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Assessment of Spatial and Temporal Variations in Water Quality Dynamics of River Ganga in Varanasi

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ABSTRACT: River Ganga is one of the prime sacred National Rivers of India, closely associated with economic, social, and cultural heritage of Indian people. Recently, it has been subjected to immense degradation and pollution as a result of receiving huge amounts of domestic and industrial wastewater as well as religious ritual activities and surface runoff. The present study attempts to study spatial and temporal changes in water quality of River Ganga while calculating its Water Quality Index (WQI) by analyzing 9 physico-chemical, 7 trace metal, and 4 microbiological parameters at eleven sampling stations, on the basis of River Ganga index of Ved Prakash. Thus it can assess water's suitability for drinking and irrigation purposes along with other human uses. The study is directed towards the use of WQI to describe pollution level in the river for a period of 1 year (from January to December 2014). It has been shown that index values as per CPCB class range between medium to good, while the ones as per NSF Index range from bad to good water quality. The study also identifies critical pollutants, affecting the river water quality within its course through the city. Finally, pH, DO, BOD, DO, EC, and FC have been found to be critical parameters for the stretch in each season of this research.

Keywords: Nitrate, Heavy Metals, Manikarnika Ghat, spatial distribution, temporal variation

INTRODUCTION

It is universally accepted that the environment keeps degrading and deteriorating at a rapid rate. The degrading development, industrialization and its concomitant urbanization, unlimited use of fossil fuels, rapid population growth, and indiscriminate use of chemical fertilizers and insecticides have depleted natural resources (Singh, 2010; Pejman et al., 2009; Kunwar, 2004). Rivers are the most vital natural resource for human development, yet presently they are being polluted by indiscriminate disposal of domestic sewage, industrial waste, and plethora of human activities, affecting its physico-chemical and microbiological quality (Mishra et al. 2009; Singh, 2014; Singh and Singh, 2007). Due to the vital importance of water resources to human health and natural ecosystems, their qualitative and quantitative monitoring overtime would be of utmost account (Tavakol et al., 2017a). Past decades have seen increased monitoring of river water quality by means of measuring various water

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quality parameters. However, due to spatial and temporal variations in water quality, often difficult to interpret, a monitoring program that provides a representative and reliable estimation of surface waters quality is necessary (Noori et al. 2010).

The River Ganga is one of world's greatest rivers, perhaps not in physical terms but in spiritual ones. It is a fact that there are few rivers on earth to be so important to so many people. Not only is it the largest inland body of water in India, it is the sustainer of its cultural, emotional, religious, philosophical, economic, and commercial system, also (Bhutiani et al., 2015). It flows in a basin in which about 37% of India's population lives. This densely populated basin with its rich water resources has always been subject to high socio-economic pressures due to rapid growth in population, urbanization, agriculture practices, industry, and deforestation, resulting in depletion of its natural characteristics. (Tavakol et al., 2017b; Basant Rai, 2013; Hamner et. al, 2006). With most of the cities and towns on the banks of Ganga having neither sewerage nor sewage treatment plant, the river water has been considerably polluted along many of these river cities. The extraordinary resilience as well as the recuperative capacity of the river has not been able to cope up with the pollution and check the rapid deterioration of its water quality anymore (Bhutiani and Khanna, 2016; Sharma and Kansal, 2011; Mishra, 2010; Vega, 1998).

The sacred city of Varanasi on the banks of River Ganga is one of the oldest living cities of the world with a recorded history of about 3000 years, being referred to even in earlier literary and mythological texts. Varanasi is situated on the left bank of the river, 1395 km away from its source at an average altitude of 80 m above sea level. There are more than 100 Ghats alongside Ganga in Varanasi. It is believed that people are cleansed physically, mentally, and spiritually in Ganga Ghats. It is in Ganga Ghats where we see life and death together. For thousands of years people have been coming to these Ghats to offer their morning prayers to the rising sun. The year 1860 saw the first attempt to build a drainage system on modern scientific lines in Dashaswamedh Ghat. A sewer line was constructed in 1899, which having passed through the entire old city of Varanasi discharged in Raj Ghat. The beginning of Ganga pollution with sewage is most closely linked to flush toilets and sewerage systems, the use of which began to spread after 1912. Further growth in using the sewerage system and increase in sewage flows to Ganga took place at the upstream point of the city. In 1964 the Diesel Locomotive Works (DLW) started discharging its sewage and industrial wastes to Ganga. Furthermore, another industrial site opened on the other side of the river, near Ram Nagar, some 5 km upstream Varanasi. This also resulted in a convenient recourse of sewage discharge into one of previously-noted open channels –the Shahi drain or Assi and Varuna River, by the Benaras municipal board. Every year millions of people bathe in Ganga River ghats in Varanasi region. It is important to monitor and judge the river water quality with reference to the indicators near the river bank (and not in terms of their average value for entire width). It is also important to keep this bathing area free from any pollution with regards to all water quality indicators, particularly the fecal coliform count.

MATERIAL AND METHOD

The city of Varanasi is located in the middle Ganga valley, North of India, in the Eastern part of Uttar Pradesh state, along the left crescent-shaped bank of the Ganga River. The urban agglomeration stretches between 82° 56'E - 83° 03'E and 25° 14'N - 25° 23.5'N. The study was performed at the selected sites, along a 12-km-long stretch of Ganga River in Varanasi for one year, from January 2014 to December 2014. This region's climate is tropical monsoonal with the year divided into a hot and dry summer (Pre-Monsoon), a humid rainy season (Monsoon), and a cold winter season (Post-Monsoon). The ambient mean temperature was lowest in December (9.9 to 26.1 °C) and highest in May-June (27.8 to 40.9 °C). The rainy months remained warm and wet, with humidity reaching close to saturation. The day length was recorded to be the longest in June (about 14 hours) and the shortest in December (about 10 hours). Wind direction shifted predominantly westerly and south-westerly in October through April and easterly and north-westerly in remaining months. Varanasi's principal attractions for pilgrims and tourists are a long string of bathing Ghats along the Ganga River. After a vigorous survey of Ganga River eleven sampling sites were selected along the stretch of the river for water quality assessment (Figure 1, Table 1).

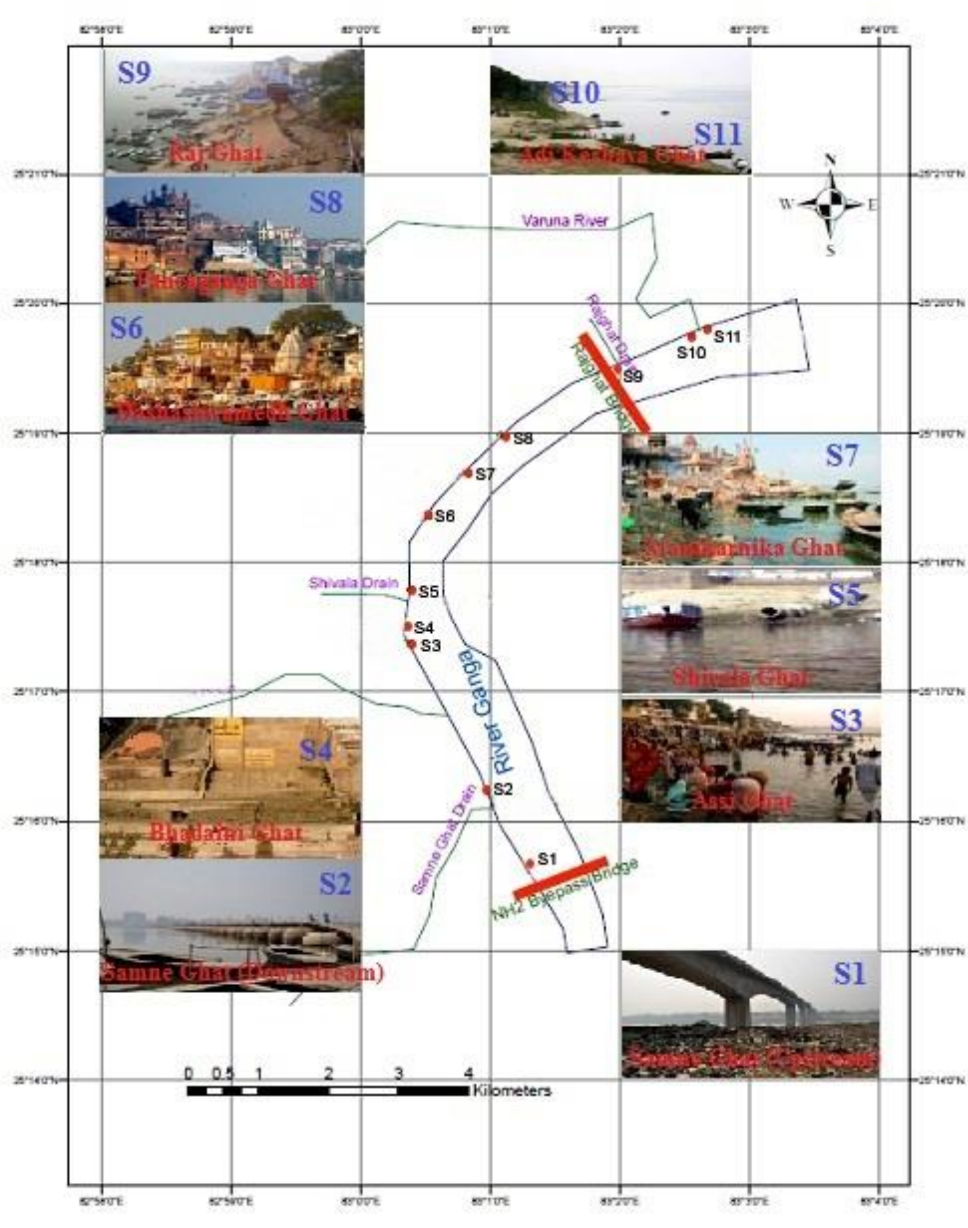

Fig. 1. Study sites at Ganga River in Varanasi

Table 1. Detailed description of the study sites at Ganga River in Varanasi along with the respective point and non-point sources of pollution.

<table>
<tr><th>Station name</th><th>Abbreviation</th><th>Geomorphic co-ordinates</th><th>Anthropogenic threats</th><th>Small and large scale industries in Varanasi</th></tr>
<tr><td>Samne Ghat (Upstream)</td><td>S1</td><td>25°16′14.2″N 83°00′58.6″E</td><td>Agricultural runoff , religious ritual activities, bathing, cloth washing, heap of municipal solid waste disposal along the river bank, domestic sewage discharge</td><td rowspan="11">REGISTERED INDUSTRIAL UNIT: 7,033

Type of industry: Agro-based, leather-based, Chemical/Chemical-based, rubber, plastic & petro-based, metal-based (steel fab.), repairing & servicing, engineering units, woolen, silk & artificial thread-based clothes, etc. (Source: DIC, Varanasi)</td></tr>
<tr><td>Samne Ghat (Downstream)</td><td>S2</td><td>25°16′17.1″N 83°00′57.3″E</td><td>Agricultural runoff, religious ritual activities, bathing, cloth washing, domestic waste disposal, domestic sewage discharge</td></tr>
<tr><td>Assi Ghat</td><td>S3</td><td>25°17′20.4″N 83°00′25.2″E</td><td>Religious ritual activities, bathing, boating, heap of domestic solid waste disposal along the river bank</td></tr>
<tr><td>Bhadaini Ghat</td><td>S4</td><td>25°17'20"N 83°0'24"E</td><td>Religious ritual activities, boating heap of domestic solid waste disposal along the river bank, domestic sewage discharge, pumping station</td></tr>
<tr><td>Shivala Ghat</td><td>S5</td><td>25°17′46.9″N 83°00′26.3″E</td><td>Religious ritual activities ,laundry station, boating, domestic sewage discharge</td></tr>
<tr><td>Dashashwamedh Ghat</td><td>S6</td><td>25°18′24.2″N 83°00′38.2″E</td><td>Religious ritual activities, boating, heap of organic waste disposal along the river bank, domestic sewage discharge, pumping station</td></tr>
<tr><td>Manikarnika Ghat</td><td>S7</td><td>25°18′39.2″N 83°00′51.5″E</td><td>Religious ritual activities, human bodies' cremation, organic waste discharge</td></tr>
<tr><td>Pancaganga Ghat</td><td>S8</td><td>25°18'54"N 83°1'5"E</td><td>Religious ritual activities, organic waste discharge, boating, domestic sewage discharge</td></tr>
<tr><td>Raj Ghat</td><td>S9</td><td>25°19'39.72" N 83°02'8.16" E</td><td>Agricultural runoff, heap of domestic and municipal solid waste disposal along the river bank. domestic sewage discharge, pumping station</td></tr>
<tr><td>Adi Keshava Ghat (Upstream)</td><td>S10</td><td>25.19N, 83.240E</td><td>Agricultural runoff, heap of domestic and municipal solid waste disposal along the river bank, fishing</td></tr>
<tr><td>Adi Keshava Ghat (Downstream)</td><td>S11</td><td>25.19N, 83.240E</td><td>Agricultural runoff, boating, fishing, heap of domestic and municipal solid waste disposal along the river bank, domestic sewage discharge</td></tr>
</table>

Samples were collected in the summer (pre-monsoon), the humid rainy season (monsoon), and the cold winter season (post-monsoon) of 2014 to monitor changes, caused by agricultural runoff, urban discharge, laundry, heap of municipal solid waste, industrial effluent, and anthropogenic as well as natural sources. The samples were analyzed as per standard methods for twenty different Physico-Chemical, trace metal, and microbiological parameters, namely pH, temperature, turbidity, total dissolved solids, dissolve oxygen, biological oxygen demand, chemical oxygen demand, free CO2, phosphates, nitrates, arsenic, led, copper, cadmium, zinc, nickel and Esherichia coli, fecal coliform Salmonella paratyphi, and Salmonella typhi. In situ measurement was adopted to determine unstable parameters, including pH, temperature, total dissolved sold (TDS), and dissolve oxygen (DO) by a portable multi parameter (Eutech -PCD650 and Eutech-CyberScan DO 110), to minimize the errors with time due to biological and chemical reactions between the atmosphere and the sample (Hutton 1983). Sampling, preservation, transportation, and analysis of other parameters was carried out in accordance with standard methods of APHA (2001). Composite sampling took place at each site, with the samples being qualitatively analyzed and presented in Table 2. The indexes used, are described below:

The River Ganga Index of Ved Prakash et al. (Abbasi and Abbasi 2012) Water Quality over the study period was evaluated, using the Ganga River Index of Ved Prakash et al. This WQI is based on the weighted multiplication form and is obtained from the following equation:

$$WQI = \sum_{i=1}^{p} WiIi$$

where Wi is the weight associated with the i^{th} water quality parameter; Ii, the sub index for the i^{th} water quality parameter; and p, the number of water quality parameters. This index is based on WQI by National Sanitation Foundation (NSF-WQI) with slight modifications in terms of the weights to conform to water quality criteria for different categories of usages, set by the Central Pollution Control Board, India.

RESULTS AND DISCUSSION

Table 2 shows the seasonal statistical variations of physicochemical, heavy metals, and microbiological parameters at different sampling sites in Ganga River during the 1-year period (January 2014–December 2014).

It has been well established that huge sewage discharge and dead body cremation are the prime sources of organic matter of Ganga River in Varanasi (Tripathi and Tripathi, 2011; Pandey et al. 2014), which in turn affect the river water quality. The highest temperature values were recorded (27.4±0.65°C) in pre-monsoon season, followed by monsoon and post-monsoon, with the river's temperature ranging between 20.30°C and 28.4°C. The maximum temperature (28.4°C) was observed at site S7 during Pre-Monsoon sampling, whereas the minimum one (20.3°C) belonged to site S3 during Post-monsoon period. Water temperatures generally fluctuate naturally both daily and seasonally with air temperature. Surface water bodies are capable of buffering water temperature; even moderate changes in water temperature can have serious impacts on river ecosystem due to narrow temperature tolerance by aquatic organisms. High amounts of sewage discharges as well as religious ritual activities along the river bank significantly change river water temperature. What is more, pH ranged from 7.1 to 8.4, with the highest mean values belonging to monsoon and the lowest ones to post-monsoon in the majority of the study sites. The highest and lowest pH values were recorded both in monsoon season, at S1 and S7, respectively. Overall, the pH value was within alkaline range, due to its direct reception of domestic waste discharge and leaches from the heap of organic waste along the river bank. High TDS in water indicates more ionic concentration, which is of inferior palatability and induces an unfavorable physicochemical reaction in the consumers (Kumar et. al. 2015). The amount of TDS recorded in the river water ranged between 342 mg/l and 702 Mg/l, with the minimum value being recorded during pre-monsoon as well as post-monsoon season in S10 and S6, respectively, and the maximum one in monsoon season in S7. Ascending trends in TDS were observed at each sampling station during monsoon season, thanks

Table 2. Seasonal Statistical variations (Range, X ±SD) among various Physico-chemical, microbiological, and heavy-metal parameters in water from eleven study sites of Ganga River, recorded in 2014

Parameters	Unit	Std.	PRM		M		POM	
			Range	X ±SD	Range	X ±SD	Range	X ±SD
T	^0C	-	26.4-28.4	27.4±0.65	25.6-27.1	26.13±0.42	20.3—21.4	20.85±0.44
p^H	-	6.5-8.5	7.2-8.3	7.87±0.32	7.1-8.4	7.89±0.40	7.2-8.2	7.59±0.42
TDS	mg/l	500	342-413	370.45±22.22	422-702	551±95.25	342-412	376.82±23.96
DO	mg/l	<6	1.8-4.6	2.7±0.97	1.9-4.7	3.03±0.89	2.1-5.3	3.5±1.08
BOD	mg/l	>2	138-242	196.82±29.73	128-216	178.18-29.85	118-206	165.18±30.16
COD	mg/l	10(WHO)	286-388	331.82±35.98	264-368	312±33.78	242-346	290.91±31.80
Free CO_2	mg/l	-	11.1-22.5	15.73±3.32	12.3-22.4	16.6±3.03	8.9-18.6	13.23±3.11
phosphate	mg/l	25(EPA)	1.32-2.58	1.77±.0.39	1.42-2.68	1.84±0.43	1.38-2.82	1.91±0.46
Nitrate	mg/l	45	1.12-2.82	1.99±0.64	1.08-2.67	1.88±0.57	1.16-2.82	1.97±0.62
As	mg/l	0.010	0.037-0.056	0.047±.005	0.033-0.052	0.040±0.006	0.036-0.052	0.043±0.005
Pb	mg/l	0.010	0.022-0.032	0.026±0.004	0.016-0.026	0.020±0.003	0.018-0.032	0.024±0.004
Cu	mg/l	0.050	0.024-0.042	0.031±0.006	0.018-0.032	0.024±0.005	0.022-0.038	0.029±0.005
Cd	mg/l	0.003	0.023-0.044	0.032±0.006	0.018-0.034	0.026±0.005	0.020-0.040	0.029±0.006
Zn	mg/l	5.0	0.286-0.920	0.444±0.20	0.256-0.822	0.412±0.197	0.282-0.718	0.405±0.150
Hg	mg/l	0.001	0.028-0.053	0.04±0.008	0.026-0.048	0.038±0.007	0.027-0.052	0.039±0.008
Ni	mg/l	0.020	0.032-0.062	0.045±0.008	0.024-0.052	0.035±0.008	0.026-0.054	0.040±0.008
EC	C	-	11.2×10^4-49.2×10^4	$26.43\times10^4\pm12.05\times10^4$	13.6×10^4-68.8×10^4	$32.7\times10^4\pm16.5\times10^4$	8.6×10^4-44.2×10^4	$24.29\times10^4\pm10.97\times10^4$
FC	C	-	8.2×10^4-48.6×10^4	$25.48\times10^4\pm12.33\times10^4$	13.2×10^4-68.6×10^4	$32.11\times10^4\pm16.7\times10^4$	7.8×10^4-$43.8.8\times10^4$	$23.89\times10^4\pm10.97\times10^4$
SP	C	-	3×10^2-8×10^2	$5.27\times10^2\pm1.16\times10^2$	16×10^2-32×10^2	$22.63\times10^2\pm4.90\times10^2$	3×10^2-7×10^2	$4.81\times10^2\pm1.47\times10^2$
ST	C	-	2×10^2-6×10^2	$3.54\times10^2\pm1.5\times10^2$	2×10^2-6×10^2	$3.54\times10^2\pm1.5\times10^2$	0	0

PRM=Pre-monsoon; **M**=Monsoon; **POM**=Post-monsoon; **X**=Mean; **SD**=Standarddeviation; **T**=Temperature; **EC** = *Escherichia coli*; **FC**= *feacal Coliform*; **SP**= ***Salmonella paratyphi: ST***= *Salmonella typhi;* **C**= CFU/100ml, **Std.**=Standard(BIS 10500 : 2012)

to the strong presence of dissociate electrolyte and dissolved organic matter, entering into the river water through a number of point and non point sources. DO is essential to maintain various forms of life in the river water. It ranged from 1.8 to 5.3 with the highest value being recorded in post-monsoon season at S2 and the lowest one in pre-monsoon at S7 and S9. The current trends of DO depletion in most sampling stations is due to the presence of high organic load, poured by drain, as well as religious ritual activities along the river bank. Inorganic reducing agents such as hydrogen sulphide, ammonia, nitrite, ferrous iron, and certain oxidizable substances also tend to decrease dissolved oxygen in water (Tarzwell, 1957). The BOD value, recorded in the river water, ranged between 118 mg/l and 242 Mg/l. The maximum BOD value of 242 mg/L was recorded in S7, followed by S3, in pre-monsoon, whereas the minimum value, equal to 118 mg/L, was observed at S1 followed by S2. In all sites BOD was higher than even the value, prescribed by the standards. Such a high value in every sampling station indicates that there has been some irreparable damages due to reckless discharge of untreated organic waste as well as religious ritual activities along the river bank. Depleting DO, increasing the TDS, high quantum discharge, and lack of adequate water flow may significantly make the BOD increase in river water bodies, with piles of garbage heaped along the river as well as dead bodies of humans and animals contributing to this phenomenon, too. COD is quite useful to find out the pollution strength of sewage as well as industrial waste. The amount of COD, recorded in the river, ranged between 242 mg/l and 388 mg/l. Maximum COD of 388 mg/L belonged to S7, followed by S9 in pre-monsoon, while the minimum (242mg/l) was found in S4 during post-monsoon season. The current trends in increasing COD concentration were found in the bottom water, which possesses more organic matter (Prasad & Qayyum, 1976). Discharge of untreated industrial and domestic waste as well as religious ritual activities along the bank of river can be considered a considerable contributor to inorganic and organic carbon to raise COD. Free CO2 is present in river water as dissolved gas, being quite useful to find out the pollution strength of organic waste. The amount of free CO2, recorded in the River water, ranged between 8.9 mg/l and 22.5 mg/l. Free CO2 were observed to be the highest 22.5 mg/l and 22.4 at S7 in pre-monsoon and monsoon seasons, respectively with the minimum value being 8.9 mg/l at S2 in post-monsoon season. Degrading organic waste as well as nutrient richness may increase free CO2 in river water. The nitrate ranged from 1.08 to 2.82 mg/l, while phosphate fluctuated between 1.32 and 2.82 mg/l. Nitrate proved to be the highest 2.82 mg/l at S9 in pre-monsoon and S6 in post monsoon, followed by S6 in pre-monsoon and S5 in post-monsoon. The minimum value was 1.08 mg/l at S8 in monsoon, followed by S8 in pre-monsoon season. At the same time, the highest amount of phosphate, equal to 2.82 mg/l, belonged to S9 in post-monsoon and the lowest one, 1.32 mg/l, to S3 in pre-monsoon. Most of the sites had been receiving domestic sewage too; therefore, heavy influx of organic load was noticed, here. Phosphate and Nitrate were higher in most locations, due to the increase of pollution load through domestic sewage, addition of nutrients, agricultural runoff, and organic matter in water (Sanap et al. 2006; Bhutiani et al. 2016).

Trace metals are considered major sources of pollution in surface waters. Owing to its toxicity, abundance, and persistence in environment, trace metal contamination in surface water is a major international concern. Arsenic is a widespread pollutant in the world; its toxicity, related to its chemical form, wherein the inorganic forms are considered more toxic than the organic ones, differing considerably in terms of effects and processes of metabolism. The concentration of arsenic was the lowest at S10 (0.033 mg/l) in monsoon season and the highest at S9 (0.056 mg/l) in pre-monsoon, followed by S9 in post-monsoon season. Significant climbs of arsenic concentrations in river water in Varanasi is due to the discharge of urban and industrial waste water, particularly sewage. The concentration of copper in the river water ranged between 0.018 mg/l and 0.042 mg/l, with the maximum amount of the metal (0.042 and 0.038 mg/l) belonging to S9 in pre-monsoon and monsoon seasons, respectively, while the minimum value (0.018 mg/l) occurred at S1 in monsoon season. The discharge of raw sewage seems to be the primary source of copper in the river water. The highest concentrations of lead (0.032 mg/l) were sighted at S1 in pre-monsoon as well as S11 in post-monsoon, while the lowest ones (0.016 mg/l) belonged to S10, followed by S5 in monsoon season. The source of Pb in Varanasi may be plastic and rubber industries, paint, metal and alloy industries, battery works, fabric works, and solid waste dumping, etc. Industrial wastewater in Varanasi is mixed with the city's sewage network, and goes untreated directly into the river Ganga. The highest and lowest concentrations of Cadmium were found at S2 (0.044 mg/l) in pre-monsoon season and S5 (0.018 mg/l) respectively. The dominance of an exchangeable fraction of Cd shows anthropogenic origin and high mobility between aqueous (water) and solid (sediment) phases under suitable physico-chemical conditions (Pandey et al. 2014; Qiao et al., 2013; Sharma and Subramanian, 2010). The concentration of zinc was the lowest at S8 (0.256 mg/l) in monsoon season and the highest at S11 (0.920 mg/l) in pre-monsoon. The source of Zn in Varanasi could be various small scale iron-alloy industries as well as discharge of untreated effluents from other medium- and small-scale establishments. In the present study, Mercury concentration varied from 0.026 mg/l (at S10 in monsoon season) to 0.053 mg/l (at S2 followed by S9, both in pre-monsoon season). Presence of mercury in the river showed that the source of pollution in Varanasi might have been untreated drains, carrying waste from urban and industrial effluent. The highest concentration of nickel (Ni) in the present study belonged to S9 (0.062 mg/l), followed by S9 (0.054 mg/l) in post-monsoon, while the lowest concentration was recorded at S1 (0.024 mg/l) in monsoon season. The higher concentration of Ni in the river water than the baseline concentration suggested the anthropogenic origin of the metal in the river (Qiao et al., 2013; Sharma and Subramanian, 2010).

Bacteria are the chief decomposer and indicator of organic pollution. Escherichia coli, Faecal coliform, Salmonella paratyphi, and Salmonella typhi were studied as microbiological pollution indicators. Bacterial population had been affected by seasonal variations with their maximum concentration being found in monsoon due to favorable temperature, high turbidity, and addition of further sewage and feacal matter through surface runoff. Low bacterial concentration of post-monsoon season was because of lowest water temperature and comparatively low input of organic matter. Feacal Coliform is supposed to be a more reliable indicator of feacal pollution of water than E. coli (Kennar, 1978), because not only are they unable to multiply outside the bodies of human and other warm blooded animals (Mathur and Ramanathan, 1966; Mishra and Tripathi, 2007) but their survival is more prolonged in surface water than other coliform types. In favorable conditions, when they find suitable hosts, these pathogenic bacteria, like Salmonella typhi, and S. paratyphi, in the water may cause acute to severe diseases. The pathogenic bacteria were prominent in monsoon season as organic matters enhanced their growth and multiplication, which was followed by pre-monsoon season.

Water quality index plays a major role in the assessment of water quality from a given source as a function of time and other influential factors. Also the sampling time significantly influenced water quality parameters and, consequently, the index value. In the modern era water quality indices are approaches that minimize the data volume to a great extent and simplify the expression of water quality status, in comparison to conventional methods, since the evaluation of water quality is based on comparison of experimentally-determined parameter values with the existing guidelines. By comparing different parameters with their standard values, WQI manages to give water quality in a single value. As many as 9 physico-chemical, 7 trace metal, and 4 microbiological parameters were considered to compute the Water Quality Index (WQI) so that river water quality could be evaluated the for different purposes (Table 4; Figure 2). WQI reveals that the water of Ganga River in Varanasi is moderately to severely polluted, being unfit for human consumption. It needs sufficient treatment and management. Sampling Stations S3, S6, S7, S9, and S11 are moderately polluted, whereas S1, S2, S4, S5, S8, and S10 are severely polluted, in comparison to NSF WQI index (Table 5), making them unfit for both human purposes such as drinking, bathing, etc. and aquatic ecosystem, as a result of anthropogenic activities such as bathing, cleaning, and leachates from solid wastes like paper, cloths, flowers, and leaves in addition to municipal sewage and industrial wastewater which is mixed with the city's sewage network and goes directly into the river untreated, being nonpoint sources of pollution in the study area. The variations of WQI values in all stations are due to the fluctuations in the quantity of water and waste disposals in the river (religious ritual activities as well as domestic, industrial, and solid wastes).

Table 3. Unit weights for the parameters of river water quality, used for the calculation of WQI

Parameter	Unit weight (*wi*)	Assigned Unit weight (Wi)	Parameter	Unit weight (*wi*)	Assigned weight (Wi)
T	0.04	0.011325	Pb	0.10	0.028313
p^H	0.12	0.033975	Cu	0.02	0.005663
TDS	0.002	0.000566	Cd	0.33	0.093431
DO	0.17	0.048131	Zn	0.20	0.056625
BOD	0.5	0.141563	Hg	1	0.283126
COD	0.10	0.028313	Ni	0.05	0.014156
Free CO_2	0.10	0.028313	EC	0.16	0.0453
phosphate	0.04	0.011325	FC	0.16	0.0453
Nitrate	0.02	0.005663	SP	0.16	0.0453
As	0.10	0.028313	ST	0.16	0.0453

Table 4. WQI of water quality for Ganga River in Varanasi City

Site	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
WQI	44.61	45.3	51.51	44.62	49.21	50.69	53.67	45.95	59.19	46.21	51.45

Table 5. NSF WQI for various designated best use*.

Serial No	NSF WQI	Description of quality (1978)	Class by CPCB	Remarks
1	63-100	Good to excellent	A	Non polluted
2	50-63	Medium to good	B	Non polluted
3	38-50	Bad	C	Polluted
4	38 & less	Bad to very bad	D,E	Heavily polluted

*CPCB 2001, Abbasi 2002.

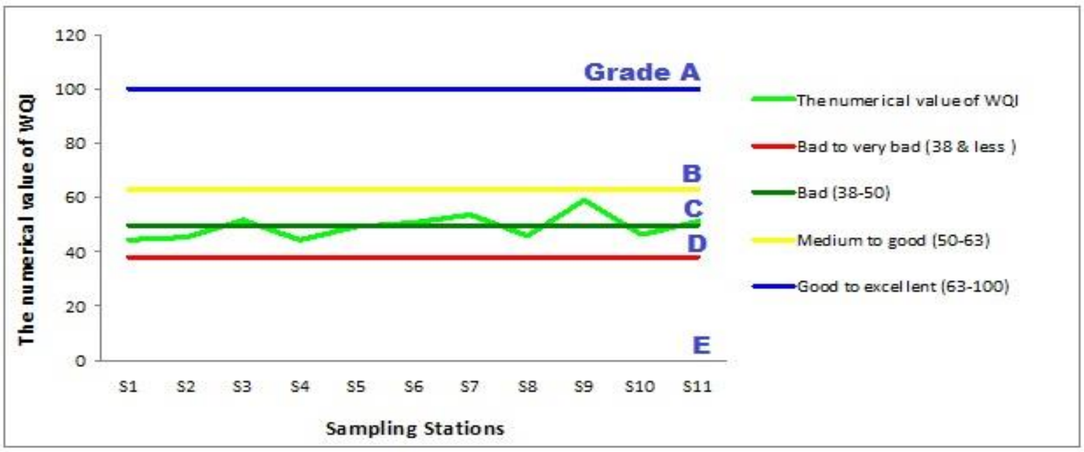

Fig. 2. WQI of Ganga River in Varanasi City with reference to NSF WQI and CPCB

CONCLUSION

Using water quality index for a complete year, the present study took a seasonal variation into account in order to make the necessary conclusions. WQI Value is a very useful tool for evaluation of overall pollution of water bodies. The WQI values of the present study indicate that the water samples from the river have been moderately contaminated with respect to physico-chemical, heavy metal, and microbiological parameters. The data for different sampling sites have been successfully collected during the aforementioned time period and it has been used to discuss the pollution level of Ganga River. Over the course of a year, the river has been subjected to human interference regularly and the water quality has been continuously deteriorated profoundly. Major anthropogenic activities, practiced in and around the stretch, including agriculture, obstruction of water for irrigation and drinking, washing clothes and utensils, discharge of sewage water as well as industrial effluent, disposal of municipal solid waste along the bank of river, and religious ritual activities along the stretch, has been posing a serious threat to biota by altering the physico-chemical, microbiological, and heavy metal concentration of the river system. Moreover, this analysis will help in future water control management program as it has outlined the parameters, contributing to pollution for every site. It is, therefore, necessary to develop a comprehensive river water quality monitoring program all over the world (Sharma and Kansal 2011).

Authors' contributions

All of the authors have the same contribution, having read and approved the final manuscript.

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