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Assessment of Water Quality in Ganga River Ghats of Varanasi District, Uttar Pradesh, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Water is the most vital biosphere component since it sustains all life, circulates and cycles nutrients. Water is also necessary for power generation, navigation, agricultural irrigation and sewage disposal. The increasing water demand is a result of the rising population and industrialization and has severely compromised water quality. Water quality assessment is the most important process for evaluating the chemical characteristics of water bodies. To assess whether the water is suitable

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for a variety of uses after locating any pollutants, contaminants, or other potentially hazardous compounds that may be present in the water. A systematic study was conducted to assess the water quality in the Ganga river in the Ghats of Varanasi district of Uttar Pradesh, India, from January to March 2019. The assessment involves water samples from different Ghats along the river, namely Babua Pandey Ghat (G_1), Digpatia Ghat (G_2), Chausatti Ghat (G_3), Ranamahal Ghat (G_4), and Darbhanga Ghat (G_5). The analytical data from various physico-chemical parameters indicates that the pH values were found to be near neutral, electrical conductivity (EC) did not differ significantly, Ca+Mg varied from 22.80 to 28.40 mg/L, Cl^- was found to be 2.40 to 3.20 mg/L, Na^+ varied from 1.0 to 1.10 mg/L, K^+ and SO_4^{2-} showed a similar trend, TS was varied from 400 to 1200 mg/L, DO varied from 5.80 to 7.30 mg/L, COD varied from 16.0 to 22.40 mg/L, NO_3^- varied from 25.27 to 29.60 mg/L, B varied from 4.90 to 5.80 mg/L, SAR is 0.27 to 0.33 mg/L, The Bureau of Indian Standard (BIS) has been considered to assess the suitability for drinking and other purposes and It concluded that some of the parameters were almost constant for all the five Ghats samples, like Na^+ and K^+ content, while other parameters varied. Out of thirteen parameters, only three (NO_3^-, B, and Cl^-) showed an increasing trend.

Keywords: Ganga River; water quality; water resources; physico-chemical properties; Varanasi.

1. INTRODUCTION

Rivers have been a crucial source of freshwater for human settlements for thousands of years, and provide water for drinking, agriculture, and industry, among other uses [1]. Ganga river is the largest river in India and the fourth largest in the world. Its catchment area is a huge 861,404 square kilometres and includes parts of various Indian states. It flows for a total length of 2,525 kilometers before emptying into the Bay of Bengal [2]. The Ganga river basin is one of the most populated river basins in the world, with millions of people living in the surrounding areas and relying on the river for their daily needs, including irrigation, transportation and drinking water [2]. Since it travels through densely populated regions, the Ganga river collects vast quantities of human pollutants, which pose substantial health concerns to individuals as well as environmental dangers to the ecosystem's sustainability [3]. The Indian government has launched several initiatives and programs aimed at cleaning and restoring the Ganga river, which aims to improve water quality and restore ecological health across the entire river basin. An exact and balanced appraisal of water quality is needed for deciding the degree of the helpfulness of water bodies for different employments. Many researchers have assessed the water quality in the Ganga river. In the Varanasi district of Uttar Pradesh some parameters, like pH, hardness, and total dissolved solids have exceeded the maximum values indicated by the world health organization (WHO) [3]. Haritash et al. [2] assessed the water quality and suitability of the Ganga river in Rishikesh, Uttrakhand, and found that the quality of irrigation water ranged from good to excellent at almost all places except for percent sodium. Kumari et al. [4] analyzed the water quality in the Ganga river at different Ghats of the Patna district of Bihar, it was found the Kali ghat was maximum dissolved oxygen, electrical conductivity biological oxygen demand and chemical oxygen demand indicating higher pollution. Another experiment was carried out to evaluate the physico-chemical properties of water in the Ganga river in the Ghazipurdistrict of Uttar Pradesh [5]. Our study is conducted to assess the water quality in the Ganga river in Varanasi city. Varanasi, also known as Banaras or Kashi, is one of the oldest continuously inhabited cities in the world and is regarded as a spiritual and cultural center of India.

2. MATERIALS AND METHODS

2.1 Site Description

Varanasi city is situated (Latitude 25°15´N to 25°22'N and Longitude 82°57'E to 83°1´E) in the middle Ganga valley of North India, in the eastern part of the state of Uttar Pradesh. Varanasi city is located in the northern part of India in the state of Uttar Pradesh. The city is situated on the banks of the holy river Ganges and is bounded by Jaunpur and Ghazipur to the north, Mughal Sarai to the southeast, Bihar state to the east, Bhadohi to the west and Mirzapur to the south. Varanasi has a humid subtropical climate with hot summers, cool winters and monsoon rains. The city experiences a less dry climate compared to other parts of Uttar Pradesh. The summer months of May and June are the hottest, with temperatures often

Table 1. Methods used for the analysis of various chemical parameters of Ganga river water of Varanasi city

Parameters	Methods	Desirable and Permissible limits, Indian Standards (BIS) (IS 10500: 1991, 2012)
pH	Electrometric method	6.5-8.5
EC	Direct determination	0.5-5.0 (dS/m)
Ca^{2+}	Complexometric titration	75 & 200 (mg/L)
Mg^{2+}	Complexometric titration	30 & 100 (mg/L)
Cl^-	Argentometric method	250-1000 (meq/L)
Na^+	Flame photometric method	20-200 (mg/L)
K^+	Flame photometric method	12 (mg/L)
SO_4^{2-}	Turbidity method	200-400 (mg/L)
TS	Gravimetric method	500-2000 (mg/L)
DO	Winkler method	6 (mg/L)
COD	Winkler method	250 (mg/L)
NO_3^-	Brucine method	45 (mg/L)
B	Calorimetric curcumin Method	0.5 -1.0 (mg/L)
SAR	Richards method	0.10-0.30 (meq/L)

exceeding 40 degrees Celsius. The monsoon season in Varanasi typically starts in the third week of June and continues till October. The city receives an annual rainfall of about 1050 to 1200 mm, which is crucial for the agricultural economy of the region. Winter in Varanasi starts in mid-October and lasts till February, with December and January being the coldest months. The average temperature during the winter is around 10 degrees Celsius. The fertile land in and around Varanasi is a result of the low-level floods in the Ganges, which continually replenish the soil with nutrients. The agricultural economy of the region depends on this fertile land, which supports a variety of crops like rice, wheat, sugarcane, and vegetables.

2.2 Sample Collection and Analysis

Water samples were randomly collected over the 60 m stretch and 1 m depth of 5 selected Ghats*viz.* G_1-Babua Pandey Ghat, G_2-Digpatiya Ghat, G_3-Chausatti Ghat, G_4-Ranamahal Ghatand G_5-Darbhanga Ghat, during January to March 2019 and the analysis of various chemical properties are shown in Table 1.

3. RESULTS AND DISCUSSION

3.1 Physico–chemical Properties

The present study was conducted to assess the water quality of the Ganga river in Varanasi city. The pH, Electrical conductivity (EC), Calcium+Magnesium (Ca+Mg), Chloride (Cl^-), Sodium (Na^+), Potassium (K^+), Sulphate (SO_4^{2-}), Total solids (TS), Chemical oxygen demand COD), Nitrate (NO_3^-), Boron (B) and Sodium absorption ratio (SAR) were estimated.

3.1.1 pH

The pH was determined by using a pH meter, which measures the concentration of hydrogen ions (H^+) in the solution [6]. In our study, the pH values of Ganga water were found to be 7.10 to 7.40 at Digpatia Ghat and Chausatti Ghat (Table 2). The alkaline pH range in almost all the water samples might be attributed to the overall alkaline character of the effluents given to sampling locations. Similar results were also reported by Singh et al. [7]. These pH values have within the desirable and permissible limit of Indian standards (BIS). From Table 3, it was found that pH is significantly positively correlated with potassium (0.6) and sulphate (0.6) and negatively significantly correlated with COD (-0.9) and sodium (-0.7). The discharge of sewage into a river can cause a decrease in the pH value of the water at and around the point of discharge [8].

3.1.2 Electrical conductivity (EC)

The concentration of total salt content in waters, expressed in terms of EC, is an essential criterion for determining the appropriateness of water quality. As shown in Table 2, the minimum mean value of EC 0.47 dS/m was found in Darbhanga Ghat and the maximum value of EC 0.49 dS/m was found in Chausatti Ghat. These EC values have lower concentrations of Indian standards (BIS). The increase in EC values of water suggests the presence of a nearby source of dissolved ions in the vicinity. A greater concentration of dissolved solids signifies a higher concentration of salt ions in water [9]. The disintegration and mineralization of organic material result in elevated amounts of conductivity and cations [10]. All downstream sites show a large rise in EC, a trend confirmed by observations reported by Srivastava and Sinha, [11]. In the observed samples we found that sodium content is positively correlated with boron (0.20) and COD (0.90) and negatively correlated with potassium (-0.60) and nitrate content (-0.10) (Table 3).

3.1.3 Ca^{2+} and Mg^{2+}

The total concentration of Ca^{2+} and Mg^{2+} cations in a given water sample is referred to as the hardness of the water [12]. In most cases, natural water contains the highest concentrations of calcium [13]. For the determination of total Ca^{2+} and Mg^{2+} (meq/L), the Ethylene diamine tetra acetic acid (EDTA) method was used. The EDTA method which is based on the reaction of Ca^{2+} and Mg^{2+} salts with EDTA or its disodium salt applies to all types of water except wastewater. This method depends on how well EDTA or its disodium salt can combine with calcium and magnesium ions to form stable complexes. In our study (Table 2), the maximum Ca^{2+} and Mg^{2+} content was at Digpatia Ghat (28.40 meq/L) while it was found to be minimum in Darbhanga Ghat (22.80 meq/L). These Ca^{2+} and Mg^{2+}content values have a lower concentration as compared to BIS standards recommended. From Table 3, it can be concluded that sodium content is positively non-significant correlated with boron (0.20) and COD (0.90) while is negatively significantly correlated with potassium (-0.60) and nitrate nitrogen content (-0.10).

3.1.4 Chloride (Cl^-)

The Cl^- value of the Ganga river of Babua Pandey Ghat was found to be 2.4 mg/L which is the minimum value among the five Ghats. The maximum values of Chloride (3.2 mg/L) were found in Darbhanga Ghat and in between the three Ghats have a constant value of 2.8 mg/L. These values are much less than the prescribed range of Indian Standards [14]. The Cl^- analysis was done by silver nitrate titration method. An increase in Cl^- content can be due to the decomposition of organic matter. High concentrations of chloride may also be due to mineral deposits, industrial waste, and domestic waste [15]. From Table 3, it can be concluded that there is a significant positive correlation with B (0.9) and NO_3^- (0.8) and a negative correlation with TS (-0.5) and EC (-0.40).

Table 2. Physico-chemical parameter levels at different ghats of the Ganga river at Varanasi city

Parameters	Locations of different Ghats				
	G_1	G_2	G_3	G_4	G_5
pH	7.30	7.10	7.40	7.30	7.20
EC (dS/m)	0.48	0.49	0.49	0.48	0.47
Ca+Mg (meq/L)	25.8	27.0	28.4	23.0	22.8
Cl^- (mg/L)	2.40	2.80	2.80	2.80	3.20
Na^+ (mg/L)	1.10	1.10	1.00	1.10	1.10
K^+ (mg/L)	1.40	1.50	1.30	1.10	1.20
SO_4^{2-} (mg/L))	19.0	23.0	35.0	36.0	21.0
TS (mg/L)	1200	800	400	800	800
DO (mg/L)	6.20	5.80	6.90	7.30	7.00
COD (meq/L)	19.20	22.4	16.0	20.8	22.4
NO_3^- (mg/L)	25.27	26.4	28.2	29.6	29.6
B (mg/L)	4.90	5.00	5.10	5.30	5.80
SAR (mg/L)	0.31	0.30	0.27	0.32	0.33

Where,Babuapandey ghat (G_1), Digpatia ghat (G_2), Chausatti ghat (G_3), Ranamahal ghat (G_4) and Darbhanga ghat (G_5)

Table 3. Correlation between differentphysico–chemical parameter levels at different ghats of the Ganga river in Varanasi city

Parameters	pH	EC (dS/m)	Ca+Mg (meq/L)	Cl^- (mg/L)	Na^+ (mg/L)	K^+ (mg/L)	SO_4^{2-} (mg/L)	TS (mg/L)	DO (mg/L)	COD (meq/L)	NO_3^- (mg/L)	B (mg/L)	SAR (meq/L)
pH	1.0	0.1	0.2	-0.3	-0.7	0.6	0.6	-0.3	0.6	-0.9	0.2	-0.2	-0.5
EC (dS/m)	0.1	1.0	0.9	-0.4	-0.5	0.4	0.4	-0.4	-0.5	-0.5	-0.4	-0.8	-0.9
Ca+Mg (meq/L)	0.2	0.9	1.0	-0.4	-0.7	0.1	0.1	-0.4	-0.5	-0.6	-0.6	-0.7	-0.9
Cl^-(mg/L)	-0.3	-0.4	-0.4	1.0	0.0	0.1	0.1	-0.5	0.5	0.4	0.8	0.9	0.3
Na^+ (mg/L)	-0.7	-0.5	-0.7	0.0	1.0	-0.6	-0.6	0.8	-0.2	0.9	-0.1	0.2	0.9
K^+ (mg/L)	0.6	0.4	0.1	0.1	-0.6	1.0	1.0	-0.7	0.6	-0.5	0.5	0.0	-0.4
SO_4^{2-}(mg/L))	0.6	0.4	0.1	0.1	-0.6	1.0	1.0	-0.7	0.6	-0.5	0.5	0.0	-0.4
TS(mg/L)	-0.3	-0.4	-0.4	-0.5	0.8	-0.7	-0.7	1.0	-0.4	0.4	-0.5	-0.2	0.6
DO(mg/L)	0.6	-0.5	-0.5	0.5	-0.2	0.6	0.6	-0.4	1.0	-0.2	0.9	0.6	0.2
COD (mg/L)	-0.9	-0.5	-0.6	0.4	0.9	-0.5	-0.5	0.4	-0.2	1.0	0.1	0.4	0.8
NO_3^-(mg/L)	0.2	-0.4	-0.6	0.8	-0.1	0.5	0.5	-0.5	0.9	0.1	1.0	0.8	0.3
B (mg/L)	-0.2	-0.8	-0.7	0.9	0.2	0.0	0.0	-0.2	0.6	0.4	0.8	1.0	0.6
SAR (mg/L)	-0.5	-0.9	-0.9	0.3	0.9	-0.4	-0.4	0.6	0.2	0.8	0.3	0.6	1.0

3.1.5 Sodium (Na^+)

As represented in Table 2, the sodium (Na^+) content of Ganga river water of all five Ghats was almost the same; having a value of 1.1 mg/L except for Chausatti Ghat which has a value of 1.0 mg/L. In the observed samples we found that Na^+ content is positively correlated with TS (0.80), COD (0.90), and SAR (0.9) and negatively correlated with K^+ (-0.60) and nitrate nitrogen content (-0.10) (Table 3). These Na^+ values have lower concentrations as compared to BIS standards recommended [7]. The Na^+ content of a sample is determined using flame photometry. It is useful for determining the quantitative and qualitative properties of several cations, particularly metals that are easily excited to higher energy levels at low flame temperatures (Na, Ca, K, Ba, Rb, Cs, and Cu). This sodium concentration value has a lower concentration as compared to the BIS standards recommended.

3.1.6 Potassium (K^+)

As shown in Table 2, The K^+ value of the water in the Ganga river at each of the five Ghats is distinct. The maximum K^+ content is found at Digpatia Ghat (1.50 mg/L) and the minimum at Ranamahal Ghat (1.10 mg/L). it was found that this value is lower than BIS standard. A similar result has been reported by Singh [16]. In the observed samples we found that K^+ content is significantly positively correlated with pH (0.6) and DO (0.6) while significantly negatively correlated with Na^+ (-0.60), TSS (-0.7) and COD (-0.5) (Table 3).

3.1.7 Sulphate (SO_4^{2-})

As represented in Table 2, the concentration of SO_4^{2-} in water samples was evaluated using the turbidimetric method. In our study, the SO_4^{2-} the content was maximum at Ranamahal Ghat (36 mg/L) and minimum at Babua Pandey Ghat (19 mg/L). These SO_4^{2-} values have a lower concentration of Indian Standards (BIS) [17]. The content of SO_4^{2-} is highest at Ranamahal Ghat and its trend goes on increasing; (Babua Pandey Ghat 19 mg/L) has minimum SO_4^{2-} content, whereas it is higher in the next Ghat (Digpatia 23 mg/L), then again more at Chausatti Ghat (35 mg/L), then highest at Ranamahal Ghat (36 mg/L), after that, it decreases at Darbhanga Ghat (21 mg/L). So, there is an increase in SO_4^{2-} content and at last, followed by a decrease. From Table 3, it can be concluded that there is a positive correlation of sulphate with pH (0.6), DO (0.6), and EC (0.40), while negatively correlated with Na^+ (-0.60). A similar result has been reported by Singh, [16].

3.1.8 Total solids (TS)

TS in the water sample was determined by the gravimetric method [6]. The maximum TS content in the Ganga River is estimated to be 1200 mg/L at Babua Pandey Ghat and 400 mg/L at Chausatti Ghat. Indian Standards (BIS) (IS 10500: 2012) for TS in the water sample is 500-2000 (mg/L) (Table 2). As a result, the TS content in the collected samples was found to be within the range. The TS content is found to be highest at the Babua Pandey Ghat, while it is lower than the previous Ghat at Digpatiya Ghat (800 mg/L), lowest at Chausatti Ghat (400 mg/L), and constant at Ranamahal Ghat (800 mg/L) and Darbhanga Ghat (800 mg/L). In the observed samples we found that TS content is positively correlated with the sodium (0.8), SAR (0.6) and COD (0.90) but negatively correlated with K^+ (-0.7) and sulphate (-0.7) content (-0.10) [7] (Table 3).

3.1.9 Dissolved Oxygen (DO)

Winkler method is followed to determine the DO content [18]. The concentration of DO has been found maximum at Ranamahal Ghat (7.3 mg/L) and minimum at Digpatiya Ghat (5.8 mg/L) (Table 2). The content of DO at Ranamahal Ghat is higher than the permissible limit as in Indian Standards (BIS) (IS 10500: 2012) for DO is 6 mg/L. So, it is unfit for use whereas water at Digpattiya Ghat has to DO content within permissible limits. The estimated content of DO content in Ganga water was found to be highest at Ranamahal ghat (7.3 mg/L) and there is no trend for its content in water rather it varies randomly. Its value is lowest at Digpatiya Ghat (5.8 mg/L); others are Babua Pandey Ghat (6.2 mg/L), Chausatti Ghat (6.9 mg/L), and lastly, Darbhanga Ghat (7.0 mg/L). In the observed samples we found that DO is significantly positively correlated with pH (0.6), Cl^- (0.5), K^+ (0.6) and sulphate (0.6) and negatively correlated with EC (-0.5), Ca & Mg (-0.5) (Table 3).

3.1.10 Chemical Oxygen Demand (COD)

When boiled with a mixture of potassium dichromate and sulfuric acid, the majority of the organic matter is destroyed, yielding carbon dioxide and water. In a sulphuric acid medium, a sample is refluxed with a specified amount of potassium dichromate, and the excess dichromate is titrated against ferrous ammonium sulphate. The oxygen needed to oxidize the oxidizable organic matter is directly proportional to the amount of dichromate consumed reported by Arya and Gupta [19]. Results are expressed as mg/L of O_2. As per BIS, the permissible limit of COD in water suitable for drinking purposes is 10 mg/L. The COD of Ganga river water is maximum at Darbhangaghat (22.40 mg/L) and minimum at Babua Pandey Ghat (16.0 mg/L) (Table 2). The COD of water samples collected from different Ghats are having higher COD than the permissible limit [20]. In the observed samples we found that CODcontent is positively correlated with the observed values of sodium (0.9), chloride (0.4), TS (0.4), boron (0.4) and SAR (0.9) while negatively correlated with pH (-0.69), EC (-0.5), Ca+Mg (-0.6), K^+ (-0.5) and sulphate (-0.5) in Table 3. This chemical oxygen demand content value has a lower concentration as compared to the BIS standards recommended.

3.1.11 Nitrate (NO_3^-)

There are three recommended techniques for measuring NO_3^-in waters and wastewaters; a) Cadmium reduction method, b) Chromotropic acid method and c) Devarda's alloy reduction method. The cadmium reduction method is appropriate for NO_3^-concentrations less than 0.1 mg/L. The chromotropic acid method can be used for concentrations ranging from 0.1 to 5.0 mg/L, and Devarda's alloy reduction method can be used for concentrations greater than 2 mg/L or total nitrogen. The chromotropic acid method will be used as the referee method. It has been stated by BIS that a concentration of 10-45 mg/L of NO_3^- is permissible in groundwater. For irrigation, a lower NO_3^- concentration than the BIS norm is advised. The NO_3^- concentration of Ganga river water is maximum at Darbhanga Ghat (29.67 mg/L) and minimum at Babua Pandey Ghat (25.27 mg/L) (Table 2). Water samples taken from the many Ghats along the Ganga have been analysed, and it was observed that Darbhanga Ghat had a higher pollution index as compared to other Ghats. In the observed samples we found that nitrate content is positively correlated with the observed values of chloride (0.9) and DO (0.9) negatively correlated with EC (-0.4), Ca+Mg (-0.6) and TSS (-0.5) (Table 3). Similar results were found by Singh et al. [7].

3.1.12 Boron (B)

B in the samples was estimated by the Calorimetric curcumin method [21]. As per IS 10500: [22] the permissible limit for B in the drinking water is 1.0 ppm. The water sample collected from different Ghats is having B concentration of more than 5 mg/L which is more than the standard prescribed by BIS. Thus, it is reasonable to conclude that this water is unsuitable for human consumption. As borate compounds are a component of domestic working agents, wastewater discharges can dramatically increase the borate concentration of surface water. Boron occurs naturally in groundwater, mostly as a result of seepage from borates and borosilicate-containing rocks and soils. In the observed samples, we found that B content is positively correlated with the observed values of chloride (0.09), DO (0.6), and negatively correlated with EC (-0.8), Ca+Mg (-0.7) and TSS (-0.2) (Table 3). Similar results were found by Singh et al. [7].

3.1.13 Sodium Absorption Ratio (SAR)

The SAR value of the Ganga river is maximum at Darbhanga Ghat (0.33 meq/L) and minimum at Chausatti Ghat (0.27 meq/L) (Table 2). The concentrations of these total SAR are lower than those suggested by BIS standards [7]. In the observed samples we found that SAR content is positively correlated with sodium (0.9) (Table 3). The concentrations of these total SAR are lower than those suggested by BIS standards.

4. CONCLUSION

Based on the experimental findings, Darbhanga Ghat encompasses the highest level of pollution among all Ghats. It might be about increased Cl^-, COD, NO_3^-, B, and SAR intensity across different Ghats/Ganges. The Ganga river's water quality may be somewhat improved if strict environmental monitoring is immediately established to ensure compliance with environmental regulations. Current technologies for communication are inadequate for reducing pollution. The Ganga water was considered appropriate for bathing from January to March 2019. The solutions for improving the Ganga river's water quality may involve defensive and proactive approaches. The defense approach requires quick sewage network upgrades, expanded sewage treatment capacity, and pollutant load prevention from rivers.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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