

Assessment of water quality and suitability analysis of River Ganga in Rishikesh, India

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Abstract The water samples were collected from River Ganga in Rishikesh during December 2008 to assess its suitability for drinking, irrigation, and industrial usages using various indices. Based on the values obtained and suggested designated best use, water in upper segment can be used for drinking but after disinfection (Class A); organized outdoor bathing in middle segment (Class B); and can be used as drinking water source (Class C) in lower segment in Rishikesh. All the parameters were within the specified limits for drinking water quality except *E. coli*. The indices of suitability for irrigation and industrial application were also evaluated. The irrigation quality ranged from good to excellent at almost all places with the exception of percent sodium. The abundance of major ions followed $K^+ > Ca^{2+} > Cl^- > HCO_3^- > Na^+ > Mg^{2+} > CO_3^{2-}$ trend. The major cations suggested that the water is alkaline (Na + K) than alkaline earth (Ca + Mg) type. The heavy metals (Pb, Cu, Zn, Ni) were found either absent or within the limits specified. There was no specific industrial input of pollutants. Industrial applications of the river water should be limited since the water was found to be aggressive, based on Langelier saturation index (0.3) and Ryznar stability index (8.8), with the problem of heavy to intolerable corrosion. Water quality of Ganga in Rishikesh was good with exception of most probable number (MPN) which needs regular monitoring and measures to control.

Keywords Ganga · Designated best use (DBU) · Rishikesh · Residual sodium carbonate (RSC) · Sodium adsorption ratio (SAR) · Permeability index (PI) · Langelier saturation index (LSI)

Introduction

Ganga River originates from Gangotri glacier situated between $30^{\circ}43'22''$ – $30^{\circ}50'49''$ North latitude and $79^{\circ}4'4''$ – $79^{\circ}16'34''$ East longitude, about 4,100 m above mean sea level. It is a valley-type glacier with a length of 30.20 km, and width varying from 0.5 to 2.5 km (NRCD 2009) situated in the Uttarkashi district of Garhwal Himalaya. Ganga river basin is the largest among river basins in India and the fourth largest in the world, with a catchment area of 8, 61, 404 sq km. and a total length of 2,525 km. It is one of the most densely populated river basins in the world, supporting 29 Class-I cities (population \geq 100,000), 23 Class-II cities (population 50,000–99,999), 48 towns, and thousands of villages. Over 500 million people were estimated to be living in the entire Ganga river basin in 2000, and this number is expected to grow to over 1 billion by 2030 (Markandya and Murty 2004). Nearly all the sewage from these cities enters the basin waterways partially treated or untreated, totalling 1.3 billion litres per day of human waste, and 260 million liters of industrial waste, primarily from agricultural fertilizers and pesticides (Markandya and Murty 2004). In addition to these domestic and industrial pollutants, hundreds of human corpses and thousands of animal carcasses are released to the river each day for spiritual rebirth. Studies have reported that waste discharge exceeded available river water in the state of Uttar Pradesh, just prior to the yearly monsoon (Lacy 2006; Vass et al. 2010). Population pressures, lack of proper investment in

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water quality infrastructure, limited governmental initiatives, and a lack of empowerment of the people all continue to contribute to the deteriorating state of the Ganga (Mishra and Tripathi 2008; Rai et al. 2010). Till date, there have been various studies on river water quality with reference to geochemistry and pollution (NRCD 2008, 2009; Li et al. 2009; Li and Zhang, 2010; Trivedi 2010; Seth et al. 2013), and suitability assessment of groundwater for different uses (Kaushik et al. 2000; Haritash et al. 2008; Srinivas et al. 2013; Sivasubramanian et al. 2013). The water from River Ganga is used for irrigation primarily; and as a source for drinking water and industrial applications. It, therefore, becomes imperative to assess the suitability of water for different uses. The present study has been undertaken to assess the water quality of Ganga in Rishikesh town and its suitability for drinking, agricultural, and industrial use.

Rishikesh, surrounded by virgin forests at the toe of the Himalayas, is the first town on River Ganga taken up under the Ganga Action Plan (GAP) Phase-I for pollution abatement of the river. The GAP works in Rishikesh comprise sewerage works to tap the sewage outfalls through appropriate pumping station, and diversion of the sewage to a pond type STP at Lakkarghat between Haridwar and Rishikesh. Still hundreds of ashrams, temples, residences, hotels and other commercial establishments dot the banks and this immense human activity, in a narrow band along the length of the town on both the banks, generates millions of litres of sewage per day into river Ganga. Rishikesh, unlike other cities, is the first pilgrimage-cum-tourist destination after the river enters plains, and upstream-located industrial/anthropogenic sources of pollution which may affect the water quality are absent. Any addition upstream of Rishikesh may be treated as natural. Since natural flow of water in winters is lean; and tourist activity during December (Christmas and New Year) is more, it may affect water quality adversely particularly during this period. The present study was, therefore, carried out in December to study the designated best use of water, and its suitability for different usages based on various indices of water quality.

Materials and methods

The study was carried out in Rishikesh town of Uttaranchal state. A total of 20 samples were collected along the banks of River Ganga from Mini Goa Beach (upstream of Rishikesh) to Bhardwaj Sthal (Downstream of Rishikesh) in December 2008. Sampling locations (Fig. 1) were identified on the basis of prominent activities of bathing, washing, addition of sewage/wastewater into the river. Bulk samples were collected from a distance at least five feet inside from the banks in pre-rinsed sterilized plastic bottles. The pH,

electrical conductivity (EC), total dissolved solids (TDS), temperature, and salinity (as NaCl) were analysed on the site using HACH (USA) made HQ40-D-*Multi* model meter (Hossain et al. 2010). Dissolved oxygen (DO) was also analysed on the site using DO probe fitted with HACH made HQ30-D-*Flexi* model meter. The samples were stored at 5 °C in an ice box, transported to the laboratory and analysed for other parameters within 6 h using standard methods of APHA (Eaton et al. 1995). Fluoride (F⁻) was measured using F⁻ ion electrode fitted with Thermo Orion model 720A20+ meter, and total organic carbon (TOC) was analysed on Analytik-jena Multi N/C-2100 TOC analyzer based on non-dispersive infra-red (NDIR) spectroscopy. Lead (Pb), Copper (Cu), Zinc (Zn), and Nickel (Ni) were analysed on Shimadzu made model AA-6300 atomic absorption spectrophotometer (AAS). In order to assess the suitability for irrigation residual sodium carbonate (RSC), soluble sodium percentage (SSP), sodium adsorption ratio (SAR), permeability index (PI), Kelley's ratio (KR), and magnesium hazard (Mg Haz.) was evaluated.

RSC = $(\text{HCO}_3^- + \text{CO}_3^{2-}) - (\text{Ca}^{2+} + \text{Mg}^{2+})$	(Eaton 1950)
SSP = $[\text{Na}^+ / (\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Na}^+)] \times 100$	(Eaton 1950)
SAR = $\text{Na}^+ / (\text{Ca}^{2+} + \text{Mg}^{2+})^{1/2}$	(Richards 1954)
PI = $[\text{Na}^+ + (\text{HCO}_3^-)^{1/2} / (\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Na}^+)] \times 100$	(Doneen 1962)
KR = $\text{Na}^+ / (\text{Ca}^{2+} + \text{Mg}^{2+})$	(Kelly 1963)
Mg Haz. = $(\text{Mg}^{2+} \times 100) / (\text{Ca}^{2+} + \text{Mg}^{2+})$	(Paliwal 1972)

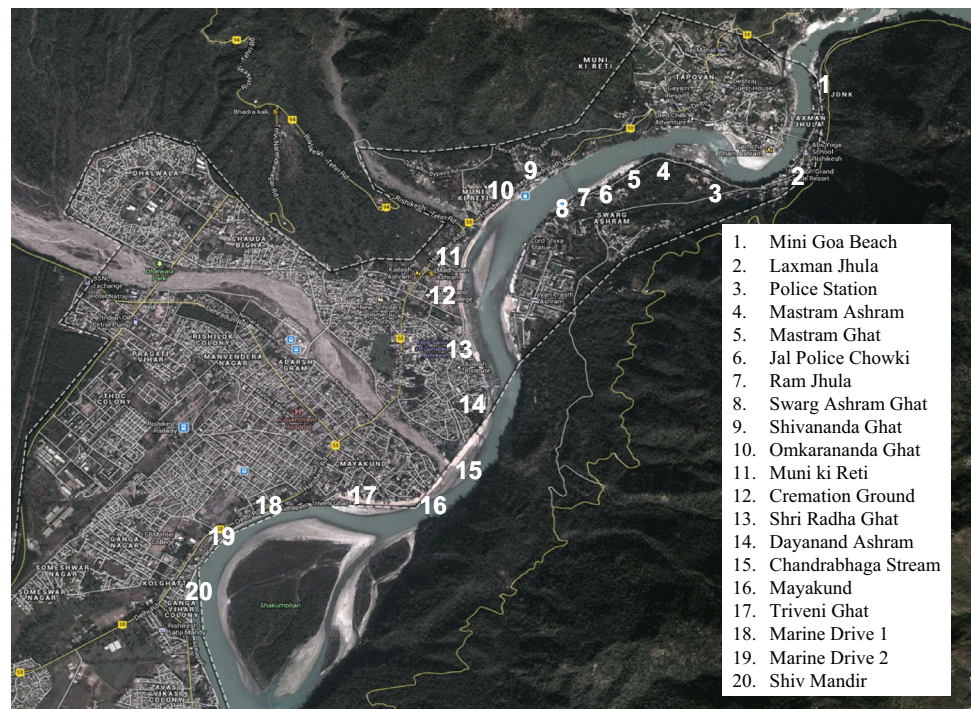
All ionic concentrations are in milli equivalent per litre (meq/l).

Results and discussion

Suitability for drinking

The representative samples collected from the study area were analysed for their physical, chemical, and biological properties for determining their designated best use. The results obtained are given in Table 1. The temperature of water was in the range of 10.2–21.0 with an average of 17.5. Comparatively higher temperatures at places could be attributed to the decreased flow rate or very shallow rocky river bed exposed to direct sunlight raising the temperature of water flowing through/over. So, temperature of the river water was observed to be a function of depth, turbulence, time of the day, and heat input from outer environment. The pH values of the samples were in the range of 9.0–10.5 with a mean value of 9.4 indicating that the water is

Fig. 1 Location of sampling sites in Rishikesh town



slightly alkaline. Electrical conductivity (EC) represents the concentration of different ions present. EC varied from 38.0 to 170 $\mu\text{S}/\text{cm}$ with the mean value of 85.2 $\mu\text{S}/\text{cm}$. Comparatively higher values were observed at location #10 and downstream owing to the external input of wastewater. Still higher values of EC from Dayanand Ashram to Triveni Ghat were a result of addition of sewage from Chandrabhaga stream and wastewater from the ashrams. The TDS ranged from 18.0 to 85.0 mg/l with an average value of 38.6. Higher values of TDS at location #11 and 12 may be attributed to addition of sewage and suspension of ashes from cremation ground near the locations. The desirable limit for TDS in drinking water is 500 mg/l. Salinity (expressed as per thousand) ranged from 0.01 to 0.08 with a mean value of 0.04. Alkalinity of the water exhibited more variation and ranged from 32.0 to 144.0 mg/l with an average value of 70.4 mg/l. About 90 % of the samples were having bicarbonate as the major species responsible for the alkalinity. As per the Bureau of Indian Standards (BIS) standards (2012) (Table 2), the limit of alkalinity in drinking water is 200 mg/l.

The dissolved oxygen (DO) in water is an important parameter to monitor the biological quality of water, and ascertain its designated best use. It supports the aquatic life forms and regulates the biological degradation of organic impurities. DO level of River Ganga in Rishikesh during December was fairly good with an average of 10.0 mg/l. A slight decrease in DO at location #11 and at confluence with Chandrabhaga could be attributed to the addition of sewage upstream. It was observed that DO concentration in

river water is a function of temperature, turbulence, depth, and organic matter present. The total hardness (TH) in river water is primarily regulated by the carbonates, bicarbonates, chlorides, sulphates, etc. of calcium and magnesium chiefly, whereas there are certain other chemical entities accounting for it. The hardness levels varied from 64.0 to 212.0 mg/l with a mean value of 101.2 mg/l. The observations revealed that the major source of hardness ions is the wastewater from domestic use. The desirable limit for total hardness in drinking water, as per BIS, India is 300 mg/l. These results revealed that wastewater from domestic use had a fair proportion of calcium bound ions adding to total hardness. The contribution of carbonate and bicarbonate ions towards hardness was analysed and it was observed that carbonate concentration was nil at most of the places except at the locations where a source of wastewater discharge was observed (4.8 mg/l). The bicarbonate concentration varied from 4.9 to 34.2 mg/l with a mean value of 18.8 mg/l. The chloride ions (Cl^-) account for the permanent hardness in water. Its concentration varied from 10.0 to 32.5 mg/l with a mean value of 22.1 mg/l, and lower concentration of chloride ions was observed at upstream locations. The concentration with respect to drinking quality was within the limit (250 mg/l) specified by BIS.

Phosphate in river water is the limiting factor for eutrophication. Phosphate levels varied from 3.6 to 4.8 mg/l with a mean value of 4.2 mg/l. Maximum concentration (4.8 mg/l) was noticed in the stretch from confluence with Chandrabhaga to Triveni Ghat and it was regulated by the

Table 1 Physico-bio-chemical characteristics of water of River Ganga in Rishikesh

Sample No.	Temp. (°C)	pH	EC (µS/cm)	TDS (mg/L)	Salinity (‰)	Alkalinity	DO	TH	CO ₃ ²⁻	HCO ₃
1	16.0	9.6	77.0	31.0	0.04	80.0	9.6	64.0	9.6	4.9
2	16.0	9.3	59.0	23.0	0.03	80.0	9.4	64.0	0.0	24.4
3	16.0	9.5	67.0	31.0	0.03	48.0	9.2	68.0	0.0	14.6
4	17.0	9.0	63.0	31.0	0.02	48.0	9.5	80.0	0.0	14.6
5	20.0	9.2	63.0	30.0	0.01	48.0	9.5	76.0	0.0	14.6
6	21.0	10.5	68.0	18.0	0.03	80.0	11.1	76.0	0.0	24.4
7	19.0	10.0	40.0	32.0	0.03	48.0	10.6	76.0	0.0	14.6
8	16.2	9.4	38.0	25.0	0.01	32.0	9.5	72.0	0.0	9.8
9	17.0	9.1	52.0	25.0	0.02	64.0	9.3	64.0	0.0	19.5
10	17.5	9.6	72.0	34.0	0.02	144.0	9.5	72.0	0.0	19.5
11	20.0	9.5	125.0	60.0	0.06	64.0	7.8	212.0	4.8	34.2
12	17.8	9.5	102.0	48.0	0.05	64.0	9.0	116.0	4.8	9.8
13	17.0	9.3	75.0	22.0	0.03	64.0	9.2	80.0	0.0	19.5
14	19.2	9.0	118.0	30.0	0.05	96.0	10.6	120.0	4.8	19.5
15	20.3	9.0	170.0	85.0	0.08	80.0	9.3	168.0	4.8	19.5
16	19.5	9.2	152.0	76.0	0.07	64.0	10.2	124.0	0.0	24.4
17	18.0	9.3	117.0	54.0	0.05	64.0	10.8	120.0	0.0	19.5
18	17.3	9.3	97.0	46.0	0.04	48.0	10.5	92.0	0.0	19.5
19	15.7	9.2	76.0	35.0	0.03	144.0	10.2	80.0	0.0	14.6
20	10.2	9.2	73.0	35.0	0.03	48.0	16.1	200.0	4.8	34.2
Range	10.2–21.0	9.0–10.5	38.0–170.0	18.0–85.0	0.01–0.08	32.0–144.0	7.8–16.1	64.0–212.0	0.0–9.6	4.9–34.2
Mean ± SD	17.5 ± 2.38	9.4 ± 0.36	85.2 ± 35.54	38.6 ± 17.94	0.04 ± 0.02	70.4 ± 29.55	10.0 ± 1.62	101.2 ± 44.86	1.7 ± 2.82	18.8 ± 7.31
Sample No.	HCO ₃	Cl ⁻	F ⁻	PO ₄ ³⁻	Na ⁺	Mg ²⁺	Ca ²⁺	TOC	BOD	MPN
1	4.9	15.0	0.25	3.6	10.1	0.0	25.6	14.5	5.4	125
2	24.4	10.0	0.27	3.8	9.8	5.0	17.6	13.3	5.6	na*
3	14.6	12.5	0.33	4.5	9.8	5.0	19.2	16.4	5.5	na
4	14.6	15.0	0.27	4.5	9.7	8.5	18.4	12.8	4.6	na
5	14.6	20.0	0.25	3.7	9.8	7.0	19.2	12.7	4.4	na
6	24.4	17.5	0.28	3.8	9.7	7.0	19.2	12.4	4.3	na
7	14.6	15.0	0.26	4.2	9.8	6.5	20.0	16.7	6.8	450
8	9.8	20.0	0.29	4.5	9.8	6.0	19.2	13.2	5.4	na
9	19.5	20.0	0.27	4.5	9.8	3.0	20.8	15.0	6.5	na
10	19.5	27.5	0.27	4.3	10.1	6.5	18.4	13.9	5.5	na
11	34.2	25.0	0.24	4.2	10.2	22.0	49.6	51.2	11.5	na
12	9.8	25.0	0.27	4.2	9.7	10.5	29.6	26.7	14.6	na

Table 1 continued

Sample No.	HCO ₃ ⁻	Cl ⁻	F ⁻	PO ₄ ³⁻	Na ⁺	Mg ²⁺	Ca ²⁺	TOC	BOD	MPN
13	19.5	32.5	0.35	3.8	10.4	7.5	20.0	15.9	12.4	3000
14	19.5	30.0	0.25	4.0	10.5	8.5	34.4	28.6	15.2	na
15	19.5	25.0	0.15	4.5	10.5	14.5	44.0	42.3	18.3	2500
16	24.4	32.5	0.22	4.8	10.4	11.5	31.2	67.0	19.3	na
17	19.5	27.5	0.22	4.8	10.4	13.0	27.2	43.9	15.6	1200
18	19.5	25.0	0.22	4.0	9.8	8.5	23.2	108.3	19.5	na
19	14.6	25.0	0.22	4.3	9.8	3.5	26.4	19.5	8.4	na
20	34.2	22.5	0.23	4.2	10.2	37.0	20.8	14.9	6.5	na
Range	4.9–34.2	10.0–32.5	0.15–0.35	3.6–4.8	9.7–10.5	0.0–37.0	17.6–49.6	12.4–108.3	4.3–19.5	125–3000
Mean ± SD	18.8 ± 7.31	22.1 ± 6.51	0.3 ± 0.04	4.2 ± 0.35	10.0 ± 0.33	6.6 ± 8.0	25.2 ± 8.84	28.0 ± 24.41	9.8 ± 5.45	1455 ± 1257

All the values expressed in mg/l except Temperature (°C), EC (µS/cm), salinity (‰), and MPN (No./100 ml); na Not Analysed

wastewater added by the stream of Chandrabhaga. Fluoride is an important parameter for establishing quality of drinking water. It was found to be fairly lower than the standard limit of 1.0 mg/l (WHO 2006). The concentration varied from 0.15 to 0.35 mg/l. The sodium (Na⁺) concentration varied from 9.7 to 10.7 mg/l with a mean value of 10.0 mg/l. Lower concentrations were represented at the sampling locations in the first segment (location #1–10) and higher levels were reported at the locations where a source of discharge was observed (location #11–17). Similarly, calcium concentration ranged from 17.6 to 49.6 mg/l with a mean value of 25.2 mg/l. It was found to be well within the limits for drinking as the desirable limit for calcium, as per Indian Standard (BIS 10500: 2012) is 75 mg/l.

In order to measure the organic pollution in Ganga, biological oxygen demand (BOD₅) and total organic carbon (TOC) were determined. The BOD₅ ranged from 4.3 to 19.5 mg/l with a mean value of 9.8 mg/l. Maximum concentration (19.5 mg/l) was observed downstream of Triveni Ghat and the probable reason is offerings in the form of milk, flowers, sweets, and addition of wastewater by a thin channel immediately downstream of Triveni ghat. Lower levels were observed in the upper segment. Similarly, TOC values were lower in the upper segment and higher in the lower stretch owing to the sources located in the region. TOC concentration varied from 12.4 to 108.3 mg/l with a mean value of 28.0 mg/l. Maximum concentration of TOC was reported at location #18. The most probable number (MPN) was determined at five locations only (S. No. 01, 07, 13, 15, and 17). It was maximum (3,000/100 ml) at location #13 followed by confluence with Chandrabhaga stream (#15) (2,500/100 ml). The disposal of night soil in river bed in the vicinity of cremation ground; and discharge from Chandrabhaga stream add the *E. coli* bacteria to the river. It reveals that most of the pollution load in River Ganga in Rishikesh is from the domestic sector.

Heavy metal is another class of pollutants responsible for many of the diseases in exposed organisms. Nickel (Ni), copper (Cu), Zinc (Zn), and Lead (Pb) were analysed in the collected water samples (Table 3). Lead was below the detection limit in all the samples. Copper was present at all the locations and ranged from 0.0321 to 0.0581 mg/l with an average value of 0.0386 mg/l. Maximum concentration was reported in lower stretch. Zinc concentration varied from 0.0304 to 1.3497 mg/l. The probable reason for the high concentration could be addition from some anthropogenic source. Nickel ranged from 0.0105 to 0.0367 mg/l. The immediately higher values at location #18 might be a result of wastewater added by a channel downstream of Triveni Ghat. The desirable limit as per BIS is 0.05 and 5.0 mg/l for Copper/Nickel/Lead and Zinc, respectively.

Table 2 Standards for drinking water (Bureau of Indian Standards (BIS) 2012; IS: 10500)

S. No.	Parameter	Acceptable limit	Permissible limit in the absence of alternate source
1.	Colour (Hazen units)	5	15
2.	Odour	Agreeable	Agreeable
3.	pH value	6.5–8.5	No relaxation
4.	Taste	Agreeable	Agreeable
5.	Turbidity (NTU units)	1	5
6.	Total dissolved solids (mg/l)	500	2000
7.	Aluminium (mg/l)	0.03	0.2
8.	Ammonia (mg/l)	0.5	No relaxation
9.	Anionic detergents (as MBAS) (mg/l)	0.2	1.0
10.	Barium (as Ba) (mg/l)	0.7	No relaxation
11.	Boron (as B) (mg/l)	0.5	1.0
12.	Cadmium (mg/l)	0.003	No relaxation
13.	Calcium (as Ca) (mg/l)	75	200
14.	Chloramines (as Cl ₂) (mg/l)	4.0	No relaxation
15.	Chloride (as Cl) (mg/l)	250	1,000
16.	Copper (mg/l)	0.05	1.5
17.	Fluoride (mg/l)	1.0	1.5
18.	Iron (mg/l)	0.3	No relaxation
19.	Lead (mg/l)	0.01	No relaxation
20.	Magnesium (mg/l)	30	100
21.	Mercury (mg/l)	0.001	No relaxation
22.	Nickel (mg/l)	0.02	No relaxation
23.	Nitrate (mg/l)	45	No relaxation
24.	Phenolic compounds (as C ₆ H ₅ OH) (mg/l)	0.001	0.002
25.	Selenium (as Se) (mg/l)	0.01	No relaxation
26.	Sulphate (as SO ₄) (mg/l)	200	400
27.	Sulphide (as H ₂ S) (mg/l)	0.05	No relaxation
28.	Total alkalinity (as CaCO ₃) (mg/l)	200	600
29.	Total arsenic (mg/l)	0.01	No relaxation
30.	Total chromium	0.05	No relaxation
31.	Total hardness (as CaCO ₃) (mg/l)	200	600
32.	Zinc (mg/l)	5.0	15.0
33.	Aldrin/Dieldrin (µg/l)	0.03	No relaxation
34.	Chlorpyrifos (µg/l)	30	No relaxation
35.	2,4-D (µg/l)	30	No relaxation
36.	DDT (µg/l)	1.0	No relaxation
37.	Endosulfan (µg/l)	0.4	No relaxation

Table 2 continued

S. No.	Parameter	Acceptable limit	Permissible limit in the absence of alternate source
38.	Radioactive α emitters (Bq/l)	0.1	No relaxation
39.	Radioactive β emitters (Bq/l)	1.0	No relaxation
40.	Total <i>Coliform</i> bacteria	Shall not be detectable in any 100 ml sample	

As per the Designated Best Use (DBU) classification (CPCB 2008), the water of River Ganga is suitable for drinking but after disinfection (Class A) in upper segment (location #1–7); is suitable for organized outdoor bathing (Class B) in middle segment (location # 8–10); and can be used as a drinking water source (Class C) in lower segment (location #11–20).

Suitability for irrigation

The criteria of suitability for drinking water, water for industrial purposes, and for agriculture are different. Therefore, water which is not fit for drinking and industrial uses may be suitable for irrigation. The suitability of waters for a specific purpose depends on the types and amounts of dissolved salts. Some of the dissolved salts or other constituents may be useful for crops. However, the suitability for irrigation is assessed in terms of the presence of undesirable constituents, and only in limited situations is irrigation water assessed as a source of plant nutrients (FAO 2008).

The most important characteristics that determine the quality of irrigation water are: pH; total concentration of soluble salts assessed through EC; Relative proportion of Na to other cations such as Ca and Mg, referred to as the sodium adsorption ratio (SAR); concentration of Boron and other elements that may be toxic to plants; concentration of carbonates and bicarbonates as related to the concentration of Ca and Mg, referred to as residual sodium carbonate (RSC); content of anions such as chloride, sulphate and nitrate. The analytical data on the above parameters are used to describe the quality of irrigation water taking standards fixed for each aspect as an index (FAO 2008). The parameters evaluated to determine the quality for irrigation are presented in Table 4. The statistical analysis of the results obtained was done on SPSS 7.5 statistical package. The suitability of the samples was analysed on the basis of results obtained and indices evaluated; comparing the obtained values with the classification as suggested by different authors (Table 5).

Table 3 Concentration of heavy metals in water of River Ganga in Rishikesh

S. No.	Ni	Pb	Zn	Cu
1	0.0227	BDL	BDL	0.0445
2	0.0105	BDL	0.1489	0.0371
3	0.0245	BDL	BDL	0.0321
4	BDL	BDL	0.0760	0.0334
5	0.0175	BDL	0.3526	0.0346
6	0.0245	BDL	BDL	0.0358
7	BDL	BDL	0.0304	0.0346
8	0.0157	BDL	0.0365	0.0334
9	0.0140	BDL	0.0578	0.0358
10	BDL	BDL	BDL	0.0334
11	BDL	BDL	BDL	0.0334
12	BDL	BDL	BDL	0.0358
13	BDL	BDL	0.0426	0.0383
14	0.0367	BDL	BDL	0.0531
15	BDL	BDL	BDL	0.0408
16	BDL	BDL	0.0669	0.0433
17	BDL	BDL	0.1763	0.0346
18	0.0314	BDL	1.3497	0.0420
19	BDL	BDL	BDL	0.0581
20	NA	NA	NA	NA

All the values expressed in mg/l

BDL Below the detection limit (0.01 mg/l), NA Not Analysed

Electrical conductivity

The concentration of total salt content in irrigation waters, estimated in terms of EC, is an important parameter for assessing the suitability of irrigation waters. Generally, all irrigation waters with an EC of less than 2250 $\mu\text{S}/\text{cm}$ are considered suitable except in some situations, e.g. very sensitive crops and highly clayey soils of poor permeability. The ideal value is less than 750 $\mu\text{S}/\text{cm}$ (Richards 1954). In our study, Electrical conductivity (EC) (in $\mu\text{S}/\text{cm}$) varied in the range from 38 to 170 with a mean value of 85.2. All the water samples have EC below 750 $\mu\text{S}/\text{cm}$ indicating good quality of irrigation water.

Sodium adsorption ratio (SAR)

The degree to which the irrigation water tends to enter into cation exchange reaction in soil can be indicated by the sodium adsorption ratio. Excess sodium gets adsorbed on soil particles, thus changes the soil properties and also reduces permeability (Ayers and Bronson 1975). In this study, SAR was found in the range of 0.24–0.43. As per

Table 4 Calculated values to assess the suitability for irrigation and industrial use

S. No.	RSC	SSP	SAR	Mg Hazard	KR	PI	LSI*	RSI*
1	-0.88	25.54	0.39	0.0	0.34	42	-0.05	9.7
2	-0.90	24.73	0.41	31.8	0.33	61	0.21	8.7
3	-1.14	23.64	0.39	29.9	0.31	51	0.21	9.1
4	-1.39	20.57	0.37	43.1	0.26	44	-0.28	9.6
5	-1.30	21.64	0.38	37.4	0.28	46	0.01	9.2
6	-1.14	21.46	0.38	37.4	0.27	54	1.50	7.4
7	-1.30	21.65	0.38	34.8	0.28	47	0.83	8.3
8	-1.30	22.59	0.39	33.9	0.29	44	-0.02	9.4
9	-0.97	24.83	0.39	19.1	0.33	58	0.01	9.1
10	-1.14	24.14	0.43	36.7	0.32	53	0.45	8.7
11	-3.59	9.32	0.24	42.1	0.10	25	1.00	7.4
12	-2.03	15.19	0.30	36.8	0.18	30	0.24	9.0
13	-1.31	21.77	0.39	38.1	0.28	49	0.17	9.0
14	-1.95	15.82	0.32	28.8	0.19	35	0.12	8.8
15	-2.93	11.81	0.27	35.1	0.13	26	0.21	8.6
16	-2.12	15.22	0.32	37.7	0.18	37	0.36	8.2
17	-2.12	15.62	0.33	43.9	0.19	35	0.29	8.7
18	-1.55	18.57	0.35	37.5	0.23	43	0.22	8.9
19	-1.37	20.91	0.35	17.9	0.26	45	0.04	9.1
20	-3.40	9.71	0.28	74.5	0.11	26	0.18	8.8
Mean	-1.7	19.2	0.4	34.8	0.2	42.6	0.3	8.8
\pm SD	± 0.8	± 5.1	± 0.05	± 13.8	± 0.08	± 10.6	± 0.4	± 0.6

Richards (1954), water with $\text{SAR} \leq 10$ is considered as of excellent quality. Figure 2 is a plot of SAR against EC for rating irrigation water in different classes which indicate the extent that the water can affect the soil in terms of salinity hazard. All the samples were found to lie in C1S1 class, i.e. low salinity and low sodium hazard class, thus excellent for irrigation purpose for almost all soils.

Bicarbonate and residual sodium carbonate (RSC)

The concentration of bicarbonates was observed to be in the range of 4.9–34.2 with mean value of 18.8 mg/l. In water having a high concentration of bicarbonate, there is a tendency for calcium and magnesium to precipitate. When this happens, there is a reduction in the concentration of calcium and magnesium and a relative increase in sodium. The calcium and magnesium are precipitated as carbonates, and any residual carbonate or bicarbonate is left in solution as RSC or bicarbonate hazard. RSC remained negative for all the water samples in this study, showing that the water is of good quality for use in irrigation.

Table 5 Classification of water quality for irrigation

Quality	EC range	RSC	KR	SAR	Mg. Hazard		
Very good	250 ^a	<1,000 ^b	<0 ^c	<1.25 ^d	<1 ^e	0–10 ^e	<50 % ^f
Good	250–750	1,000–2,000	0–2.5			10–18	
Marginal	750–2,000	2,000–4,000	2.5–5.0	1.25–2.5	1–2	18–26	
Poor	2,000–3,000	4,000–6,000	5.0–7.5	>2.5	>2		>50 %
Harmful	3,000	>6,000	>7.5			>26	

^a Wilcox 1955; ^b Bhumbla and Abrol 1972; ^c Bishnoi et al. 1984; ^d Eaton 1950; ^e Richards 1954; ^f Paliwal 1972; ^g Kelly 1963

Soluble sodium percentage (SSP)

Water intended for agricultural use should have a lower concentration of sodium ions and higher concentrations of calcium and magnesium ions. This is just opposite for water in domestic use. Excessive amounts of Na⁺ ions may cause a significant decrease in the permeability of agricultural soils receiving such irrigation water. SSP was found to be in the range of 9.71–25.54 with the mean value of 19.24. SSP values were observed to be in lower range with a non-significant effect on irrigation quality of water.

Magnesium hazard

It is widely reported that Ca and Mg do not behave identically in soil systems, and the Mg deteriorates soil structure particularly where waters are sodium dominated and highly saline. A high level of Mg usually promotes a higher development of exchangeable Na in irrigated soils (FAO 2008). Water with magnesium hazard less than 50 is suitable for irrigation (Paliwal 1972). In our study, it is observed that magnesium hazard was less than 50 in 95 % of samples. Thus, it can be safely used for irrigation except the water sample taken from the location 20, which had Mg hazard ratio as 74.8.

Kelly’s ratio and permeability index (PI)

The Kelley’s ratio of water samples collected at all the locations or sources ranged from 0.1 to 0.34 with mean value of 0.243, which is well below unity indicating that the water is free from sodicity hazard and can be used for irrigation purpose.

The soil permeability is affected by long-term irrigation influenced by Na⁺, Ca²⁺, Mg²⁺ and HCO₃⁻ contents of the soil. The permeability index values indicate the suitability of water for irrigation. The Doneen’s diagram plots the permeability index, calculated from the relative proportions of sodium and bicarbonate ions on one hand, and the sum of the major cations on the other hand, against the total ion content of the water in milliequivalents per litre.

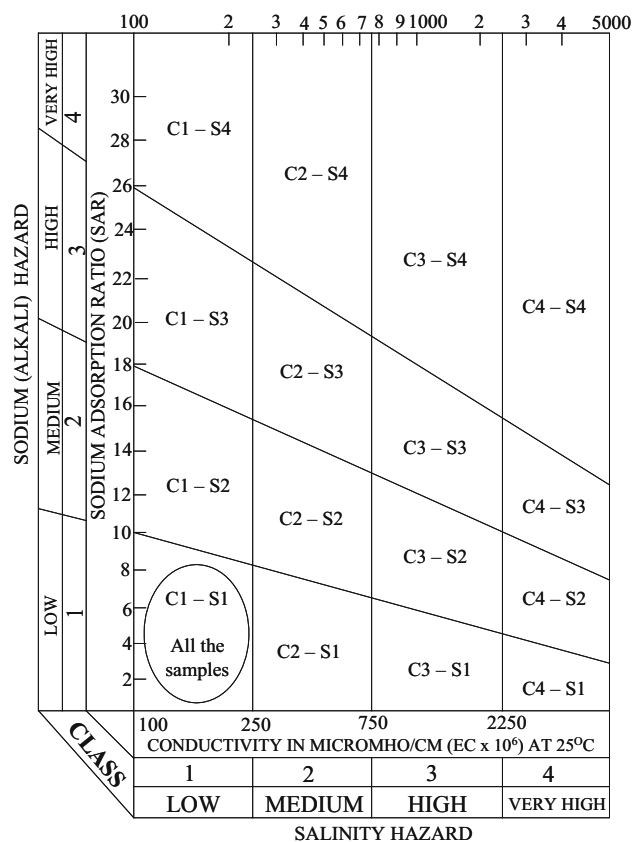


Fig. 2 Plot of calculated values of SAR and EC of water samples for classification of irrigation water (after US Salinity Laboratory Staff, 1954)

The samples of the study area fall in Class II (25–75 %) and the water of the study area is of good quality for irrigation.

Chloride ion

Chloride ion up to a concentration of 70 mg/l is considered safe. It can cause several problems in crops at concentration >350 mg/l (Hopkins et al. 2007). In our study, the values were found in the range of 10–32.5 with a mean value of 22.1. Thus, the water from these locations/sources is within the limits and found suitable for irrigation.

Table 6 Classification of water quality for industrial use

RSI	Inference (Ryznar 1944)	RSI	Inference (Carrier 1965)
<5.5	Heavy scale will form	4–5	Heavy scale
		5–6	Light scale
5.5–6.2	Scale will form	6–7	Little scale or corrosion
6.2–6.8	No difficulties	7–7.5	Corrosion significant
6.8–8.5	Water is aggressive	7.5–9	Heavy corrosion
>8.5	Water is very aggressive	>9	Corrosion intolerable

Each of the above parameters has a bearing on the quality of irrigation water. However, each water source will have its specific suitability or hazardous nature depending on the presence (and the degree) or absence of each of the constituents. Different chemical constituents interact with one another and cause a complex effect on soil properties and plant growth. Water with a low SAR and low EC is widely suitable. However, when a value of any one of these parameters (or both) increases in its content, the water becomes less suitable for irrigation purposes. The selection of crops for such situations becomes critical. Salt-tolerant crops can be grown in such areas. Soil type is also an important consideration under such situations (FAO 2008).

Suitability for industrial application

Water for industrial use refers to applications such as cooling water, boiler feedwater, and in manufacturing processes. The water quality must be monitored to prevent pipe corrosion in utilities. For indicating the extent to which water flowing through pipes will precipitate or dissolve calcium carbonate, important factors such as Saturation Indices are used to test the quality of water. The Langelier saturation index is a calculated number used to predict the calcium carbonate stability of water. It indicates whether the water will precipitate, dissolve, or be in equilibrium with calcium carbonate. The LSI is expressed as the difference between the actual system pH and the saturation pH.

$$LSI = \text{pH (measured)} - \text{pHs (Langlier 1936)}$$

If the actual pH of the water is below the calculated saturation pH, the LSI is negative and the water has a very limited scaling potential. If the actual pH exceeds pHs, the LSI is positive, and being supersaturated with CaCO_3 , the water has a tendency to form scale. At increasing positive index values, the scaling potential increases. It is also worth noting that the LSI is temperature sensitive. The LSI becomes more positive as the water temperature increases. This increase in temperature can cause scaling, especially

in cases such as hot water heaters. LSI was calculated for all the samples and it indicated that 85 % of the samples had $LSI > 0$. This indicates that the water at these sources is under saturated and will have a tendency to dissolve solid CaCO_3 protective coatings in pipelines and equipment.

The Ryznar stability index (RSI) uses a database of scale thickness measurements in municipal water systems to predict the effect of water chemistry.

Ryznar saturation index (RSI) is defined as:

$$RSI = 2 \times \text{pHs} - \text{pH (measured)}$$

Ryznar gives only an indication about the aggressiveness of the water but carrier gives an indication about the scale and corrosion potential of the water (Table 6). RSI values indicated that 90 % water samples ($RSI > 7.5$) have heavy corrosion potential. 45 % water samples have intolerable water potential. As per Ryznar, all the water samples taken have aggressive water, thus unsuitable for transportation through pipes.

Conclusion

During the study, it was observed that the water quality of River Ganga was good at most of the locations in Rishikesh town. The upper segment of Ganga had good quality of water to be used for drinking with minimal treatment but after disinfection. Even the concentration of heavy metals was either non-detectable or within the safe limits. The middle and lower segments had higher levels of pollutants, especially the TDS, organic matter, and MPN. Such areas may be dedicated for organized outdoor bathing for tourists and pilgrims. Night soil disposal in river bed and wastewater discharge through open channels need immediate attention to control MPN and organic load. MPN was found to be a critical parameter which needs regular monitoring and measures to control. Addition of phosphate from wastewater channels is of concern since it may lead to eutrophication particularly in the time of year when the flow is lean. The channels may be intercepted and diverted to sewage treatment plants. The water was observed to be of good to excellent quality throughout with respect to its use in irrigation for a long period of time. In industrial application, the water will not result in scale formation but may result in corrosion of pipes used for transporting the water. Such water may be used in different industrial processes with minimal pretreatment.

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