 to 8.3 in June (pre-monsoon), 7.30 to 8.02 in October (post-monsoon) and 7.42 to 8.28 in February (spring) (Figure 1). In general the pH was higher in June followed by February and October at all locations except for the site 4 in June. The pH of the upstream sites was more alkaline than the downstream of the site 4. An abrupt downfall in the pH was observed after the site 3 and 4 during all the seasons which might be due to the discharge of the wastewater to the river by Najafgarh drain before the site 5. Overall, the pH recorded was in the range of different classes of the water quality criteria described by CPCB. The variation of the temperature, humidity and rainfall during the study period at the selected area is shown in the Table 3. The increased surface pH at some locations can be related to more metabolic activities of the autotrophs present, which in general utilize CO_2 and liberate O_2 thus reducing H^+ ion concentration while the liberation of acids from decomposing organic matter under low O_2 concentration result in low pH (Kaul and Handoo, 1980). The pH of all the sites throughout the sampling period was in the prescribed range of the class A-D of CPCB (Table 2).

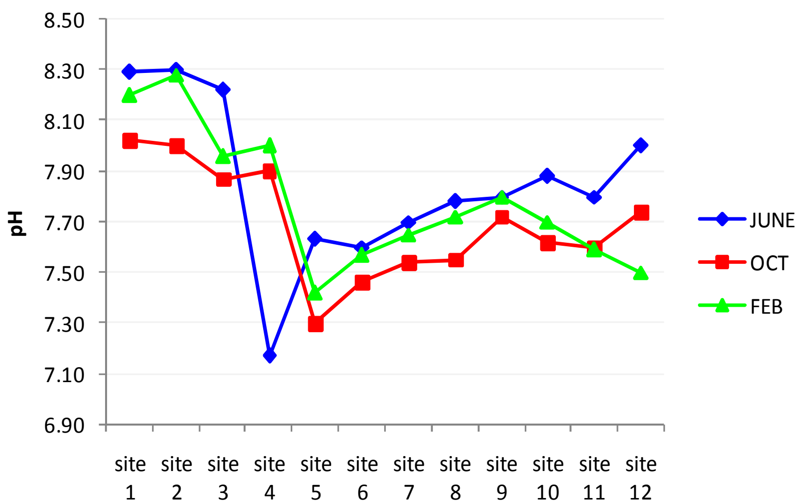

FIGURE 1: Spatial variation of the pH of river Yamuna River at different locations along the Delhi stretch during different seasons

TABLE 2: Water quality criteria according to CPCB

Designated-Best-Use	Class of water	Criteria
Drinking Water Source without conventional treatment but after disinfection	A	• Total Coliforms Organism MPN/100ml shall be 50 or less • pH between 6.5 and 8.5 • Dissolved Oxygen 6mg/l or more • Biochemical Oxygen Demand 5 days 20°C 2mg/l or less
Outdoor bathing (Organised)	B	• Total Coliforms Organism MPN/100ml shall be 500 or less pH between 6.5 and 8.5 Dissolved Oxygen 5mg/l or more • Biochemical Oxygen Demand 5 days 20°C 3mg/l or less
Drinking water source after conventional treatment and disinfection	C	• Total Coliforms Organism MPN/100ml shall be 5000 or less pH between 6 to 9 Dissolved Oxygen 4mg/l or more • Biochemical Oxygen Demand 5 days 20°C 3mg/l or less
Propagation of Wild life and Fisheries	D	• pH between 6.5 to 8.5 Dissolved Oxygen 4mg/l or more • Free Ammonia (as N) 1.2 mg/l or less
Irrigation, Industrial Cooling, Controlled Waste disposal	E	• pH betwwn 6.0 to 8.5 • Electrical Conductivity at 25°C micro mhos/cm Max.2250 • Sodium absorption Ratio Max. 26 • Boron Max. 2mg/l
	Below-E	Not Meeting A, B, C, D & E Criteria

* Source http://www.cpcb.nic.in/Water_Quality_Criteria.php (assessed on 12/09/2015)

TABLE 3: Temperature, humidity and rainfall of Delhi during the study period (Jun-2013 to Feb-2014)

	Mar 13	Apr -13	May -13	Jun -13	Jul -13	Aug -13	Sep -13	Oct -13	Nov -13	Dec -13	Jan -14	Feb -14
Max. Temp. (ºC)*	30.7	36.1	41.5	37.9	35.4	33.6	35.1	32.4	27.2	22.7	22#	26#
Min. Temp. (ºC)*	16	21.2	26.1	27.7	26.8	25.9	25.1	20.6	12.2	9	6#	6#
Humidity (%)*	77	53	40	70	82	85	75	84	81	94	NA	NA
Rainfall (mm)**	12.6	11.6	0.0	151.0	459.8	521.9	108.1	109	0.4	6.8	18.6	63.5

Source *Statistical abstract of Delhi 2014, Directorate of Economics & Statistics, New Delhi **http://www.iari.res.in/?option=com_content&id=402&Itemid=322 Accessed on 11-09-2015 #http://www.accuweather.com

The DO dropped at an alarming level after the site 3 during all the study periods (Figure 2). The maximum values of the DO were observed at the Site 1 followed by Site 2 and 3 in the February. In general DO of these three sites have higher values than the other locations with an increasing order form June to February. Increase in DO can be related to the decreasing temperature in months of October and February (Table 3). Almost all DO values of the sampling locations after site 4 were nil through all the sampling periods except for few locations in October. An increase in the DO was observed after the monsoon period in October when it was recorded 7.09mg/l, 6.55 mg/l, and 6.73 mg/l for the site 1, site 2, and site 3 respectively and 1.82 mg/l, 0.55 mg/l, and 0.55 mg/l, for the site 9, site 10, and site 11 respectively. Higher DO from site 1 to 2 indicated that the water was comparatively clean and had less microbial activity. When water contains high amounts of oxidizable matter, in particular organic pollutants, microorganisms utilize the dissolved oxygen to oxidize the organic matter resulting into low DO.

The availability of dissolved oxygen in water depends on the exchange across the air and water interface, subjected to the conditions such as temperature, partial pressure of gases, solubility, photosynthetic activity of the aquatic plants and respiration by microorganisms, plants and animals in the water (Krishnaram *et al.*, 2007). Increased surface DO in winter and early spring and decreased DO in summer was also observed in an estuary in a previous report (Yin *et al.*, 2004). Comparatively high DO concentrations that were observed during monsoon season can be related to the mixing of the fresh water and high rainfall in the preceding months.

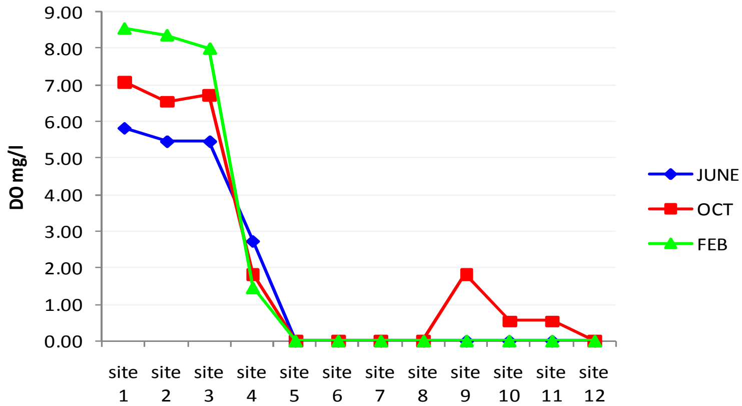

FIGURE 2: Spatial variation of the DO (mg/l) of river Yamuna River at different locations along the Delhi stretch during different seasons

BOD gives the quantity of oxygen needed for the microbiological oxidation or decomposition of organic matter present in water. Thus, lower the BOD, lesser is the presence of organic contaminants and microorganisms flourishing on these contaminants while higher the BOD, high will be the quantity of microorganisms and organic contaminants. Maximum BOD (58.2 mg/l) was observed at site 5 during February while minimum (2 mg/l) at site 1 during October. The BOD was found to be in the range of 2.5 to 7.3 mg/l in June, 2.0 to 5.5 mg/l in October and 2.4 to 7.3 mg/l in February for the site 1 to site 4. After site 4 the BOD increased sharply to 52.7 mg/l, 49.1 mg/l and 58.2 mg/l at site 5 for the June, October and February respectively. After the site 5 a little drop was observed; from site 6 to site 12 the BOD was in the range of 32.7 mg/l to 43.6 mg/l for June, 27.3 mg/l to 32.7 mg/l for October and 29.1 mg/l to 40.0 mg/l for February. In general, the BOD is low in October shortly after monsoon than in June and February.

The high BOD at site 5 is consistent with the fact of Najafgarh drain falling into the river before the site. The BOD at this site and sites thereafter also indicates the improper treatment of the wastewater of the drains prior to release into the river. Thus BOD can also be used to determine the effectiveness of current water treatment plants that discharge the water into the river to ensure proper treatment processes.

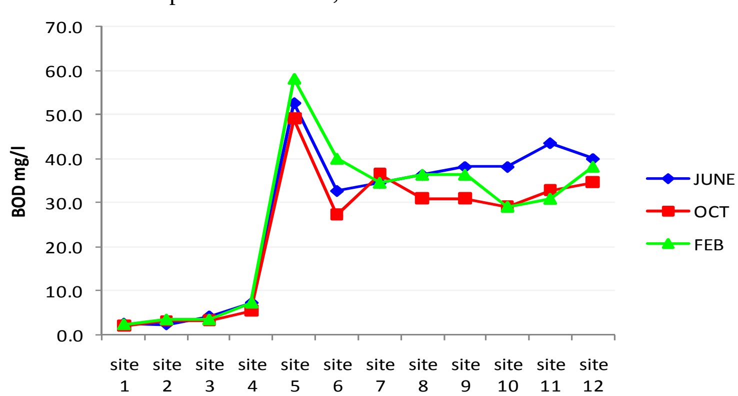

FIGURE 3: Spatial variation of the BOD (mg/l) of river Yamuna River at different locations along the Delhi stretch during different seasons

Lower COD (20mg/l to 24 mg/l) was observed from site 1 to site 3 that are upstream to Wazirabad barrage during all the sampling periods. Exceptional high increase in COD was observed after the site 3 which continued downstream to Wazirabad barrage up to site 5 where the COD was maximum, *i.e.*, 260 mg/l, 172 mg/l and 244 mg/l for June, October and February respectively. COD decreased slightly downstream at site 5, with little increase at the last sampling locations (site 10 to 12). In general, the values of COD were in the range of 140 mg/l to 260 mg/l for June, 80 mg/l to 172 mg/l for October and 80 mg/l to 244 mg/l for February through the segment of river Yamuna from the site 5 to site 12.

COD gives an idea about the total amount required for the total oxidation of the organic matter chemically. High COD is related to the high amount of the organic pollutants present in the water. COD is a useful indicator of organic pollution in surface water and deterioration of the water quality caused by the discharge of industrial effluent (Mamais *et al.*, 1993). Considering the findings, the surface water quality of river Yamuna in Delhi except site 1, did not meet the requirements of the Class C and was not suitable to be used as drinking water source after conventional treatment and disinfection. Excluding site 3 and upstream, water quality did not even fulfil the requirements of the Class D and was not suitable for propagation of wild life and fisheries (Table 2).

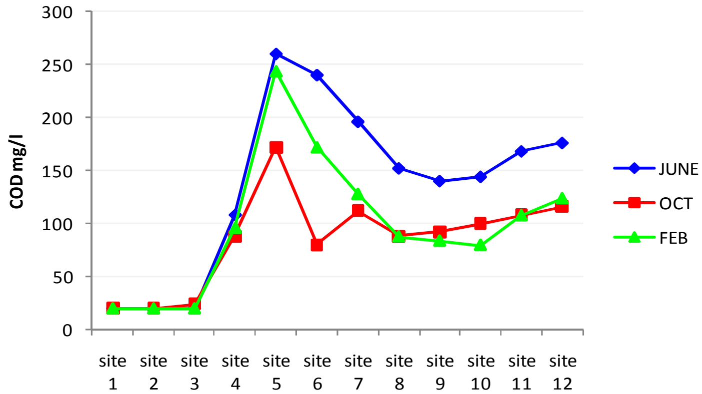

FIGURE 4: Spatial variation of the COD (mg/l) of river Yamuna River at different locations along the Delhi stretch during different seasons

To study the inter-relationships between various parameters at different sampling period the Karl Pearson's coefficient of correlation was calculated and correlation matrix with distribution histogram and scatter plot was constructed with the statistical software R (Table 3) (Figure 5) (R Core Team, 2013). Strong correlation was observed between most of the parameters with each other indicating close association of these parameters with each other. Within different period of the sampling the strong relationship was observed for the DO, BOD and COD respectively having correlation coefficient (r) larger than 0.8829 and p-value less than 0.001 for all the sampling periods. While the pH of October and February were strongly related with each other (r=0.8829, p< 0.001), pH values of June were having weak correlation with October and February (r=0.4934, p=0.103 and r=0.4556, p=0.136, respectively). In general, DO-BOD, DO-COD, pH-BOD and pH-COD were negatively correlated to each other. The relationship was very strong among DO and BOD with r value from -0.934 to -0.8322 and p< 0.001 in all the sampling periods. Although the correlation of DO with COD was also found to be strong but the relationship was stronger within DO of all three sampling period with the COD of June and October (r = -0.9185 to -0.8512, p < 0.001) as compared to the correlation of DO with COD of February (r= -0.7806 to -0.7307, p≤0.007). The pH values of October and February sampling were having stronger relationship with the BOD and COD of all sampling periods (r= -0.9264 to -0.822, p≤0.001) as compared to the relationship among pH readings of June with COD of all sampling period (r= -0.6349 to -0.6278, p=0.027 to 0.029), while pH readings of June were found to have weak relationship with BOD of all sampling periods (= -0.4246 to -0.3818, p=0.169 to 0.221). The DO for all sampling period was having positive and high correlation with pH of October and February (r=, p=) while DO was having moderate to strong relationship with the pH of the June (r= 0.5823 to 0.7215, p=0.047 to 0.008). The BOD and the COD was also having positive and strong correlation with each other (r= 0.9364 to 0.7688, p≤0.001 to 0.003). Considering all the correlation results, strong correlation was observed between pH, DO, BOD and COD with an exception of pH recorded in the June. The downfall of water quality in the recent years, upstream of Wazirabad barrage, has been due to release of pollutants from upstream towns. Major portion of the river water is collected for drinking water at Wazirabad. Thus, the 22 km urban stretch of the river in Delhi between Wazirabad barrage and Okhla barrage is left with the sewage from drains and fresh water from Wazirabad barrage during monsoon (CPCB, 2006; MOEF, 2013). The natural flow of the river in this stretch is quite restricted. At site 12 again an increase in the pollution level was observed that can be related to the discharge of Hindon cut canal from Hindon river before the Okhla barrage. The Hindon is also a highly polluted river, it receives the discharge for the upstream districts of Ghaziabad, effluents and wastes from industrial estates located in Ghaziabad, Noida and Sahibadad (Suthar *et al.,* 2010). The DO, BOD, COD and TDS, were several times higher than the prescribed standards for inland water bodies while he geoaccumulation index indicates that Hindon is moderately polluted with Cu, Cr, Fe, unpolluted to moderately polluted with Mn, Pb and Zn and very strong polluted with Cd (Suthar *et al.,* 2009, 2010). Thus, Hindon also contributes to the pollution load of Yamuna.

Despite of continuous efforts since last few decades, river water quality in India is not improving. Yamuna Action Plan (YAP) was launched in 1993, with subsequent YAP phase II in the year 2001with an aim to rejuvenate the river but Yamuna has not been able to achieve the desired river standards after completion of two phases of the plan, leading to another extension of second phase. The current finding tells the different side of the story that the plan was a complete failure. In a study it was reported that out of 80 districts in the Yamuna river basin, 20 districts face high water stress caused either due to depletion in water quantity or deterioration in water quality (Narula *et al.,* 2001). Large difference between sewage generation and treatment capacity, improper allocation of sewage treatment plants (STPs) and mixing of treated and raw sewage due to far positioning, are identified as the major reasons for poor water quality of Yamuna in Delhi stretch (Upadhyay *et al.,* 2011).

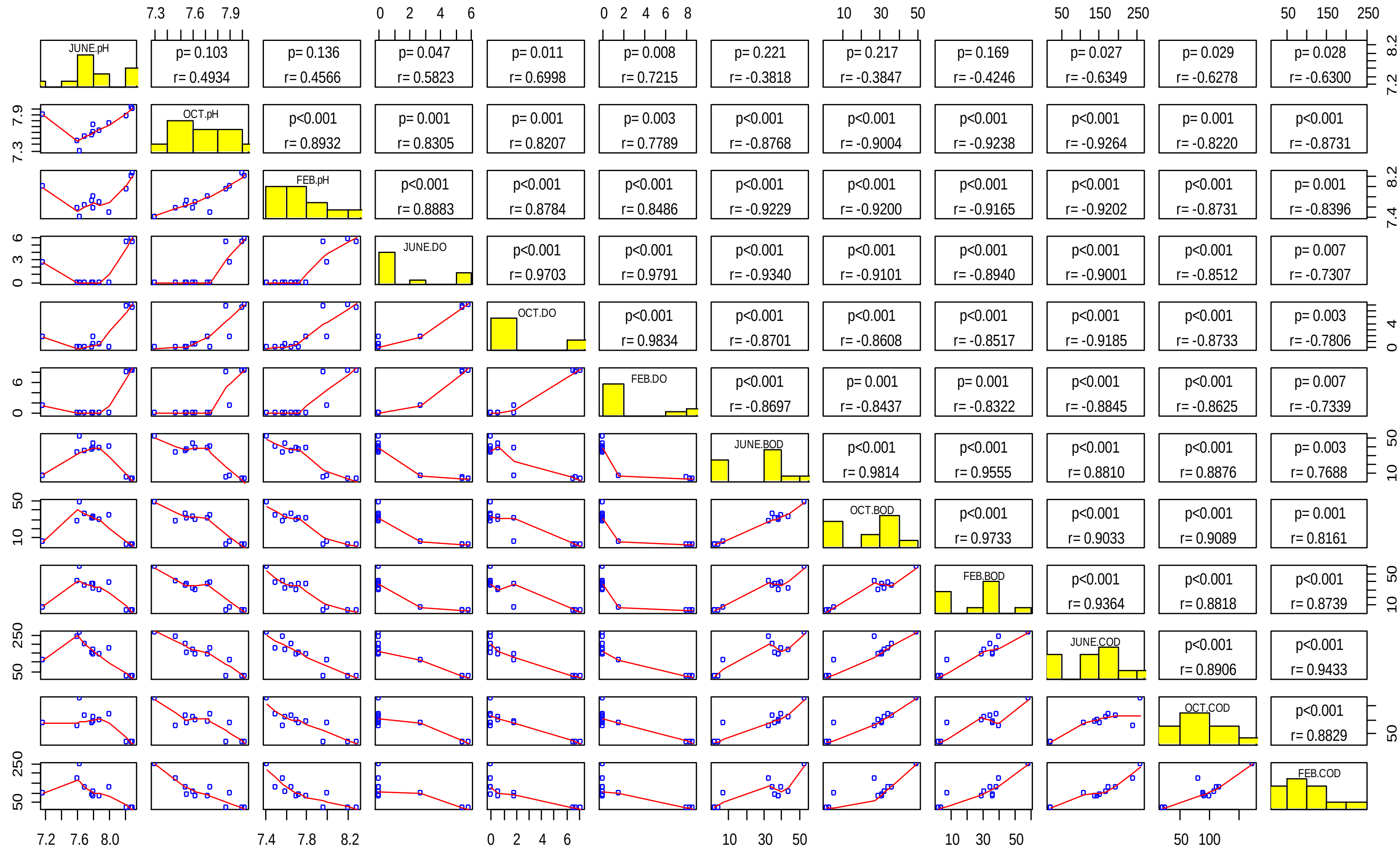

FIGURE 5: Correlation matrix with scatter plot and histogram of the studied parameters of water quality of Yamuna River along the Delhi stretch during different seasons

Based on the already available facilities, implementation of the corrective measures such as proper sewerage planning, efficient STPs, regulatory guidelines for operation and maintenance of STPs, strong water management plan, controlling industrial pollution, awareness through community participation, maintaining the minimum ecological flow and a sustainable management plan are needed to control the pollution in river Yamuna (Upadhyay *et al.,* 2011). Upflow anaerobic sludge blanket (UASB) reactors used for treatment of sewage discharged into the river are either of under capacity or not good enough to get the desired results within the limits of Indian discharge standards (Von Sperling *et al.,* 2004; Walia *et al.,* 2014).

CONCLUSION

Form the above study it can be concluded that the Yamuna in Delhi is not in good condition. While the water quality before entering the Delhi segment was much better, it deteriorates considerably after the river passes through the national capital of Delhi. Though the study has not evaluated water quality of the wastewater discharged into the river but the highest impact observed was of the Najafgarh drain as downstream to it the water was highly polluted. It can also be concluded that except pH, all parameters crossed the prescribed limits of CPCB and water is not safe for drinking and for agriculture and industrial use at most of the locations. Results indicate that the increase in pollution is indicative of alarming situation and the preventive measures are not good enough to control the same. Domestic sewage treatment plants or small community sewage treatment plants should be set up to reduce the pressure on the existing STPs.

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