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ORIGINAL ARTICLE

Assessment of Ganga river ecosystem at Haridwar, Uttarakhand, India with reference to water quality indices

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Abstract The river Ganges is regarded as one of the most holy and sacred rivers of the world from time immemorial. The evaluation of river water quality is a critical element in the assessment of water resources. The quality/potability of water that is consumed defines the base line of protection against many diseases and infections. The present study aimed to calculate Water Quality Index (WQI) by the analysis of sixteen physico-chemical parameters on the basis of River Ganga index of Ved Prakash, weighted arithmetic index and WQI by National sanitation foundation (NSF) to assess the suitability of water for drinking, irrigation purposes and other human uses. These three water quality indices have been used to assess variation in the quality of the River Ganga at monitored locations over an 11-year period. Application of three different indexes to assess the water quality over a period of 11 years shows minor variations in water quality. Index values as per River Ganga Index by Ved Prakash et al. from 2000 to 2010 ranged between medium to good, Index values as per NSF Index for years 2000–2010 indicate good water quality, while Index values as per the weighted arithmetic index method for the study period indicate poor water quality.

Keywords Water quality · Water Quality Index (WQI) · River Ganges · Drinking purpose · Water pollution

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Introduction

The river Ganges in India is regarded as the most holy and sacred rivers of the world by Hindus from time immemorial. Bhagirathi is the source stream of Ganga. It emanates from Gangotri Glacier at Gaumukh at an elevation of 3,892 m (12,770 feet). Many small streams comprise the headwaters of Ganga. The important among these are Alaknanda, Dhauliganga, Pindar, Mandakini and Bhilangana. At Devprayag, where Alaknanda joins Bhagirathi, the river acquires the name Ganga. It traverses a course of 2,525 km before flowing into the Bay of Bengal. The Ganga river basin is the largest river basin in India, extending over the states of Uttarakhand, Uttar Pradesh, Haryana, Himachal Pradesh, Delhi, Bihar, Jharkhand, Rajasthan, Madhya Pradesh, Chhattisgarh and West Bengal (MoEF 2009). The most culturally significant hotspot of the river is at Haridwar where according to Hindu mythology it is said to have descended from the heavens. The holy city of Haridwar is located in the north Indian state of Uttaranchal at a distance of 214 km from Delhi at the foothills of Shivalik. The distance from Rishikesh to Hardwar is about 28.3 km. Haridwar extends from latitude 29°58′ in the north to longitude 78°13′ in the east. The city is situated at a height of almost 300 m above sea level and the temperature usually hovers around 40 °C during summers. Winters see the mercury dipping to as low as 6 °C.

The river has been the focus of national and international intervention and study for past several decades to identify and establish causes and impact of anthropogenic activities on river water quality. Ganga river basin, which was comparatively free from anthropocentric activities until the 1940s, became a disposal site for agricultural, industrial and sewage wastes after independence of India in 1947 (Singh 2010). Ganga plain is one of the most densely populated regions of the world, due to its availability of water, fertile soil and suitable landscape. Today, over 29 cities, 70 towns and thousands of villages extend along the Ganga banks. Nearly all of their sewage—over 1.3 billion liters per day—goes directly into the river, along with thousands of animal carcasses, mainly cattle (Bhardwaj et al. 2010). Domestic and industrial wastewater constitute as a constant polluting source, whereas surface runoff is a seasonal phenomena mainly controlled by climate (Singh et al. 2004). Cultural and religious tourism on the banks of the river Ganga along with heavy influx of tourists has been one of the reasons of deterioration in water quality (Farooquee et al. 2008). Unwarranted activities such as location of toilets within submergence area of the river beach during rainy season, disposal of untreated liquid waste, disposal of garbage, etc., affect the quality of river water. Activities such as the Kumbh mela contribute to the change in water quality. An examination of water quality of River Ganga at Allahabad (Shrivastava et al. 1996) concluded that mass bathing causes significant changes in river water quality.

Assessment of surface water quality can be a complex process undertaking multiple parameters capable of causing various stresses on overall water quality. Water Quality Index (WQI) is a very useful and efficient method for assessing the suitability of water quality. It is also a very useful tool for communicating the information on overall quality of water to the concerned citizens and policy makers. The concept of WQI to represent gradation in water quality was first proposed by Horten. The use of WQIs simplifies the presentation of results of investigation related to a water body, as it summarizes in a single unitless value, the combined effect of a number of water quality parameters analyzed. Several water quality indexes are in use to assess quality of natural waters (Tyagi et al. 2013). Thus, the indices not only convey information concerning water quality but also facilitate spatial and temporal comparisons. WQI indicates water quality in terms of a single index number and is useful in monitoring water quality. To analyze water quality, different approaches such as statistical analyses of individual parameter, multi-stressors water quality indices, etc., have been considered (Venkatesharaju et al. 2010). WQI has been used for assessing quality of River Ganga in the past. WQI using C++ program found River Ganga water to be unsuitable in Uttarpradesh (Aenab and Singh 2013). WQI index based on computer program of River Ram Ganga in western UP classified river water into permissible, slight, moderate and severe on the basis of the pollution strength selected from upstream to downstream of the river for a period of 3 years (Alam and Pathak 2010). Bhargava (1982) in a survey of total length of the river Ganga found that quality index was far above the prescribed limit at Kanpur. He further found that the Ganga water was having unusually fast regenerating capacity by bringing down biochemical oxygen demand (BOD) owing to the presence of large amount of well-adopted microorganisms. Analysis of river Ganga water at Rishikesh using WQI at Rishikesh for drinking, recreation and other purpose using eight water quality parameters: turbidity, dissolved oxygen (DO), BOD, chemical oxygen demand (COD), free carbon dioxide (free CO_2), total solids (TS), total suspended solids (TSS) and total dissolved solids (TDS) revealed that the water is not suitable for drinking purpose (Chauhan and Singh 2010).

Materials and methods

This study is an attempt to evaluate the historical changes in water quality of River Ganga at Haridwar. For this study, three water quality indices have been used to assess variation in the quality of the River Ganga at monitored locations (Fig. 1) over an 11-year period. The samples were analyzed as per standard methods for sixteen different Physico-Chemical parameters namely temperature, conductivity, turbidity, velocity, total solids, total dissolved solids, pH, D.O., B.O.D., C.O.D., free CO_2, alkalinity, hardness, phosphates, nitrates and chlorides. In situ measurement was adopted to determine unstable parameters including; pH, EC and DO by portable meters. The probe of each meter device was placed in the center of the stream in approximately half of its total depth. Analysis of the other parameters was carried out by volumetric analysis in accordance with standard methods of (APHA 1998). The indexes used have been 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 River Ganga Index of Ved Prakash et al. This WQI is based on the weighted multiplication form and is given by the equation:

$$\mathrm{WQI} = \sum_{i=1}^{p} W_i I_i$$

where, I_i denotes subindex for ith water quality parameter, W_i is the weight associated with ith water quality parameter, and p is the number of water quality parameters.

This index is based on the WQI by National sanitation foundation (NSF-WQI) with slight modifications in terms of weightages to conform to the water quality criteria for different categories of uses set by the Central Pollution Control Board, India. A list of parameters was selected

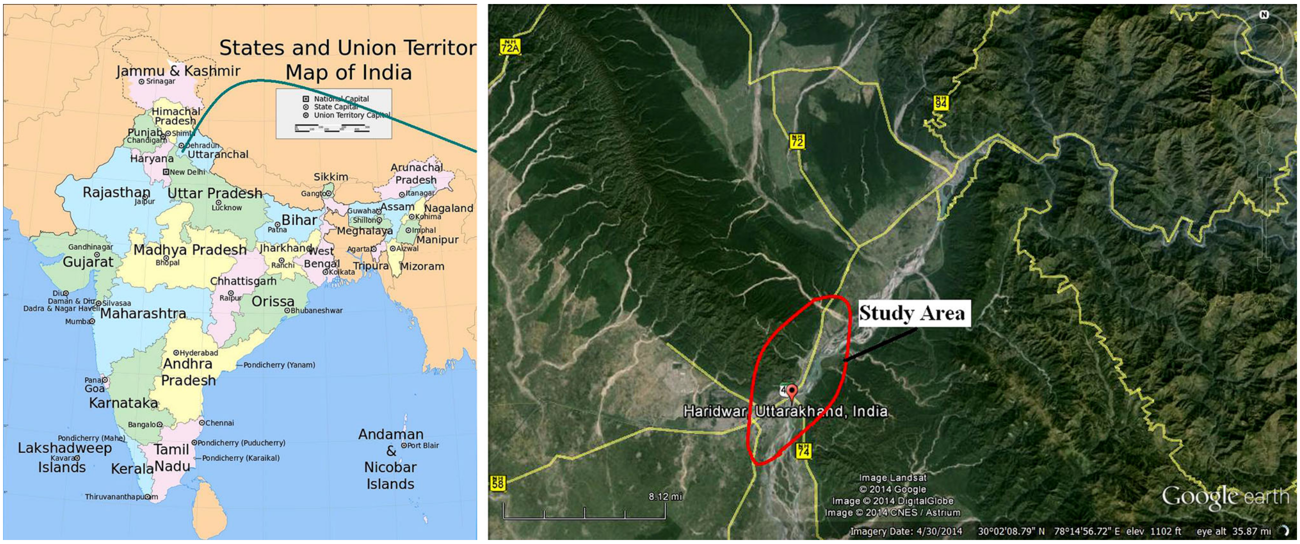

Fig. 1 Study area for monitoring water quality

through Delphi. Subindex values were obtained from sub-index equations for different parameters.

To assign weightages, significance ratings were given to all parameters. A temporary weight of 1 was assigned to parameter with highest significance rating e.g., Dissolved Oxygen. Final weight was arrived at by dividing the temporary weight by the sum of all weights.

WQI by National Sanitation Foundation (NSF-WQI)

NSF is a World Health Organization Collaborating Centre for Food and Water Safety and Indoor Environment and was founded from the University of Michigan's School of Public Health. Brown et al. (1970) developed a WQI which was supported by the National Sanitation Foundation (NSF). Browns Index is also referred to as NSF-WQI. This Index represents general water quality and does not recognize specific water use functions such as drinking, agriculture, etc. As part of index development, 142 experts were asked to rate 35 water quality parameters for inclusion in the index. The experts were asked to assign values for each parameter for variation in water quality caused due to change in concentration of each parameter. Judgement of all respondents was averaged to produce a set of curves; for each parameter, eleven factors were chosen and based on their merit a weighted mean was used to combine the values. The index originally proposed by Brown et al. (1970) had the form

$$\mathrm{WQI} = \sum_{i=1}^{9} w_i T_i(p_i) = \sum_{i=1}^{p} w_i q_i$$

where, $P =$ measured value of the ith parameter, $T =$ quality rating transformation (curve) of the ith parameter value. p_i into a quality rating q_i, such that,

$T_i p_i = q_i$, and

w_i is the relative weight of the ith parameter.

Arithmetic weighted index

In this study, WQI was calculated by the arithmetic index method as described by Cude (2001). The arithmetic weighted index method has been used by several water quality investigators (Ramakrishniah et al. 2009; Chowdhury et al. 2012; Rao et al. 2010; Balan et al. 2012; Ahmad et al. 2012).

As per this method, different water quality components were multiplied by a weighting factor and were then aggregated using simple arithmetic mean. For assessing the quality of water in this study, the quality rating scale (Q_i) for each parameter was calculated using the following equation;

$$Q_i = \{[(V_{\text{actual}} - V_{\text{ideal}}) / (V_{\text{standard}} - V_{\text{ideal}})] * 100\}$$

where $Q_i =$ quality rating of ith parameter for a total of n water quality parameters $V_{\text{actual}} =$ actual value of the water quality parameter obtained from laboratory analysis $V_{\text{ideal}} =$ ideal value of that water quality parameter can be obtained from the standard tables. V_{ideal} for pH $= 7$ and for other parameters it is equaling to zero, but for DO $V_{\text{ideal}} = 14.6$ mg/l $V_{\text{standard}} =$ recommended WHO standard of the water quality parameter.

After calculating the quality rating scale (Q_i), the Relative (unit) weight (W_i) was calculated by a value inversely proportional to the recommended standard (S_i) for the corresponding parameter using the following expression;

$$W_i = 1/S_i$$

Table 1 Mean values and fluctuations among physico-chemical parameters of River Ganga during 11 years

Parameters	Year of study											Average
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	
Temp. (°C)	14.40 ± 2.14	15.84 ± 1.24	15.42 ± 2.45	16.10 ± 2.57	15.78 ± 1.98	16.5 ± 2.03	15.10 ± 2.44	16.80 ± 2.68	16.90 ± 2.93	15.9 ± 2.87	16.5 ± 1.45	15.93 ± 0.75
Conductivity (µ mhos/cm)	187.70 ± 28.12	199.30 ± 30.15	175.20 ± 29.54	182.30 ± 31.11	178.00 ± 32.25	185.30 ± 29.87	205.60 ± 30.25	195.00 ± 31.56	198.80 ± 32.57	210.00 ± 33.15	195.50 ± 28.88	192.04 ± 11.24
Turbidity (JTU)	3.57 ± 0.98	2.47 ± 0.89	2.69 ± 1.01	3.50 ± 1.12	1.95 ± 0.99	3.57 ± 1.12	4.20 ± 1.20	3.95 ± 0.87	2.98 ± 1.01	3.56 ± 1.15	3.99 ± 1.16	3.31 ± 0.70
Velocity (m/s)	1.50 ± 0.21	1.44 ± 0.10	1.50 ± 0.18	1.75 ± 0.09	1.80 ± 0.07	2.10 ± 1.01	1.75 ± 0.87	1.99 ± 0.64	2.32 ± 0.55	3.50 ± 0.77	3.00 ± 0.49	2.05 ± 0.65
T. S. (mg/l)	112.00 ± 24.10	545.20 ± 35.22	450.00 ± 33.56	455.00 ± 41.25	540.60 ± 84.54	555.50 ± 95.23	450.30 ± 79.50	590.60 ± 99.23	650.60 ± 87.28	625.30 ± 85.12	590.50 ± 68.58	505.93 ± 147.87
T.D. S. (mg/l)	395.00 ± 98.57	406.50 ± 106.5	435.10 ± 111.5	495.20 ± 112.5	398.30 ± 98.57	415.20 ± 99.68	390.30 ± 87.59	412.10 ± 97.54	398.30 ± 86.36	402.30 ± 89.99	399.30 ± 91.54	413.39 ± 29.78
pH	7.10 ± 0.06	7.25 ± 0.04	7.15 ± 0.02	7.25 ± 0.04	7.10 ± 0.03	7.20 ± 0.04	7.12 ± 0.02	7.30 ± 0.02	7.12 ± 0.05	7.15 ± 0.04	7.19 ± 0.05	7.17 ± 0.06
D.O. (mg/l)	10.82 ± 0.78	9.56 ± 0.59	9.50 ± 0.48	10.15 ± 0.87	9.75 ± 0.78	10.50 ± 0.91	11.50 ± 0.56	9.85 ± 0.45	10.75 ± 0.49	11.00 ± 0.67	9.50 ± 0.58	10.26 ± 0.69
B.O.D (mg/l)	1.75 ± 0.69	2.10 ± 0.75	2.25 ± 0.89	1.80 ± 0.45	2.10 ± 0.67	2.15 ± 0.45	1.25 ± 0.56	1.95 ± 0.37	1.90 ± 0.61	1.30 ± 0.34	1.75 ± 0.34	1.84 ± 0.32
C.O.D. (mg/l)	12.00 ± 0.68	8.69 ± 0.56	9.50 ± 0.98	10.25 ± 0.87	8.95 ± 0.67	11.75 ± 0.78	10.26 ± 0.98	9.85 ± 0.85	9.25 ± 0.79	8.75 ± 0.94	9.25 ± 0.79	9.86 ± 1.12
Free CO_2 (mg/l)	1.95 ± 0.11	2.91 ± 0.18	2.25 ± 0.17	1.90 ± 0.21	2.10 ± 0.25	1.75 ± 0.14	2.25 ± 0.16	1.90 ± 0.17	2.20 ± 0.12	1.95 ± 0.16	2.20 ± 0.11	2.12 ± 0.31
Alkalinity (mg/l)	59.00 ± 3.54	50.67 ± 4.58	62.25 ± 6.54	65.50 ± 6.57	59.50 ± 4.89	55.55 ± 4.57	63.35 ± 6.54	54.25 ± 5.48	59.56 ± 5.47	68.35 ± 4.58	63.35 ± 4.97	60.12 ± 5.18
Hardness (mg/l)	61.00 ± 8.57	97.27 ± 9.58	73.45 ± 10.24	85.54 ± 11.24	95.25 ± 8.56	69.59 ± 10.56	79.90 ± 12.45	89.95 ± 15.57	67.75 ± 13.24	86.65 ± 11.25	92.85 ± 10.78	81.74 ± 12.24
Phosphates (mg/l)	0.05 ± 0.01	0.07 ± 0.02	0.05 ± 0.01	0.06 ± 0.01	0.08 ± 0.01	0.05 ± 0.02	0.07 ± 0.02	0.06 ± 0.01	0.05 ± 0.03	0.06 ± 0.01	0.05 ± 0.01	0.05 ± 0.01
Nitrates (mg/l)	0.05 ± 0.02	0.03 ± 0.02	0.02 ± 0.01	0.05 ± 0.01	0.07 ± 0.01	0.05 ± 0.01	0.06 ± 0.02	0.07 ± 0.03	0.07 ± 0.01	0.06 ± 0.02	0.05 ± 0.01	0.05 ± 0.01
Chlorides (mg/l)	7.20 ± 0.24	5.40 ± 0.35	6.50 ± 0.44	7.25 ± 0.56	6.75 ± 0.34	7.56 ± 0.54	5.95 ± 0.64	5.98 ± 0.24	6.95 ± 0.28	6.95 ± 0.33	7.52 ± 0.45	6.72 ± 0.69

± standard deviation

where, W_i = relative (unit) weight for nth parameter S_i = standard permissible value for nth parameter 1 = proportionality constant.

Finally, the overall WQI was calculated by aggregating the quality rating with the unit weight linearly using the following equation:

$$\mathrm{WQI} = \sum Q_i W_i / \sum W_i$$

where, Q_i = quality rating, and W_i = relative weight

In general, WQI is defined for a specific and intended use of water. In this study, the WQI was considered for human consumption or uses, and the maximum permissible WQI for the drinking water was taken as 100 score.

Results and discussion

A-physiochemical parameters

The result of various physico-chemical parameters is tabulated in Table 1. The value of temperature ranges from 14.4 ± 2.14 to 16.90 ± 2.93 °C. The average value of 11 years was found to be 15.93 ± 0.75 °C. The maximum amount of conductivity was found to be 210.00 ± 33.15 µ mhos/cm and the minimum value of 175.20 ± 29.54 µ mhos/cm was noticed. The average value of 11 years was found as 192.04 ± 11.24 µ mhos/cm. Semwal and Akolkar (2006) found the value of conductivity in between 172.75 and 175.00 S/cm while working on river Ganga. Turbidity exhibited the highest value of 4.20 ± 1.20 JTU, while the least value was found to be 1.95 ± 0.99 JTU. Badola and Singh (1981) investigated almost similar trend in the rivers of Garhwal region. Velocity was observed maximum at 53.50 ± 0.77 m/s, while minimum value of 1.44 ± 0.44 m/s was noted. The average value of 11 years was found as 2.05 ± 0.65 m/s. Total solids were observed maximum 650.60 ± 85.12 mg/l and the minimum value was noticed as 112.00 ± 24.10 mg/l; the average value for 11 years was found as 505.93 ± 147.87 mg/l. Total dissolved solids were observed to be the highest 495.20 ± 112.50 mg/l and the minimum value was noticed as 390.30 ± 87.59 mg/l. The average value of 11 years was found as 413.39 ± 29.78 mg/l. Same thing was observed by Khanna et al. (2006), Badola and Singh (1981) in Suswa River and Abbasi et al. (1996) in Punmurpuzha River of Kerala. pH was observed to be the highest 7.30 ± 0.02 and the minimum value was noticed as 7.10 ± 0.06. The average value of 11 years was found as 7.17 ± 0.06 mg/l. Dissolved oxygen showed the extreme value 11.00 ± 0.67 mg/l, while the least value was observed to be 9.50 ± 0.48 mg/l in year 2002 and 2010. The average value of 11 years was found as 10.26 ± 0.69 mg/l. Biochemical oxygen demand displayed the highest value 2.25 ± 0.89 mg/l and the lowest value of 1.25 ± 0.56 mg/l was observed during course of study. The average value of 11 years was found as 1.84 ± 0.32 mg/l. Khaiwal et al. (2003) and Khanna et al. (2007) noted the similar thing in river Yamuna and in river Ganga correspondingly. The minimum value as well as maximum value of chemical oxygen demand was observed to be 8.69 ± 0.56 and 12.00 ± 0.68 mg/l, respectively. The average value of 11 years was found as 9.86 ± 1.12 mg/l. Khanna et al. (2007) worked on the River Ganga and found average value of chemical oxygen demand to be 3.94 mg/l. The Ganga water contained highest free CO_2 2.91 ± 0.18 mg/l during course of this study followed by a gradual decrease to its lowest value of 1.75 ± 0.14 mg/l. The average value of 11 years was found as 2.12 ± 0.31 mg/l. The Ganga water contained highest alkalinity 63.35 ± 4.97 mg/l during course of this study in the year 2006 and 2010 followed by a gradual decrease to its lowest value of 50.67 ± 4.58 mg/l. The average value of 11 years was found to be 60.12 ± 5.18 mg/l. Same observation was also made by Holden and Green (1960). The maximum (97.27 ± 9.58 mg/l) hardness of water was recorded and the minimum 61.00 ± 8.57 mg/l was noted during course of study. The average value of 11 years was found as 81.74 ± 12.24 mg/l. Khanna et al. (2007) found average value of total hardness 12.71 mg/l while working on river Ganges. The nitrate ranged from 0.02 to 0.07 mg/l, while Phosphate fluctuated from 0.05 to 0.08 mg/l. Some sites receive domestic sewage too, so heavy influx of organic load is noticed here. Parameters such as turbidity, COD, total alkalinity and total hardness, phosphate and nitrate were higher in some locations; this was because of increase in pollution load by domestic sewage, addition of nutrients, agricultural runoff and organic matter in water (Sharpley and Menzel 1987; Gupta et al. 2003; Sanap et al. 2006).

Calculation of WQI

Table 2 shows the results of WQI for the study period from Year 2000 to Year 2010 obtained by River Ganga index by Ved Prakash et al, NSF index and Weighted arithmetic index. Application of three different indexes to assess the water quality over a period of 11 years shows minor variations in water quality. Index values as per River Ganga Index by Ved Prakash et al from 2000 to 2010 were 51.69, 51.96, 50.68, 52.55, 50.78, 51.42, 52.26, 52.82, 51.50, 52.64 and 52.05, respectively, indicating water quality to be ranging between medium to good. Index values as per NSF Index for years 2000–2010 were 78,74,75,76,74,72,75,74,73,74 and 74, respectively, indicating good water quality. Index values as per the Weighted Arithmetic Index method for the study period

Table 2 Water Quality of River Ganga during study period as per different indexes

Year	River Ganga index by Ved prakash et al.		NSF index		Weighted arithmetic index	
	WQI	Description	WQI	Description	WQI	Description
2000	51.69	Medium to good	78	Good	58.13	Poor water quality
2001	51.96	Medium to good	74	Good	70.35	Poor water quality
2002	50.68	Medium to good	75	Good	58.19	Poor water quality
2003	52.55	Medium to good	76	Good	66.84	Poor water quality
2004	50.78	Medium to good	74	Good	73.05	Poor water quality
2005	51.42	Medium to good	72	Good	60.09	Poor water quality
2006	52.26	Medium to good	75	Good	72.63	Poor water quality
2007	52.82	Medium to good	74	Good	69.50	Poor water quality
2008	51.50	Medium to good	73	Good	56.28	Poor water quality
2009	52.64	Medium to good	74	Good	64.72	Poor water quality
2010	52.05	Medium to good	74	Good	63.44	Poor water quality

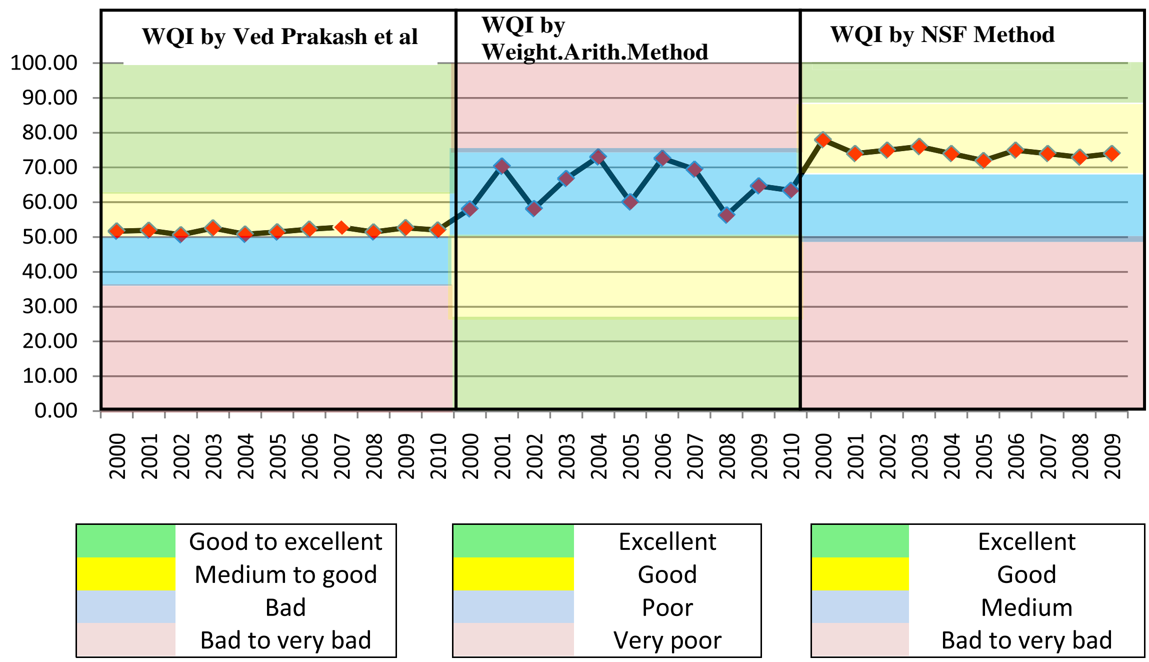

Fig. 2 Comparison of WQI scores by different methods

were 58.13, 70.35, 58.19, 66.84, 73.05, 60.09, 72.63, 69.5, 56.28, 64.72 and 63.44, indicating good water quality as per index parameters. While the River Ganga Index by Ved Prakash et al and the NSF Index showed similar water quality, the weighted Arithmetic method assigned poor water quality to the Ganga river with deterioration in water quality from 2000 onwards (Fig. 2).

Conclusion

The River Ganga Index by Ved prakash et al. showed that water quality in study area ranged between medium and good quality. As per the NSF, the WQI of the river is good whereas as per the weighted Arithmetic method the quality of river water is poor. Thus, it can be concluded that the water quality of the River Ganga over the 11-year study period ranges from poor to good, which also conforms to various studies on WQI of the river. Keeping in mind increasing urbanization and pollution loading of rivers, necessary measures should be taken to reduce future contamination loads from entering the river. The study establishes that sewerage, solid and liquid waste contaminants or organic nature are the prime sources of pollution. The study supports planned periodic monitoring of water quality through use of WQI for selected parameters to benchmark water quality by season and locations.

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