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Seasonal assessment of physicochemical parameters and evaluation of water quality of river Yamuna, India

Bilal Nabi Bhat[*]**, Saltanat Parveen, Taskeena Hassan**

Limnology Research Laboratory, Department of Zoology, Aligarh Muslim University, Aligarh, India

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ABSTRACT

The concentrations of toxic effluents released into freshwater aquatic environments are increasing day by day and affect the aquatic biota. The present study outlined the evaluation of *physicochemical parameters such as* water temperature, pH, dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), phosphates (PO_4^{2-}-P), nitrates (NO_3^--N), electrical conductivity (EC) chlorides (Cl^-). Also, the *Water Quality Index (WQI)* for the water samples collected from the selected stations of the Yamuna River was calculated in order to assess its suitability for *drinking*, *irrigation* and *agricultural purposes*. The *Weighted Arithmetic Index method was used to calculate the WQI.* The WQI was found to be above 100 at all three stations, which was critical and indicated that the water quality grading fell in the E category, which made the water unsuitable for drinking and agricultural purposes. The assessment of physicochemical parameters indicated that the selected stations were badly impacted by industrial effluents and domestic sewage; thus, the river water should be treated before use to avoid water-related diseases that can have harmful effects on humans and aquatic biota.

1. Introduction

Water is an indispensable natural resource and a lifeline that provides habitat to millions of aquatic organisms. From couple of decades, man's anthropogenic activities, rapid urbanization and prompt industrialization have created the ecological pressure on aquatic habitat which directly or indirectly enhances the human health concern. The aquatic ecosystem very often serves as the mirror of environmental deterioration due to various anthropogenic activities. Rivers provide a livelihood, particularly for communities living on the basin; they also provide a support to agricultural as well as industrial and urban sectors, but indiscriminate activities put enormous pressure on the environment and natural resources. In recent years, the inland aquatic resources which constitute rivers and their floodplains, reservoirs, estuaries and lakes have been subjected to increasing anthropogenic stress. In India, most of the rivers have been plagued with water quality problems because of intense urbanization resulting in the discharge of untreated domestic wastes into the water bodies which has increased the level of bacteriological sewage concentration in river water [1-3]. In the Yamuna River, 85% of the total pollution load comes from domestic sources which include the dumping of waste by urban centres like Panipat, Delhi, Mathura, Vrindavan, Agra, etc. The pollution constitutes organic matter, microorganisms, untreated or partially treated sewage, undetected and untreated pesticide, dead body dumping, and cattle washing; these residues leave a toxic mark all across the river [4]. The changing nutrient concentration in the Yamuna River depends upon the land use pattern, industrial setup and population density, particularly on the river basin. Waste generated from large unauthorized colonies existing in various urban centers with no sewage system is transported and discarded straight into the Yamuna River. The discharging of unprocessed effluents into the river is a result of robust industrial development across the Yamuna River basin at various places including Nagda, Panipat, Sonepat, Yamuna Nagar, Delhi, Ghaziabad, Mathura, Agra, etc. An unabated agricultural practice,

*Corresponding author. Tel: +91-7417529458
E-mail address: bilalnabiamu@gmail.com
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particularly on the catchment area, has primarily affect the Yamuna water quality [5]. The river Yamuna and its catchment contributes to a total of 3, 66,223 km^2 area (catchment basin area in various states accounts for 3, 45,848 km^2 and the Yamuna river area is 20,375 km^2), which is 42.5% of the total Ganga River Basin and 10.7% of the total geographical landmass of the country (Table 1) [6]. Since rivers offer many kinds of ecological services which benefit the villages and city dwellers, increasing river pollution has become a national issue and cause of concern for environmentalists. In the last few decades, WQI has helped to communicate the general water quality status of water sources for both surface and groundwater quality evaluation all around the world [7-13]. The WQI transforms a complex set of water quality data into comprehensible and practicable information by which even the average person can understand the status of the water source [14].Therefore, with the above backdrop, the primary focus of the present study was to analyze the physicochemical parameters of water samples collected from different stations of the Yamuna River. Also, the WQI was calculated to illustrate the overall water quality in order to find out its current pollution status. The analyzed physicochemical parameters of the Yamuna River were compared with the findings of others rivers (Table 2).

2. Material and methods

2.1. Description of study area

Three stations of the Yamuna River, viz. Station 1 (NCT Delhi), Station 2 (Mathura) and Station 3 (Agra), were selected for monitoring the physicochemical parameters of the water. The monitoring was done during a period of twelve months from April 2015 to May 2016 on a seasonal basis, i.e., summer, monsoon and winter. Samples were collected in sterilized sampling bottles and analyzed according to standard methodologies (Figure 1) Table 3 [15].

Table 1: Catchment area details of the Yamuna River [6]

		Area in the major sub basin (Sq.km)					
State	**Area (Sq.km)**	**River Hindon**	**River Chambal**	**River Sind**	**River Betwa**	**River Ken**	**Other Sub Basin**
Uttaranchal	3771						3711
UP	70437	7083	452	748	14438	3336	44380
HM	5799						
Haryana	21265						
Rajasthan	102883		79495				
MP	140208		59838	25131	33502	21090	647
NCT - Delhi	1485						1485
Total	345848 (100%)	7083 (2.0%)	139785 (40.50%)	25879 (7.50%)	47940 (13.90%)	24426 (7.10%)	100735 (29.10%)

P=Uttar Pradesh, HM= Himachal Pradesh, MP= Madhya Pradesh)

Table 2: Comparison between various physicochemical parameters of river Yamuna with some other rivers

Locations	Parameters analyzed	References
River Yamuna, India	Temp., pH, DO, COD, BOD, EC, NO_3^-, PO_4^-, Cl^-	This study
Dongjiang river, southern China	pH, Temp., TSS, NH_4^+-N, NO_3^-, DO, NO_2^-, PI, TN, TC, TIC, TOC, Turbidity	[16]
River Ganga, India	Temp., EC, Turbidity, Velocity, TS, TDS, pH, BOD, COD, CO_2, Alkalinity, Hardness, PO_4, NO_3^-, Cl^-	[17]
Tajan river, Iran	Depth, Altitude, DO, pH, water temp., EC, Turbidity, NO_3^-, PO_4^-, NH_4-N, BOD, TSS	[18]
Kaduna river, Nigeria	pH, DO, TDS, BOD, COD, Cl, SO_4, NO_4–N, Ca, Mg, EC, NO_3^-,T.coli, Temp.	[19]
Taizi river, China	pH, DO, EC, TDS, Cl, SO_4, BOD, COD, NH_3-N, PO_4, NO_2-N, NO_3-N, TP, TN	[20]
Lis river, Portugal	pH, Temp., EC, DO, Turbidity, COD, BOD, TOC, TSS, NO_3^-, NH_3-N	[21]
Turag river, Dhaka Bangladesh	pH, EC, Salinity, Hardness, DO, BOD, COD, CO_2	[22]
Han river, South Korea	pH, Temp., DO, BOD, COD, SS, TP, TN	[23]
Bagmati river, Kathmandu, Nepal	Water temp., pH, DO, EC, TDS, TSS, Ca, Mg, BOD, COD, SO_4, Cl, Hardness,PO_4-P, TP, NH_4-N, NO_2-N, NO_3-N	[24]
Indian River lagoon (IRL), Florida	DO, Sp. Cond., pH, Turbidity, Color, TSS, NO_2-N, NO_3-N, NH_4-N, TKN, PO_4-P, TP	[25]
Rivers of Alfeios and Pineios, Peloponnisos, Greece	pH, Temp., DO, EC, TDS, PO_4, NH_3, NO_2, NO_3, SO_4, BOD, COD	[26]
Chillan river, Central Chile	pH, Temp., COD, EC, DO, BOD, Nitrates, Ca, Hardness	[27]

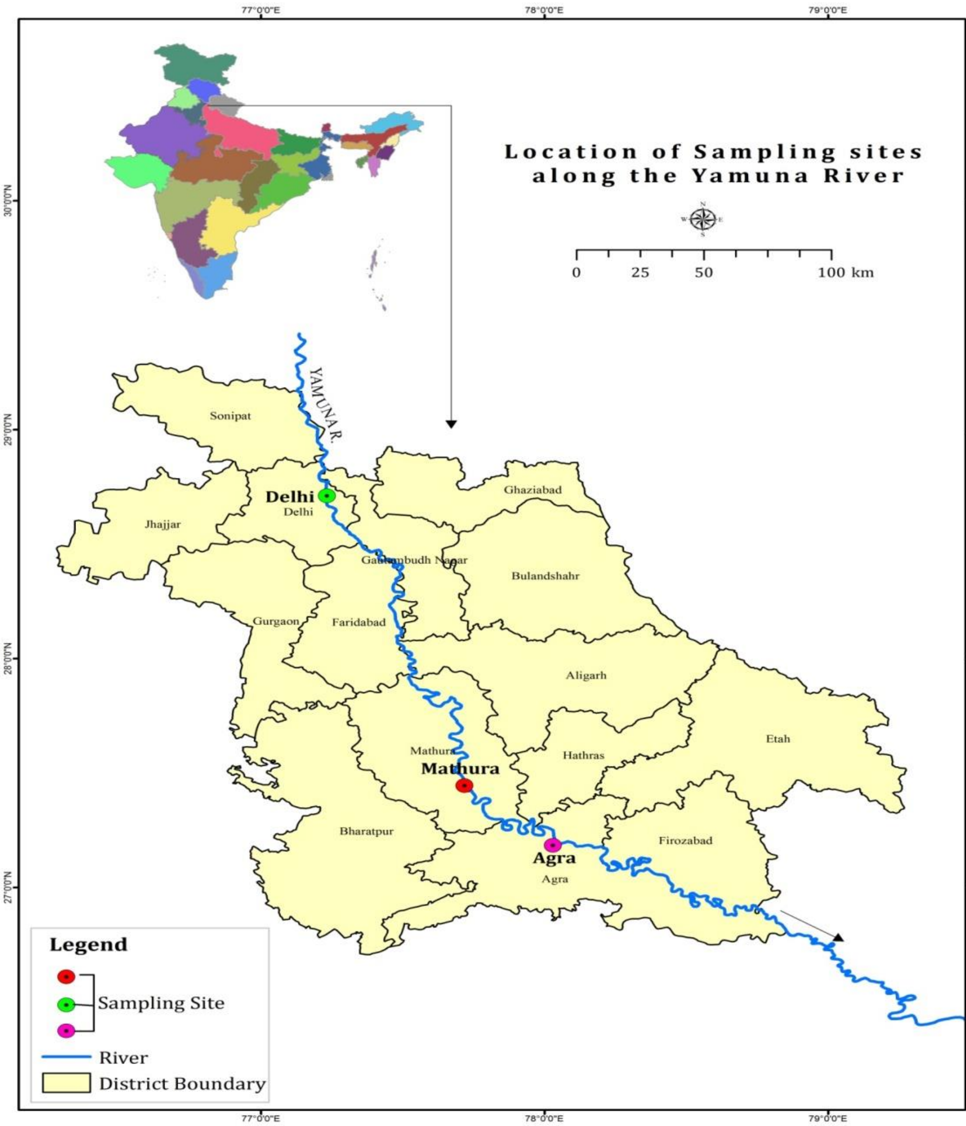

Figure 1: Geographical representation of the study area.

2.2. Physicochemical analysis

The water samples were collected in 500 ml polyethylene bottles previously washed with deionized water, rinsed with the sample to be collected from different stations, and acidified with 5 ml concentrated nitric acid. Then they were carried to the laboratory in an ice box using ice gel packs and kept in a refrigerator at 4°C until analysis. All the samples were analyzed in triplicate. All the reagents used for the analysis were of analytical reagent grade. The quality assurance and quality procedures were also used (Table 3) [15].

Table 3: Water quality parameters, instruments used and methods adopted

Parameter	Instrument used	Method adopted
WT	Mercury thermometer	Recorded by mercury thermometer
pH	Digital pH Meter (HANNA: HI98107)	Recorded by pH meter
EC	Digital Conductivity Meter (HANNA: HI98303)	Recorded by Conductivity meter
BOD	BOD incubator and titration assembly	Winkler azide method, APHA (1998)
COD	Refluxing assembly	Reflux titrimetry method, APHA (1998)
DO	Titration assembly	Winkler iodometric method, APHA (1998)
PO_4-P	UV- Spectrophotometer	Colorimetric Stannous chloride method APHA (1998)
NO_3-N	UV- Spectrophotometer	Phenol disulphonic acid method, APHA (1998)
Cl^-	Titration assembly	Argentometric method APHA (1998)

2.3.1. Weighted arithmetic water quality index

The weighted arithmetic water quality index method [28] classifies the water quality according to the degree of purity by using the most commonly measured water quality variables. The WQI was generated by taking the overall mean value of pH, COD, DO, BOD, nitrates, chlorides and phosphates.

The calculation of the WQI was made by using the following equation:

$WQI = \sum Q_i W_i / \sum W_i$

Q_i = the quality rating scale for each parameter is calculated by using this expression:

$Q_i = 100[(V_i - V_o / S_i - V_o)]$

Where,

V_i = Estimated concentration of ith parameter in the analysed water

V_o = The ideal value of this parameter in pure water $V_o = 0$ (except pH =7.0 and DO = 14.6 mg/l)

S_i = Recommended standard value of ith parameter

W_i = the unit weight for each water quality parameter is calculated by using the following formula:

$W_i = K/S_i$

Where,

K = Proportionality constant and can also be calculated by using the following equation:

$K = 1/\sum (1/S_i)$

2.4. Data analysis

Data analysis was done by using SPSS® (17.0). One-way ANOVA was used to analyze the significant differences in all the physicochemical parameters between different stations. Duncan's test was performed to ensure significant differences. The normality of the data was done through the Shapiro-Wilk test. All the physicochemical parameters studied were observed as having non normal distribution, which were then correlated using Spearman's rank order (rho) correlation.

3. Results and discussion

The seasonal variations of various physicochemical parameters at different stations of the river Yamuna are presented in Table 4.

Table 4: Seasonal fluctuations in physicochemical parameters at different stations of river Yamuna

Parameters	Season	Delhi Station 1	Mathura Station 2	Agra Station 3
Water Temperature(°C)	Summer	30.00±2.00^{a}	22.33±2.51^{c}	23.00±3.00^{bc}
	Monsoon	26.66±1.52^{a}	19.33±1.52^{c}	20.33±2.51^{bc}
	Winter	14.33±2.08^{a}	9.66±0.57^{b}	9.33±1.52^{b}
pH	Summer	7.12±0.04^{c}	7.03±0.02^{c}	7.51±0.09^{a}
	Monsoon	7.27±0.06^{c}	7.68±0.09^{a}	7.51±0.03^{b}
	Winter	7.65±0.05^{a}	7.71±0.14^{a}	7.31±0.15^{b}
Electrical Conductivity (µS/cm)	Summer	1339±167.52^{ab}	1407±199.36^{a}	1041±53.46^{c}
	Monsoon	585±5.68^{c}	683±12.58^{b}	988±57.51^{a}
	Winter	1143±13.05^{c}	1673±7.63^{a}	1171±53.92^{c}
COD (mg/l)	Summer	76.38±2.53^{a}	55.38±3.08^{d}	70.08±2.65^{bc}
	Monsoon	51.70±3.02^{b}	25.00±5.43^{c}	51.75±2.51^{b}
	Winter	94.03±2.66^{a}	65.41±3.22^{bc}	60.75±3.19^{c}
BOD (mg/l)	Summer	69.08±6.58^{a}	29.23±18.10^{b}	11.96±3.57^{c}
	Monsoon	33.90±4.34^{a}	16.75±12.37^{bc}	8.75±0.52^{c}
	Winter	54.73±.±.63^{a}	24.15±2.92^{c}	16.58±2.57^{d}
DO (mg/l)	Summer	0.08±0.15^{c}	0.13±0.02^{bc}	0.29±0.03^{a}
	Monsoon	1.78±0.23^{b}	2.10±0.22^{a}	1.05±0.04^{c}
	Winter	0.19±0.10^{c}	1.15±0.02^{a}	0.74±0.24^{b}
Phosphates (mg/l)	Summer	1.50±0.10^{a}	1.10±0.10^{b}	1.23±0.05^{b}
	Monsoon	0.44±0.02^{d}	0.20±0.07^{e}	0.58±0.01^{c}
	Winter	1.70±0.10^{c}	1.76±0.15^{bc}	1.80±0.10^{bc}
Nitrates (mg/l)	Summer	9.67±0.97^{c}	14.84±1.56^{a}	13.09±2.17^{ab}
	Monsoon	5.59±1.16^{c}	9.42±2.21^{abc}	11.11±2.09^{ab}
	Winter	25.97±2.25^{a}	9.56±1.55^{c}	10.46±0.57^{c}
Chloride (mg/l)	Summer	398±2.12^{a}	372±3.23^{c}	305±2.29^{d}
	Monsoon	248±1.92^{a}	133±2.54^{e}	205±4.11^{c}
	Winter	395±3.53^{b}	313±5.05^{d}	343±4.14^{c}

Mean values followed by different letters are statistically different (ANOVA; Duncan's test, $P < 0.05$).

3.1. Water Temperature

In the present study, low water temperature was recorded in winter at station-3 (Table 4) while the highest was recorded in the summer at station-1 (Table 4). The higher temperature at station 1 could be attributed to the thermal pollution caused by power plants and industrial manufacturers, where water was used as a coolant and later drained into the river. The variation in temperature could also be related to the temperature of atmosphere and weather conditions.

3.2. pH

The mean value of pH was recorded to be varying from 7.03 to 7.71 at different sampling stations. The maximum pH was recorded at station-2 (Table 4) during the winter and the minimum at station-2 during the summer (Table 4). However, the values of pH were found within the permissible limit [29]. The high pH value at station-2 may be due to the increased influx of bicarbonates and carbonates of calcium and magnesium from wastewater, coming mainly from urban runoff and industrial effluents. The same results have been previously reported [30]. However, the lower value of pH at station-2 during the summer season can be attributed to the accumulation of free CO_2 and higher respiration of organisms at higher temperature. An inverse relation between pH and carbon dioxide has also been reported from the Yamuna River [31]. According to the Central Pollution Control Board, 70% of the pollution in rivers comes from untreated sewage [32]. In the present study, the pH showed a significant negative correlation with temperature (-0.560) (Table 5).

3.3. Electrical Conductivity (EC)

In the present study, EC ranged from 585µScm^{-1} to 1673 µScm^{-1} at the studied stations. The maximum EC was measured at station-2 (Table 4) during the winter season, and the minimum value was measured at station-1 (Table 4) during the monsoon season. High EC at station-2 may have been due to the mixing of various drains from various urban centres into the main stream of the river carrying effluents from adjoining industries and sewage fed drains; the low EC at station-1 could be from the dilution of effluents during the monsoons and increase in water current densities. The values of EC were above the prescribed limit, i.e., 15 µS cm^{-1} for drinking purpose [29]. High EC values indicated the presence of a high amount of dissolved salts and inorganic chemicals.

Table 5: Spearman's rank correlation matrix for different water quality parameters

Parameters	Temp	pH	EC	BOD	COD	DO	PO_4-P	NO_3-N	Cl^-
Temp	1								
pH	-.560**	1							
EC	-.320	-.124	1						
BOD	.463*	-.178	.017	1					
COD	-.087	-.059	.548**	.280	1				
DO	-.258	.484*	-.537**	-.297	-.699**	1			
PO_4-P	-.520**	-.099	.719**	.144	.759**	-.447*	1		
NO_3-N	-.219	-.121	.324	.024	.400*	-.516**	.283	1	
Cl^-	-.021	-.375	.684**	.411*	.786**	-.840**	.692**	.377	1

*Correlation is significant at the 0.05 level **. Correlation is significant at the 0.01 level

3.4. Chemical Oxygen Demand (COD)

In the present investigations, the mean values of COD ranged from 94.03mg/l to 25.00mg/l at selected stations. The maximum COD was observed at station-1 during the winter season (Table 4) while the minimum was at station-2 during the monsoon season (Table 4). The higher values of COD exceeded the value, i.e., 10 mg/l [29]. The higher values of COD at station 1 could be related to the following circumstances: uncontrolled and untreated discharge of agricultural runoff, industrial waste and urban sewage from various drains, viz. Najafgarh drain, sweeper colony drain, magazine drain, Metcalf house drain, powerhouse drain, Barapulla drain and maharani bagh drain. A large number of industrial units including pulp & paper, sugar, distilleries, textiles, leather, chemical, pharmaceuticals, oil refineries, thermal power plants, food, etc. were established on the Yamuna River basin, particularly at NCT Delhi. These industries discharge wastewater into the Yamuna River, which creates havoc in the river ecosystem and elevates the COD level. The present study is in conformity with other findings [33]. The COD showed a significant positive correlation with EC (0.548) (Table 5).

3.5. Biological Oxygen Demand (BOD)

During the study period, the BOD increased during the summer with the maximum value at station 1 (Table 4), while it decreased during the monsoons to the minimum value at station 3 (Table 4). The higher value of BOD at station-1 could be due to a high organic load with a higher microbial activity which escalated the BOD and resulted in the depletion of DO. Also, high nitrate levels coming from domestic sewage and agricultural runoff containing pesticides and fertilizers also resulted in high BOD. The present results are in conformity with findings [34]. Whereas, the lower value at station-3 could be attributed to the dilution in the concentration of dissolved organic matter and decrease in temperature. The studied water samples showed the BOD well above the permissible level, i.e., 6 mg/l [29]. The BOD showed a significant positive correlation with temperature (0.463) (Table 5).

3.6. Dissolved oxygen (DO)

The mean value of the dissolved oxygen varied from 0.08 mg/l at station-1 during the summer (Table 2) to 2.10 mg/l (maximum) at station-2 during the monsoon season (Table 2). The maximum dissolved oxygen in the water of the Yamuna River was recorded in the monsoon season; thereafter, it started declining gradually and reached the lowest concentration in the summer. The low concentration of DO at station 1 could be associated with the direct discharge of industrial effluents containing organic matter and municipal sewage from various drains, particularly the Najafgarh and Shahdara drains. These two drains alone contribute about 81% of the total discharge of the 22 major drains that join the Yamuna River at Delhi. Therefore, consequent biodegradation of organic matter and decay of vegetation at higher temperature leads to consumption of oxygen from water. The current findings are in conformity with findings [35]. The observed DO concentrations were well below the desirable limit, i.e., 5 mg/l [29]. It showed a significant positive correlation with pH (0.484) and significant negative correlation with EC (-0.537) and COD (-0.699) (Table 5).

3.7. Phosphate-phosphorus

In this study, the phosphate values ranged from 0.20 mg/l (minimum) at station-2 during the monsoons (Table 4) to 1.80 mg/l (maximum) at station-3 during the winter (Table 4). The high phosphate concentration at station-3 could be attributed to the decomposition of organic wastes and phosphate containing pesticides. The present findings are in conformity with findings [36]. The lower values of phosphates at station-2 might be due to utilization of phosphate as nutrients by algae and other aquatic plants. The mean phosphate values exceeded the prescribed limit of 0.1-1 mg/l [29] during all the seasons at all the stations. Phosphate showed a significant positive correlation with EC

(0.719) and COD (0.759) and a significant negative correlation with temperature (-0.520) and DO (-0.447) (Table 5).

3.8. Nitrate-Nitrogen:

The concentration of nitrates ranged from maximum at station-1 during the winter season (Table 4) to a minimum at station-1 during the monsoon season (Table 4). The higher amount of NO_3-N at station-1 may be due to the disposal of domestic wastes from the city, sludge from factories containing nitrogenous substances, and the use of nitrogen containing fertilizers around the river banks. The minimum value during the monsoons can be due to the dilution of river water by frequent rains. The values were found within the standard limit of 50 mg/l [29]. Nitrate showed a significant positive correlation with COD (0.400) and a significant negative correlation with DO (-0.516) (Table 5).

3.9. Chlorides

The mean concentration of chloride in the studied area fluctuated from a maximum at station-1 during the summer (Table 4) to a minimum at station-2 during the monsoons (Table 4). The higher chloride concentration at station-1 might be due to the discharge of domestic sewage containing a large amount of chlorides. The present results show conformity with results [37], whereas the minimum value of chloride at station-2 was recorded during the monsoons which could be attributed to the dilution effect of heavy rains. The values found were above the standard value for most of the study samples, i.e., 250 mg/l [29]. The chlorides showed a significant positive correlation with EC (0.684), BOD (0.411), COD (0.786) and PO_4 (0.692) as well as a significant negative correlation with DO (-0.840) (Table 5).

4. The WQI results recorded at all the selected stations were above the critical level which indicated a water quality grading in the E category at all the stations (Table 6 a, b). This meant that the water was unsuitable for drinking and agricultural purposes.

5. Conclusions

The present study concluded that the values of the parameters pH, EC, DO, BOD, COD, phosphate, and chlorides were such that the water was seriously affected by the direct or indirect entry of wastes into the river water from the surrounding industrial, domestic and agricultural units. This was especially so far the 22 km Delhi stretch, which recorded negligible DO as well as high BOD and COD as compared to the river stretch in Mathura and Agra. The results from the WQI study evaluated the critical parameters in order to design, formulate and implement pollution abatement strategies as well as improve the knowledge base about the status of the water quality. The water quality of the river could be restored by adopting the following measures: restricting inflow of raw sewage from residential and commercial establishments; preventing unabated dumping of solid waste by communities residing alongside the river; and desilting to improve the carrying capacity of the Yamuna River. The recycling and reuse of treated wastewater are also opportunities by which pollution load can be minimized.

Table 6a: Calculation of overall Water Quality Index (WQI)

Parameter	S_1Q_i	S_2Q_i	S_3Q_i	Unit weights(W_i)	$S_1(Q_iW_i)$	$S_2(Q_iW_i)$	$S_3(Q_iW_i)$	WHO (2004)
pH	68	94	88	0.11	7.48	10.34	9.68	6.5-9.2
BOD (mg/l)	876.16	389.5	207.16	0.11	96.37	42.84	22.78	6
COD (mg/l)	740.3	485.9	608.6	0.10	74.03	48.59	60.86	10
DO (mg/l)	133	140	144	0.17	22.61	23.8	24.48	5
Phosphates (mg/l)	1210	1020	1200	0.10	121	102	120	0.1-1
Nitrates (mg/l)	27.48	22.54	23.1	0.10	2.74	2.55	2.31	50
Chloride	138.8	108.8	113.6	0.07	9.71	7.61	7.95	250
WQI					**333.94**	**237.37**	**248.06**	

Table 6b: Water Quality Rating as per Weight Arithmetic Water Quality Index Method [16]

WQI value	Rating of water quality	Grading
0-25	Excellent water quality	A
26-50	Good water quality	B
51-75	Poor water quality	C
76-100	Very poor water quality	D
Above 100	Unsuitable for drinking purpose	E

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References

[1] Khadse, G. K., Patni, P. M., Kelkar, P. S., Devotta, S. (2008). Qualitative evaluation of Kanhan River and its tributaries flowing over central Indian plateau. *Environmental Monitoring and Assessment*, 147(1-3), 83-92.

[2] Juang, D. F., Lee, C. H., Hsueh, S. C. (2009). Chlorinated volatile organic compounds found near the water surface of heavily polluted rivers. *International Journal of Environmental Science and Technology*, 6(4), 545-556.

[3] Venugopal, T., Giridharan, L., Jayaprakash, M., Velmurugan, P. M. (2009). A comprehensive geochemical evaluation of the water quality of River Adyar, India. *Bulletin of Environmental Contamination and Toxicology*, 82(2), 211-217.

[4] Sharma, D. and Kansal, A. (2011). Water quality analysis of River Yamuna using water quality index in the national capital territory, India (2000–2009). *Applied Water Science*, 1(3-4), 147-157.

[5] Gopal, B. and Sah, M. (1993). Conservation and management of rivers in India: case-study of the river Yamuna. *Environmental Conservation*, 20(3), 243-254.

[6] Rai, R. K., Upadhyay, A., Ojha, C. S. P., & Singh, V. P. (2011). *The Yamuna river basin: water resources and environment* (Vol. 66). Springer Science & Business Media.

[7] Sekabira, K., Origa, H. O., Basamba, T. A., Mutumba, G., Kakudidi, E. (2010). Assessment of heavy metal pollution in the urban stream sediments and its tributaries. *International Journal of Environmental Science and Technology*, 7(3), 435-446.

[8] Dash, A., Das, H.K., Mishra, B., Bhuyan, N.K. (2015). Evaluation of water quality of local streams and Baitarani River in Joda area of Odisha, India. *International Journal of Current Research*, 7(3), 13559–13568.

[9] VishnuRadhan, R., Zainudin, Z., Sreekanth, G. B., Dhiman, R., Salleh, M. N., Vethamony, P. (2017). Temporal water quality response in an urban river: a case study in peninsular Malaysia. *Applied Water Science*, 7(2), 923-933.

[10] Yadav, K. K., Gupta, N., Kumar, V., Sharma, S., Arya, S. (2015). Water quality assessment of Pahuj River using water quality index at Unnao Balaji, MP, India. *International Journal of Sciences: Basic and Applied Research*, 19(1), 241-250.

[11] Krishan, G., Singh, S., Gurjar, G., Kumar, C. P., Ghosh, N. C. (2016). Water quality assessment in terms of water quality index (WQI) using GIS in Ballia district, Uttar Pradesh, India. *Environmental and Analytical Toxicology*, 6(366), 2161-0525.

[12] Kaviarasan, M., Geetha, P., Soman, K. P. (2016). GIS-based ground water quality monitoring in Thiruvannamalai District, Tamil Nadu, India. In: *Proceedings of the International Conference on Soft Computing Systems* (685-700). Springer India.

[13] Akoteyon, I. S., Omotayo, A. O., Soladoye, O., Olaoye, H. O. (2011). Determination of water quality index and suitability of urban river for municipal water supply in Lagos-Nigeria. *European Journal of Scientific Research*, 54(2), 263-271.

[14] Bhutiani, R., Khanna, D.R., Tyagi, P.K. and Tyagi, B. (2014). Application of CCME WQI to evaluate feasibility of potable water availability: A case study of Tehri dam reservoir. *Environment Conservation Journal*, 15 (1-2)13-19.

[15] APHA (1998). *Standard Methods for the Examination of Water and Wastewater*. Edn. 2 American Public Health Association. AWWA, WCPF Washington, D.C.

[16] Sun, W., Xia, C., Xu, M., Guo, J. and Sun, G. (2016). Application of modified water quality indices as indicators to assess the spatial and temporal trends of water quality in the Dongjiang River. *Ecological Indicators*, 66, 306-312.

[17] Bhutiani, R., Khanna, D. R., Kulkarni, D. B., Ruhela, M. (2016). Assessment of Ganga river ecosystem at Haridwar, Uttarakhand, India with reference to water quality indices. *Applied Water Science*, *6*(2), 107-113.

[18] Aazami, J., Esmaili-Sari, A., Abdoli, A., Sohrabi, H. and Van den Brink, P.J. (2015). Monitoring and assessment of water health quality in the Tajan River, Iran using physicochemical, fish and macroinvertebrates

indices. *Journal of Environmental Health Science and Engineering*, 13(1), 13-29.

[19] Ogwueleka, T.C. (2015). Use of multivariate statistical techniques for the evaluation of temporal and spatial variations in water quality of the Kaduna River, Nigeria. *Environmental Monitoring and Assessment*, 187(3), 1-17.

[20] Bu, H., Meng, W., Zhang, Y. and Wan, J. (2014). Relationships between land use patterns and water quality in the Taizi River basin, China. *Ecological Indicators*. 41,187-197.

[21] Vieira, J.S., Pires, J.C., Martins, F.G., Vilar, V.J., Boaventura, R.A. and Botelho, C.M. (2012). Surface water quality assessment of Lis river using multivariate statistical methods. *Water, Air, & Soil Pollution*, 223(9), 5549-5561.

[22] Rahman, A.L., Islam, M., Hossain, M.Z. and Ahsan, M.A. (2012). Study of the seasonal variations in Turag river water quality parameters. *African Journal of Pure and Applied Chemistry*, 6(10), 144-148.

[23] Chang, H. (2008). Spatial analysis of water quality trends in the Han River basin, South Korea. *Water Research*, 42(13), 3285-3304.

[24] Prakash, R.K., Seockheon, L. and Sushil, R.K. (2007). Spatial-temporal variation and comparative assessment of water qualities of urban river system: a case study of the river Bagmati (Nepal). *Environmental Monitoring and Assessment*, 129 (1), 433–459.

[25] Qian, Y., Migliaccio, K.W., Wan, Y. and Li, Y. (2007). Surface water quality evaluation using multivariate methods and a new water quality index in the Indian River Lagoon, Florida. *Water Resources Research*, 43(8), 1-10.

[26] Iliopoulou-Georgudaki, J., Kantzaris, V., Katharios, P., Kaspiris, P., Georgiadis, T. and Montesantou, B. (2003). An application of different bioindicators for assessing water quality: a case study in the rivers Alfeios and Pineios (Peloponnisos, Greece). *Ecological Indicators*, 2(4), 345-360.

[27] Debels, P., Figueroa, R., Urrutia, R., Barra, R. and Niell, X. (2005). Evaluation of water quality in the Chillan River (Central Chile) using physicochemical parameters and a modified water quality index. *Environmental Monitoring and Assessment*, 110(1-3), 301-322.

[28] Brown, R. M., McClelland, N. I., Deininger, R. A., O'Connor, M. F. (1972). A water quality index-crashing the psychological barrier. *Indicators of Environmental Quality*, 1(1), 173-182.

[29] World Health Organization (2004). *Guidelines for drinking-water quality*. 2(1). World Health Organization, Geneva.

[30] Suthar, S., Sharma, J., Chabukdhara, M. and Nema, A.K. (2010). Water quality assessment of river Hindon at Ghaziabad, India: impact of industrial and urban wastewater. *Environmental Monitoring and Assessment*, 165(1-4), 103-112.

[31] Jindal, R., Rumana, H. S. (2000). Bio monitoring of water pollution in western Yamuna Canal at Yamuna agar, Haryana. *Journal of Punjab Academy of Sciences*, *2*(1), 177-182.

[32] CPCB (2000). Water quality status of Yamuna River, Central Pollution Control Board, Parivesh Bhawan, Delhi India.

[33] Shobhika, P., Vir, S. (2015). Water Quality Parameters of River Yamuna in Delhi after 20 years of the Yamuna Action Plan. *International Journal of Science and Nature,* 6 (4), 662-669.

[34] Fokmare, A. K. and Musaddiq, M. (2002). A study of physico-chemical characterstics of Kapsi Lake and Purna River waters in Akola District of Maharashtra (India). *Nature Environment and Pollution Technology.* 1 (3): 261-263.

[35] Hassan, T., Parveen, S., Bhat, B. N., & Ahmad, U. (2017). Seasonal Variations in Water Quality parameters of River Yamuna, India. *International Journal of Current Microbiology and Applied Sciences,* vol. 6 (5), 694-712.

[36] Korostynska, O., Mason, A., Al-Shamma'a, A. (2012). Monitoring of nitrates and phosphates in wastewater: Current technologies and further challenges. *International Journal on Smart Sensing and Intelligent Systems*, *5*(1) 149-176.

[37] Addo, M. A., Darko, E. O., Gordon, C., Nyarko, B. J. B. (2013). Water quality analysis and human health risk assessment of groundwater from open-wells in the vicinity of a cement factory at Akporkloe, South eastern Ghana. *e Journal of Science & Technology,* 4(8), 15-30.