International Journal for Environmental Rehabilitation and Conservation

essence

ISSN: 0975 — 6272
XI (SP2): 445 — 466
www.essence-journal.com

Original Research Article

Evaluation of physicochemical, heavy metal pollution and microbiological indicators in water samples of Ganges at Uttarakhand India: an impact on public health

Kumar, Prashant[1]; Kothari, Ashish[3]; Kumar, Avinash[2]; Rathi, Himani[1]; Goyal, Bela[1]; Gupta, Pratima[3]; Singh, Bhupender[5]; Mirza, Anissa Atif[1]; Dhingra, Gulshan Kumar[4]

[1]Department of Biochemistry, All India Institute of Medical Sciences, Rishikesh, India
[2]Department of Zoology and environmental science, Gurukula Kangri (Deemed to be University), Haridwar
[3]Department of Microbiology, All India Institute of Medical Sciences, Rishikesh, India
[4]Department of Botany Pt. L.M.S P.G. College Rishikesh, India
[5]Central Research Lab Indian Institute of Technology Delhi, India
Corresponding author anissa.bchem@aiimsrishikesh.edu.in; gulshan_k_dhingra@yahoo.com

ARTICLE INFO

Received: 11 July 2020 | Accepted: 15 August 2020 | Published Online: 30 September 2020

EOI: 10.11208/essence.20.11.SP2.135

ABSTRACT

River water is an indispensable natural environmental resource for all living beings, documented with a direct correlation between the quality of river water and the impact on public health. During the study while statistically significant positive correlation ($p < 0.05$) of physicochemical, metal, and microbiological variables of ten study sites when compared with the Gomukh water sample site and WHO acceptable limits as controls. A high concentration of arsenic (As) and mercury (Hg) were found significantly high in plain regions (Rishikesh, Haridwar, Roorkee, and Shukartal) of Ganges water. The potential non-carcinogenic risk to adults and children was evaluated with the ingestion of heavy metals using hazard quotient (HQ) and hazard index (HI). The HQ values indicated that Hg leading the risk to children only at Devprayag, Triveni Ghat (Rishikesh), and Har Ki Pauri (Haridwar). The study recommends water treatment facilities of Ganga River to improve quality of water, and have a positive impact on public quality health .

KEYWORDS

Ganges Uttarakhand | Physicochemical | Heavy metals | Microbiological | Health Index | Water quality Index

CITATION

Kumar, Prashant[1]; Kothari, Ashish[3]; Kumar, Avinash[2]; Rathi, Himani[1]; Goyal, Bela[1]; Gupta, Pratima[3]; Singh, Bhupender[5]; Mirza, Anissa Atif[1]; Dhingra, Gulshan Kumar[4] (2020): Evaluation of physicochemical, heavy metal pollution and microbiological indicators in water samples of Ganges at Uttarakhand India: an impact on public health. ESSENCE Int. J. Env. Rehab. Conserv. XI (SP2): 445 — 466. https://eoi.citefactor.org/10.11208/essence.20.11.SP2.135

Introduction

Natural environmental resources are predominant factors for the health of humanity and other living beings on Earth. Water is an utmost indispensable natural creation for liveliness. Rivers are significant natural resources of water, for countless human utilities for domestic purposes of drinking, washing, bathing, irrigation of basins, for the cultivation of staple foods, fisheries, aquaculture, water sports, *etc*. Gange's is most sacred and one of the longest trans-boundary rivers of Asia, initiating from western Himalayas of Gangotri glacier on Gomukh (30036′N; 79004′ E) at Uttarkashi District of Uttarakhand, in India at an altitude of around 3800 m upstairs mean sea level in Garhwal Himalayas. The Ganga River flows through Shivalik hills before entering in plain regions of Rishikesh, Haridwar, Roorkee, and Shukartal in Uttar Pradesh by upper Ganga canal. Its further flows, crossing other Indian states, and finally ends in Bay of Bengal covering approximately 2525 km. The Ganga River is considered as most holistic and sacred by Indians due to its important cultural, economic, and environmental values. It is a lifeline for millions of people who live along its course and delivers water for approximately 45 crore people with over 550 individuals per square kilometer (Behera *et al*., 2011). People take baths in the holy river and accomplish their rituals (Kumar *et al.,* 2018). Several tourist picnic spots, pilgrim, and spiritual facts have been recognized to accomplish various religions along with entertaining activities (Kumar *et al.,* 2012). Thus, Ganges is reflected as the most blessed river amongst different rivers in the country. River contaminations through various anthropogenic activities are depriving the overall quality of river water, being affected due to sewage waste disposal directly in rivers and expansion of industrial urban belts along riverbanks.

There is a direct correlation between the quality of river water and the impact on public health, river pollution has increased day by day and it is well documented in studies conducted in developing countries globally (Lonergan and Vansickle, 1991) (Vadde *et al.,* 2018). High attention of Heavy metals and Pathogenic Microbes are often a puzzle for Biota and ecosystem management. Changes in the quality of river water significantly depend on the energetic environmental conditions causing the multifaceted interplay between terrestrial as soil erosions and water domains (Buffam *et al.,* 2011). The Ganges permits sideways 29 class I grade cities, 23 class II grade cities, and almost 50 towns that releases different types of wastes into this mighty river eco-system (Paul 2017). Direct discharges of industrial wastes, domestic wastes, agricultural run and anthropogenic activity along the riverbank, culminate into its accumulation and contamination of river water. These wastes hold health hazard chemicals similar to salts of chromium, copper, cadmium, arsenic, mercury, and lead which interact with the aquatic environment and upset the river ecosystem (Sankhla *et al.,* 2018). The industries which attribute heavy metals in river water mostly paint pigment, metals industries, varnishes pulp, and cotton textiles, paper, rubber, steel plant, thermal power plant, galvanization of iron products and mining industries as well as disorganized use of heavy metal-containing pesticides and fertilizers in agriculture field (Sinha 2011).

Various studies have measured metal pollution load in the river including Gomati in India (Singh *et al.,* 2005), Ganga, India (Pandey and Singh, 2017) Tigris River, Turkey (Varol and Şen 2012) Krotova, Bangladesh (Islam *et al.,* 2015) Brisbane River, Australia (Duodu *et al.,* 2017). Heavy metal-containing pollutants gather into the water column, sediment, and organisms like plants and animals (Kanaujia *et al.,* 2017) which may have deleterious effects on humans consuming them.

Different indicators of microbes have been used universally as a device to denote contamination of river water through human wastes. Various studies have depicted altered Physico-chemical *and* microbiological characteristics of the Ganga River water and have crossed the acceptable or essential limits, (Agarwal and Rajwar 2010). The values of SPC (5.4×105 *and* 6.8×106 SPC 100 ml -1) and MPN (3.5×108 *and* 4.6×108 MPN100 ml -1) ranged at different sampling sites as Har ki Pauri (HKP), Daksh Mandir (DM), Pul Jatwara (PJ), Vishnu Ghat (VG), and these were quite higher to the values of SPC (4.5×105 SPC ml -1) and MPN (3.2×108 MPN100 ml -1) in comparison to control site (Bhimgoda Barrage BGB (Kumar *et al.,* 2018). According to the Central Pollution Control Board (CPCB) criteria, permissible BOD level of water is 2 mg/L or less and the permissible DO level 6 mg/L. Latest data of (CPCB) most of the Ganga River Water in the Uttar Pradesh, West Bengal stretch found unhealthy for consumption and bathing.

To best of our knowledge, since there was no holistically approached evidenced-based documented data available in published literature for the Ganges river overall water quality and level of pollution index flown all along in hilly and plain regions of Uttarakhand state India, present observational analytical study was planned and conducted. The present study was aimed to find out post-monsoon effects on contamination levels and variations of physical, biochemical, and microbiological aspects of sacred river water flown in various hilly and plain riverbank sites of the Ganges. The study evaluated physicochemical variables, eight metal analysis and identified microbiological indicators in water samples collected from the Ganges at specific five hilly and six plain regions of water sampling sites, after the post-monsoon season to evidenced out overall contamination level, a grade of water pollution which further related with health risks and impact of water pollution on public health through a questionnaire-based survey.

Material and Methods

Study design and ethical clearance

This was an observational analytical, community-based study designed in context to study the seasonal effects of natural environments on water resource quality and the impact of human health. The study obtained ethical clearance from the institutional ethics committee before its initiation. The study aimed to evaluate the water quality of the river Ganges flowed through hilly and plain regions of Uttarakhand state India at post-monsoon phase through an assessment of physicochemical, metal and microbiological variables along with documentation of anthropogenic sources and a questionnaire-based survey of the population residing and dependent on the Ganges for their domestic use for the long run.

Study Area

The present study was conducted at 11 specific sites (Fig.1) along with a 440 km stretch of Ganga River. The 11 sites included 5 sites from hilly and 6 sites of plain regions of the Ganges which covered the state of Uttarakhand. Water samples were collected from The Ganges Initiated from Gomukh to Shukartal. The places from where the samples were collected in post-monsoon season in October 2019 includes Gomukh (GG1), Gangotri (GG2), Uttarkashi (GU), New Tehri (GT), Devprayag (GD), Rishikesh1(GR1), (GR2) Haridwar (GH 1), (GH 2), Roorkee (GRR) and Shukartaal (GS) as shown in Fig 1 and table 1.

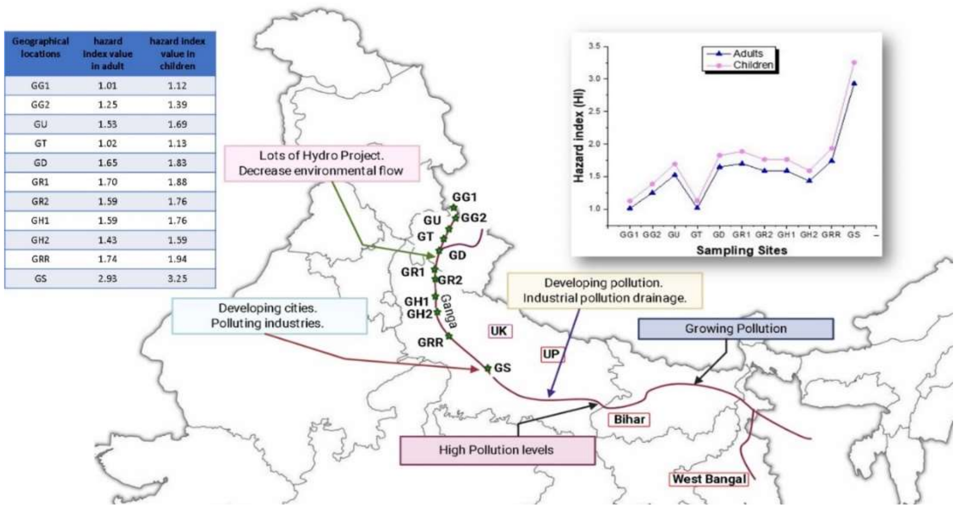

Fig 1: The diagrammatic representation showing Hazard Index of the water samples collected from different 11 sites, the lowest hazard Index were recorded in Gomukh (Adult 1.01 and Children 1.12) and the highest hazard index were shown in Shukarataal. Eleven blue stars shows water sample collection stations of Ganga River in Uttarakhand.

Sampling sites	Demarcation	Landmark of sampling zone	GPS Geo-coordinates of sites	Elevation	Source of water pollution
Gomukh	GG1	Origin of Ganga	Latitude:30^{0}49'59.99''N Longitude:79^{0}09'60.00''E	13,200feet	No
Gangotri	GG2	Near Temple Ghat	Latitude:30^{0}58'48.00''N Longitude:78^{0}55'48.00''E	10,200feet	Bathing& others human activities
Uttrakashi	GU	Ghat at main city	Latitude:30^{0}58'48.00''N Longitude: 78^{0}27'0.00 E	3,799 feet	Domestic sewage & anthropogenic
Tehri dam	GT	Water sports centre	Latitude:30^{0}22'40'N Longitude: 78^{0}28'50'E	5,740 feet	Stored water
Devprayag	GD	Ghat	Latitude:30^{0}08'45'N Longitude: 78^{0}35'55'E	1548 feet	Domestic sewage
Rishikesh I	GR1	Trivani Ghat	Latitude:29^{0}59'4.834'N Longitude: 78^{0}54'55.733'E	1,220 feet	Domestic sewage, small industry like paint, Agriculture runoff
Rishikesh II	GR2	Barraj near AIIMS	Latitude:29^{0}59'4.834'N Longitude: 78^{0}54'55.733'E	1220 feet	Stored water Domestic sewage, small industry
Haridwar I	GH1	Har ki pauri	Latitude:29.945^{0}N Longitude: 78.163^{0}E	1,030 feet	Bathing centre, Agricultural Runoff
Haridwar II	GH2	Prem nagar Ashram ghat	Latitude:29.945^{0}N Longitude: 78.163^{0}E	1,030 feet	Domestic sewage
Roorkee	GRR	Near sham shan Ghat	Latitude:29^{0}52'29.49''N Longitude: 77^{0}53'23.74''E	879.26 feet	Industrial effluent, Agricultural Runoff
Shukartaal	GS	Ghat	Latitude:29.4876^{0}N Longitude: 77.9824^{0}E	814 feet	Domestic and Industrial effluent, Sugar factory waste and agricultural Runoff.

Table 1. Location of Sampling sites, its geo coordinates and elevation

Water Sample Collections

Water samples were collected after post-monsoon in October 2018 from a total of eleven study designed sampling sites in a water sampling sites of the Ganga River flowing in Uttarakhand were nominated on the source of catchment characteristics and sources of anthropogenic involvement along its course of a run. Among water sampling sites of Ganges, five sites were of hilly regions (GG1, GG2, GU, GT, and GD) and six sites were in plain regions (GR1, GR2, GH1, GH2, GRR, and GS) of Uttarakhand. Sample sites were divided into two groups as Group I included Gomukh as a control and all other 10 sites were included in Group II. From every sampling site, water was collected in triplicates at the depth of 10 cm below the superficial water level; water samples were mixed and poured in three separate sterile polyethylene containers. Each container filled with water sample was tightly sealed and labelled with a site of water sampling, and mode of specific analysis viz physicochemical, metal and microbiological analysis. Water sample containers were transported and stored in an icebox shield until analysed in laboratories.

Physiochemical Analysis

All Ganga river water samples collected in polyethylene sterile containers from eleven different sites were checked for physicochemical analyses using a specific methodology. pH, temperature, conductivity, and dissolved oxygen were measured by HACH HQ40D portable multipara meter two channels advanced digital meter. Dissolved Oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), and total solid solutes were measured by Wrinkle′s methods, volumetric analyzer, and titration methods. (APHA, 2005).

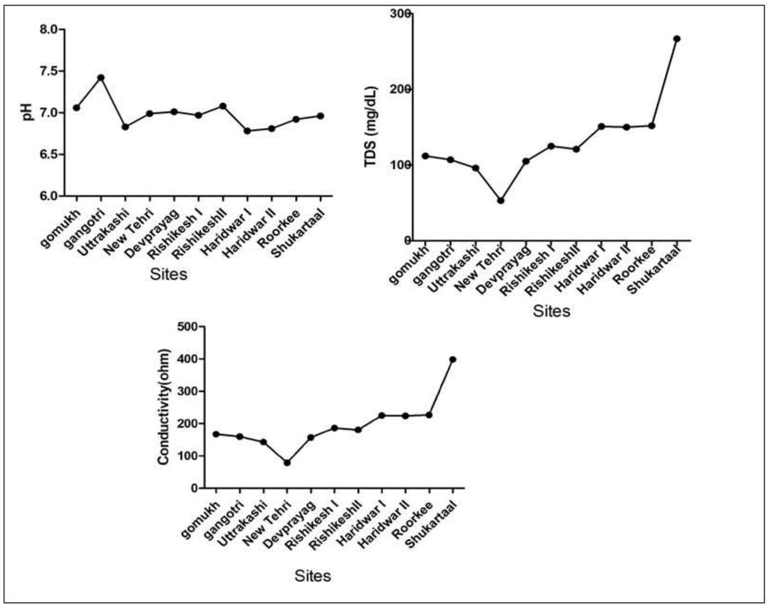

Fig 2: The sub-indices are derived based on segmented nonlinear functions as follows. We measured the pH from all 11 sites of our study where we saw the much variation in pH, in Gangotri the pH was 7.4 upper in pH scale in Uttarkashi pH was 6.7 lower in pH scale. B. as we check the TDS for 11 sites here we also seen the high variation in the results the lowest value range was 50mg/dL in New Tehri and highest value was seen Shukartaal was 285mg/dL. C. same as in case of Conductivity in New Tehri conductivity was 60ohm and in Shukarataal was more than 400ohm.

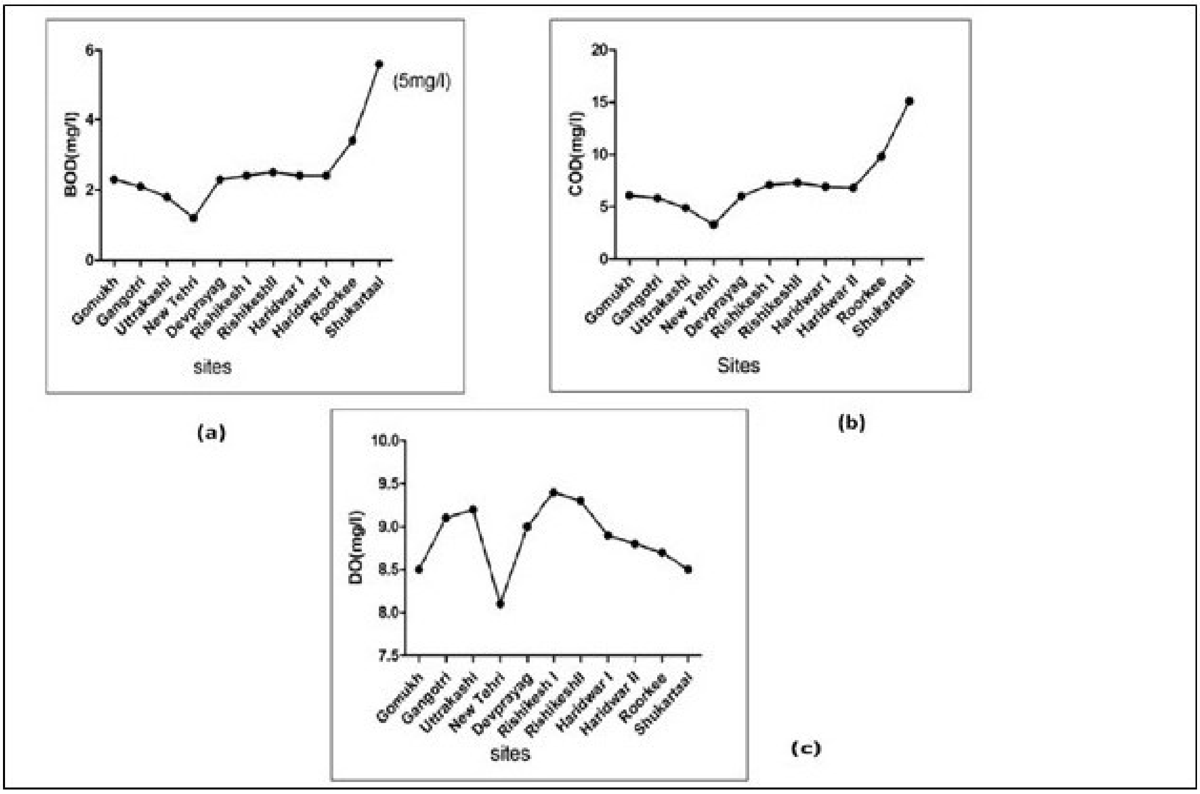

Fig 3: Here we see the trend of change in BOD, COD and DO of Ganga water at 11 study sites. There is a lot more fluctuation in the 160 km area.

Parameters	**GG1**	**GG2**	**GU**	**GT**	**GD**	**GR1**	**GR2**	**GH1**	**GH2**	**GRR**	**GS**	**BIS (2012)**	**WHO (2017)**
pH	7.06	7.42	6.83	6.99	7.01	6.97	7.08	6.78	6.81	6.92	6.96	6.5-8.5	6.5-9.2
TDS (mg/L)	112	107	96	53	105	125	121	151	150	152	267	500	500
Conductivity (µS/cm)	167.2	159.7	143.3	79.1	156.7	186.5	180.6	225.4	223.9	226.8	398.5	-	-
BOD mg/L)	2.3	2.1	1.8	1.2	2.3	2.4	2.5	2.4	2.4	3.4	5.6	-	< 5.0
COD mg/L)	6.1	5.8	4.9	3.3	6	7.1	7.3	6.9	6.8	9.8	15.1	-	< 10.0
DO (mg/L)	8.5	9.1	9.2	8.1	9	9.4	9.3	8.9	8.8	8.7	8.5	-	6.5-9.5
As (µg/L)	2.511	3.974	6.143	2.957	5.358	5.972	6.429	5.108	5.211	6.772	16.142	< 10	< 10
Pb (µg/L)	0.071	0.008	0.02	0.021	0.087	0.064	0.011	0.012	0.01	0.014	0.933	< 10	< 2
Hg (µg/L)	5.206	5.695	6.053	5.164	7.82	7.494	6.221	7.462	6.092	7.085	6.944	< 1.0	< 2
Cd (µg/L)	0.177	0.19	0.036	0.004	0.006	0.008	0.006	0.008	0.005	0.012	0.005	< 3.0	< 5
Cr (µg/L)	0.633	0.571	1.535	1.328	1.881	3.259	2.61	3.331	3.391	3.03	7.171	< 50	< 100
Cu (µg/L)	0.534	0.319	0.605	1.257	0.578	0.439	0.425	0.48	0.611	0.994	0.677	< 50	< 1300
Zn (µg/L)	5.058	9.632	3.754	2.937	1.533	5.519	0.95	1.673	1.532	0.981	0.498	< 5000	< 5000
Ni (µg/L)	23.28	21.125	2.54	0.734	0.885	0.974	0.878	1.058	1.084	1.038	1.811	< 20	< 25
TC	0	0	4	9	0	1100	150	150	93	1100	1100	Nil	Nil
FC	0	0	4	4	0	1100	93	150	93	1100	1100	Nil	Nil
E.coli	0	0	4	4	0	150	7	21	43	240	460	Nil	Nil
MPN	0	0	9	9	0	2400	240	460	240	2400	2400	Nil	Nil
FS	0	0	0	0	0	7	3	4	0	0	3	Nil	Nil
Salmonella, Shigella, V. *cholaerae*, Fungal	No growth	No growth	No growth	No growth	No growth	No growth	No growth	No growth	No growth	No growth	No growth	No growth	No growth

Table 2: Physicochemical parameters, heavy metals and microbiological analysis in Ganga water

Metals Analysis

All collected water samples were subjected for eight metal analysis Arsenic (As), Lead (Pb), Cadmium (Cd), Mercury (Hg), Chromium (Cr), Copper (Cu), Zinc (Zn), and Nickle (Ni) using a standard protocol of Inductive Coupled Plasma-Mass Spectrometry (ICPMS) manufactured by Perkin Elmer ELAN DRC-e. The instrument was calibrated with multi-elemental standards of metals before run water samples of each site. 45 ml Ganga water samples were digested with 3 ml of concentrated HNO3 and 2 ml H2O2 at ~ 80oC until the solution remains about 5 ml (APHA 2005). The solutions were filtered through What man filter paper no. 42 and diluted to 50 ml with double distilled water (APHA 23th ED-3111.C). The filter paper was rinsed with diluted nitric acid solution and used to remove the siliceous impurities from the digested solution.

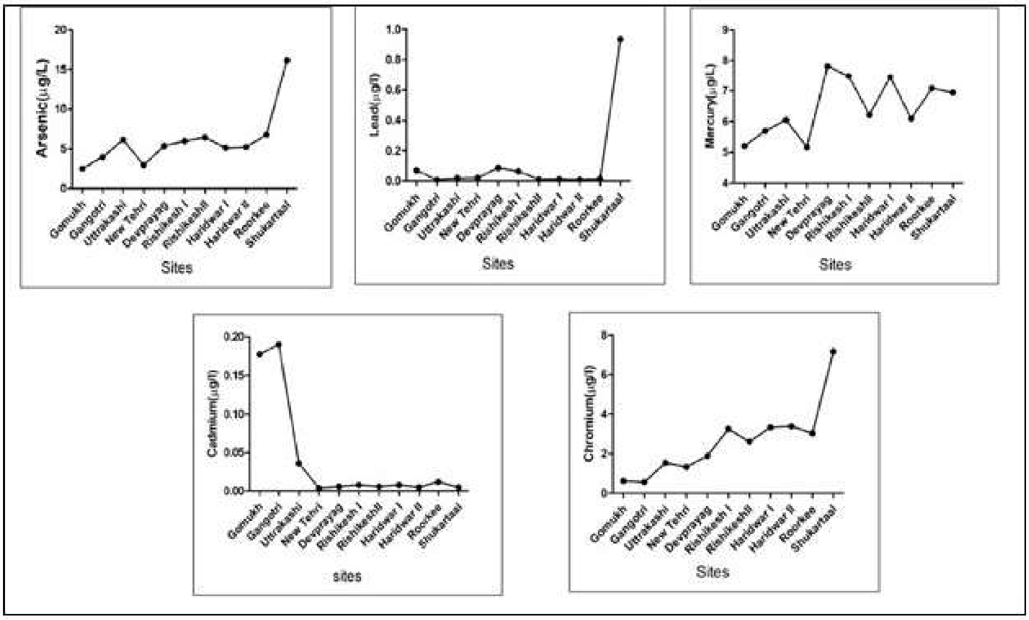

Fig 4: Trend of change in Heavy metals (As, Pb, Hg, Cd, and Cr) of Ganga water at study sites.

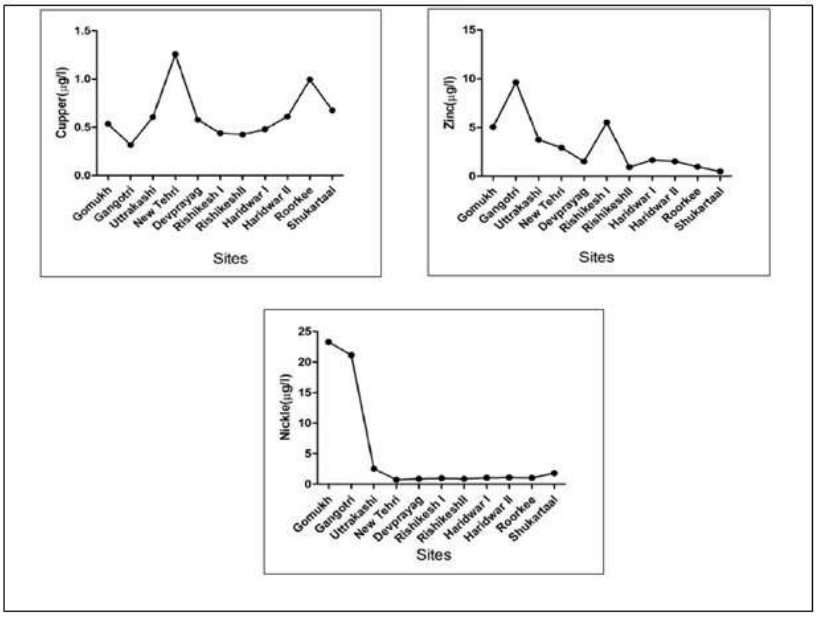

Fig 5: Trend of change in trace metals (Zn, Ni, and Cu) of Ganga water at study sites.

The concentration of nitric acid was so adjusted that it remained the same as that of blank and standard solutions. In ICP-MS, elements from water samples at high temperatures were ionized and directed further into MS. The MS then sorted the ions according to their mass/charge ratio followed by directing them to an electron multiplier tube detector. This detector then identified and quantified each ion from processed water samples on the display unit of the instrument. Heavy metals showed the level of Arsenic was significantly higher (p <0.07) in group II as compared to group I. The concentration of Hg, Cd, Cr, and Ni were significantly higher in group II p = 0.007, 0.0005, 0.004, 0.04 & 0.0001 respectively as compared to Group I. (table 3).

Microbiological Analysis of Water samples

Most probable number test (MPN Test) – Included presumptive test, confirmation test, and complete test. In the MPN method by the use of sterile pipette 10 ml, 1ml and 0.1ml of water samples from sterile containers were inoculated in a 50 ml test tube having 10 ml double strength Lauryl Tryptase (LT) broth medium and 5 ml single strength and 5 ml LT broth respectively. All tubes were incubated for 24 hours at 37°C. After the growth of mixed culture, they were inoculated in the Broth culture tube for confirmation test viz. Brilliant Green Bile Broth (BGBB), EC Broth, and Tryptone water, Azide Dextrose for a complete test. Selenite F Broth, Alkaline peptone water was used to a culture of some specific bacteria like Vibrio cholera and salmonellae typhi species, growth present was then subcultured on Xylose Lysine Deoxy Cholate (XLD), Thiosulfate-Citrate-Bile Salt-Sucrose (TCBS) Agar culture plate respectively.

Parameters	Group I (control)	Group II Mean± SD (n=10)	*P* value /Significant (*)
pH	7.06	6.970 ± 0.19	0.025*
TDS	112	132.7 ± 56.14	0.27
DO	8.5	8.90 ± 0.39	0.01*
BOD	2.3	2.6 ± 1.1	0.43
COD	6.1	7.3 ± 3.2	0.26
Conductivity	167.2	198.1 ± 83.79	0.27
Heavy Metals			
As	2.51	6.407 ± 3.609	0.07*
Pb	0.071	0.118 ± 0.287	0.62
Hg	5.206	6.603 ± 0.879	0.007*
Cd	0.177	0.080 ± 0.0577	0.0005*
Cr	0.633	2.811 ± 1.814	0.0042*
Cu	0.534	0.638 ± 0.2845	0.28
Zn	5.058	2.901 ± 2.817	0.038*
Ni	23.28	3.213 ± 6.317	0.0001

Table 3. To compare physicochemical parameters and heavy metals between group 1 and group II

Various morphological characteristics of improved isolates, colony morphology shape, color, arrangement, biochemical tests, and Gram staining were carried out for the identification of isolates. Antibiotic sensitivity was done to check out the cultural sensitivity of significant bacterial culture. The water samples were also checked for Fungi using two methods, direct plate and dilution plate with the use of two types of growth media Sabouraud's dextrose agar (SDA) and potato dextrose agar (PDA) incubate for 7 days on 25oc.

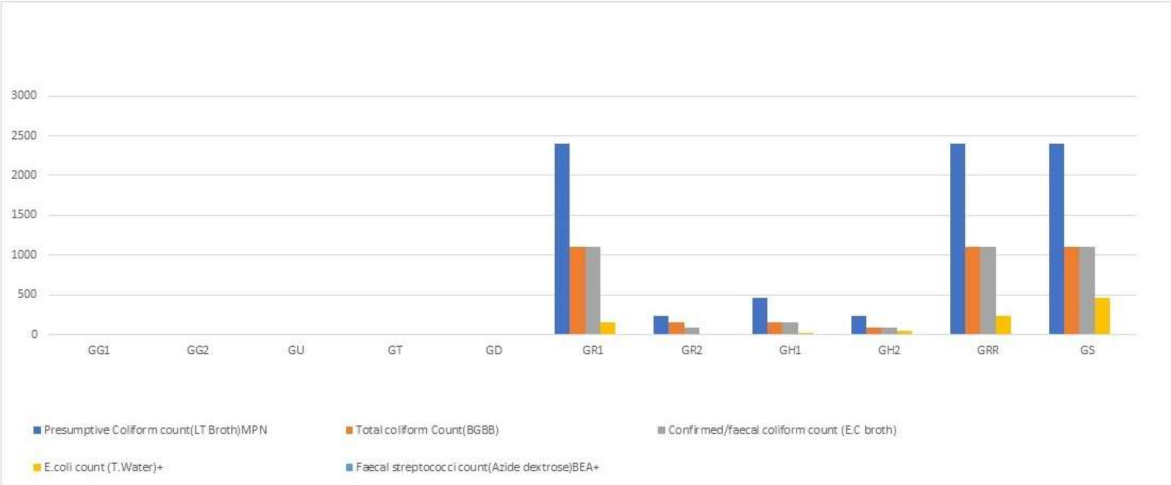

Fig 6: The variation in bacterial count at different sites in Ganga River water.

Risk assessment on human health

A questionnaire-based survey found that the population of the plain area had a high incidence (75%) of water-born disease as compared to the hilly area (20%). The estimated result of hazard quotient (HQ) and hazard index (HI) for non-carcinogenic concern related to adult and child by ingestion of Ganga River water is presented in table 4.

Distribution of Anthropogenic Sources along the Ganga river course around water sampling sites

During the collection of water samples of the Ganga River at different water sampling sites noted various sources of pollution, main sources were quoted and documented as natural environmental processes, anthropogenic sources, industries, sugar factories, sewage disposals, agricultural and Carpenters shops, daintier generated wastes, *etc*.

Assessment of Impact of Public Health through the filling of questionnaire and interview:

Total 220 subjects, with 20 participants from each water-sampling site, localized residence along Ganga River who were dependent upon river water for their routine, regular domestic uses, were randomly allocated to participate for filling of the predesigned questionnaire and short interview related to over health all candidates were participated after taking their written consent. As per the criteria for participation in predesigned questionnaire, participants/subjects who participated in the study were in the age group of 20 to 50 years with non- alcoholic habits and had their residences. These people were using normal water except RO water

Health risk assessment

The health risk to humans by heavy metals could occur through direct ingestion, inhalation, and dermal contact; however, ingestion is the main significant way of exposure (USEPA 2004; Giri and Singh 2015). The risk posed through direct ingestion of Ganga River water was assessed for the study region as per the guidelines of USEPA (2004). It was conducted as the following equation:

$$ADD_{ingestion}=\frac{C_i \times IR \times EF \times ED}{BW \times AT} \quad (1)$$

where, ADD ingestion is the average daily dose; Ci is the mean concentration (µg/L) of ith trace metal; IR is the water intake rate (2 L/day for adults and 0.64 L/day for children) (Xiao *et al.,* 2019); EF, exposure frequency (350 days/year) (USEPA 2004); ED, exposure duration (70 years for adults and 6 years for children); BW, average body weight for Indian adult is 52 Kg (Mishra et al 2014) and 15 Kg for children (Njuguna *et al.,* 2020); AT, average exposure time (365days/year × 70 or 6 years).

The non-carcinogenic risk from individual metal was characterized by the hazard quotient (HQ), which is the ratio of ADD and RfDi (reference dose for ingestion) proposed by USEPA from a dose-response experiment. The HQ > 1, indicates the increased health risk to exposed masses from contaminants (Njuguna *et al.,* 2019).

$$HQ=\frac{ADD_{ingestion}}{R_fD_i} \quad (2)$$

Where the RfDi (µg/kg-day) values for As, Pb, Hg, Cd, Cr, Cu, Zn and Ni are 0.3, 14, 0.3, 0.5, 3, 40, 300 and 20 respectively (USEPA 1994).

To posed the overall non-carcinogenic risk through the ingestion of individual metal, accumulation of HQ of each metal was employed and expressed as hazard index (HI). The equation for the calculation of HI is as follows:

$$HI=\sum_{i=1}^{n} HQ_i \quad (3)$$

Statistical Analysis

Study data were calculated with support of MS Excel 2016, SPSS 12.0, and analysed by a one-sample t-test for determining standard deviation and p-value. Karl Pearson's coefficient of correlation was used to find out the correlation and one-sample t-test to generate a p-value on 95% CI (Confidence interval).

Results

The sources of pollution in Ganga are mainly distributed into four types' industrial effluent, sewage pollution, religious activities, and agricultural runoff. An effect of anthropogenic disruption in the Ganga river water has been extensively noted when Ganga water reached in plain areas of Rishikesh, Haridwar, and Shukartal. Analyzed results from river water samples collected at plain sites of the Ganga River documented increased river water pollution when compared with the results of water samples of hilly regions

Physicochemical Analysis

pH, TDS, Conductivity, BOD, COD, and DO were measured as a part of physicochemical analysis in collected samples. Levels of physicochemical properties at different sites

Sites	Consumer	HQ_{inges}								HI
		As	Pb	Hg	Cd	Cr	Cu	Zn	Ni	
GG1	Adult	3.09E-01	1.87E-04	6.40E-01	1.31E-02	7.78E-03	4.92E-04	6.22E-04	4.29E-02	1.01E+00
	Child	3.42E-01	2.07E-04	7.10E-01	1.45E-02	8.63E-03	5.46E-04	6.90E-04	4.76E-02	1.12E+00
GG2	Adult	4.89E-01	2.11E-05	7.00E-01	1.40E-02	7.02E-03	2.94E-04	1.18E-03	3.90E-02	1.25E+00
	Child	5.42E-01	2.34E-05	7.77E-01	1.55E-02	7.79E-03	3.26E-04	1.31E-03	4.32E-02	1.39E+00
GU	Adult	7.55E-01	5.27E-05	7.44E-01	2.66E-03	1.89E-02	5.58E-04	4.62E-04	4.68E-03	1.53E+00
	Child	8.38E-01	5.84E-05	8.25E-01	2.95E-03	2.09E-02	6.19E-04	5.12E-04	5.20E-03	1.69E+00
GT	Adult	3.64E-01	5.53E-05	6.35E-01	2.95E-04	1.63E-02	1.16E-03	3.61E-04	1.35E-03	1.02E+00
	Child	4.03E-01	6.14E-05	7.04E-01	3.27E-04	1.81E-02	1.29E-03	4.01E-04	1.50E-03	1.13E+00
GD	Adult	6.59E-01	2.29E-04	9.61E-01	4.43E-04	2.31E-02	5.33E-04	1.88E-04	1.63E-03	1.65E+00
	Child	7.31E-01	2.54E-04	1.07E+00	4.91E-04	2.57E-02	5.91E-04	2.09E-04	1.81E-03	1.83E+00
GR1	Adult	7.34E-01	1.69E-04	9.21E-01	5.90E-04	4.01E-02	4.05E-04	6.78E-04	1.80E-03	1.70E+00
	Child	8.14E-01	1.87E-04	1.02E+00	6.55E-04	4.44E-02	4.49E-04	7.53E-04	1.99E-03	1.88E+00
GR2	Adult	7.90E-01	2.90E-05	7.65E-01	4.43E-04	3.21E-02	3.92E-04	1.17E-04	1.62E-03	1.59E+00
	Child	8.77E-01	3.21E-05	8.48E-01	4.91E-04	3.56E-02	4.35E-04	1.30E-04	1.80E-03	1.76E+00
GH1	Adult	6.28E-01	3.16E-05	9.17E-01	5.90E-04	4.10E-02	4.43E-04	2.06E-04	1.95E-03	1.59E+00
	Child	6.97E-01	3.51E-05	1.02E+00	6.55E-04	4.54E-02	4.91E-04	2.28E-04	2.16E-03	1.76E+00
GH2	Adult	6.41E-01	2.63E-05	7.49E-01	3.69E-04	4.17E-02	5.63E-04	1.88E-04	2.00E-03	1.43E+00
	Child	7.11E-01	2.92E-05	8.31E-01	4.09E-04	4.62E-02	6.25E-04	2.09E-04	2.22E-03	1.59E+00
GRR	Adult	8.33E-01	3.69E-05	8.71E-01	8.85E-04	3.72E-02	9.16E-04	1.21E-04	1.91E-03	1.74E+00
	Child	9.24E-01	4.09E-05	9.66E-01	9.82E-04	4.13E-02	1.02E-03	1.34E-04	2.12E-03	1.94E+00
GS	Adult	1.98E+00	2.46E-03	8.54E-01	3.69E-04	8.82E-02	6.24E-04	6.12E-05	3.34E-03	2.93E+00
	Child	2.20E+00	2.73E-03	9.47E-01	4.09E-04	9.78E-02	6.92E-04	6.79E-05	3.70E-03	3.25E+00
R_fD_{inges} (µg/kg-day)		0.3	14	0.3	0.5	3	40	300	20	

Table 5: Heath risk assessment (HQ and HI values) of Ganga River water intake by adults and children at various monitoring sites

are represented in table 2 and trends in change of physicochemical properties of different sites of River Ganga flows from Gomukh to Shukartal are represented in Fig 2 and 3. According to WHO optimal pH range for acceptable aquatic life is 6.5 - 8.2, BIS standards for drinking water. In the present study water pH of all analyzed water, samples were in an acceptable range. Maximum TDS was found in Shukartal Ganga water. The conductivity of GS1 Ganga water sample was found to be highest 398.5 µmhos/cm in comparison to other analyzed samples (table 2 and fig. 2,3) Biological oxygen Demand were observed 3.54 and 5.6 mg/L at Roorkee and Shukartal Ganga water respectively and Chemical Oxygen Demand of Roorkee and Shukartal were observed to be 9.8 and 15.1 respectively, which were very high in comparison to the WHO acceptable limits standard requirements of BOD (2-3mg/l) and COD (<8.0mg/l) for drinking ability of water. Rishikesh Ganga water DO more than 8mg/L was found in extreme compared to all other sample sites (Table 2). To compare the physicochemical properties between group I and group II were shown a highly significant pH and DO level. (Depicted in Table 3)

Metals Analysis

Ganga water samples were analyzed by ICP-MS (Perkin Elmer) at the Indian Institute of Technology (IIT) Roorkee and KGMU Lucknow. Heavy metal concentrations in the hilly region and plain area are shown in table 2. Arsenic concentration was occurring in acceptable level (< 10ppb) in all sites except the Shukartaal region, which reached up to 16 ppb. Lead, Cadmium, and Chromium also fell within an accepted level (<2ppb, <5ppb, and <100 ppb) in all water samples of 11 study sites. Mercury levels were high in all analysed water samples of study sites. The maximum concentration of Hg 7.8 µg/L and minimum Conc. 5.2 µg/L were recorded in all sites as compared to the accepted level(<5ppb) (table 2). The level of Copper and Zinc in all sites within the accepted level (<1300 µg/L) and (<3000 µg/L) respectively. Nickel levels were also found in the accepted limit (<25ppb) in all regions, but Gomukh and Gangotri level were found very high 23.28 ppb and 21.1 ppb respectively as compare to another site (table 2 and Fig 4, 5).

Heavy metals showed the level of Arsenic was significantly higher ($p < 0.07$) in group II as compared to group I. The concentration of Hg, Cd, Cr, and Ni were significantly higher in group II p = 0.007, 0.0005, 0.004, 0.04 *and* 0.0001 respectively as compared to Group I (Table 3).

Microbiological Analysis

All microbiological analyses were carried out at Microbiology Department, AIIMS Rishikesh. Microbiological Reports showed the most probable number MPN count 2400/ 100 ml at Triveni Ghat, Rishikesh and gram-negative (E. coli) and gram-positive bacteria (Enterococcus) found in Rishikesh and Haridwar water samples. The bacterial concentration (MPN, TCC, FCC, EC, FSC,) at different sites and Presumptive coliform count were maximum at GR1, GRR *and* GS as indicated in table no. 2 and fig. no. 6 (a, b, c, d *and* e).

Risk assessment on human health

A questionnaire-based survey found that the population of the plain area had a high incidence (75%) of water-borne disease as compared to the hilly area (20%) (Table 4). The estimated result of hazard quotient (HQ) and hazard index (HI) for non-carcinogenic concern related to adult and child by ingestion of Ganga River water is presented in table 5.

The HQ value for each metal was observed below the health risk level (less than 1) at every monitoring station for both adults and children (Table 5). However, the mercury

(Hg) was found as toxic metal, indicated highest HQ at Devprayag (1.07E+00), Triveni Ghat: Rishikesh (1.02E+00) and Har-Ki-Pauri: Haridwar (HQ: 1.02E+00) for children. Other than this, arsenic (As) was shown the second-highest HQ, 1.98E+00 for adult, and 2.20E+00 for a child at the downstream site, Shukartal. A comparison of HQ among a total of 11 studied locations illustrated 4 sites with high HQ (>1), which is 36.36% of all sites. Whereas, considering all the locations the range of HQ for Hg varied from 6.35E-01 to 9.61E-01 for adults, suggests low health risk at remained locations. The minimum HQ value was reported of Pb 2.11E-05 for adults and 2.34E-05 for child cases at the Gangotri site in comparison to other locations.

The observation of HI was found higher than 1 for both adult and child cases at all monitoring locations (table 5). The range of HI values varied from 1.01E+00 to 2.93E+00 for adults and 1.12E+00 to 3.25E+00 for a child as we move from upstream to downstream of covered river stretch during the study period. The graphical presentation of variation in HI values of each monitoring location is represented in Fig. 7. The overall result of HI suggests potential health risks to both adults and children on consuming Ganga River water for drinking purposes. The contribution analysis of heavy metals towards hazard index (HI) for each sampling station is given in Fig. 8. Hg followed by As, Ni, and Cd to the value of HI, while the rest of the metals contributed least to total HI caused the highest contribution for non-carcinogenic risk to adults and children.

Area	Subject Only Residential persons	Age	Drinking water	GIT/Water born disease
Hilly Area	100	20 to 50 years	Water fall stored water	20% peoples having Gastritis, Abdomen pain like complains
Plain Area	120	20 to 50 years	Ground water near Ganga	75% peoples having complain of Jaundice, Typhoid fever, Diarrhoea, Dysentery like disease.

Table 4: Water born disease incidence at hilly and plain area: questionnaire-based survey

Discussion

Water an utmost important entity of the environment is indispensable for human being's health. Rivers are natural sources of water where all living beings are dependent on some approach for their daily needs. information concerning Gange's river water superiority is vital for the diligence of life. Humans in some approach or the other, depending on the river for their daily needs. The present study has evaluated physicochemical parameters, heavy metals analysis, and microbiological analysis in the river water samples which were collected from 11 different sites of hilly (5 sites) and plain (6 sites) regions. Study data revealed physio-chemical-microbial variations in Ganges river water of hilly and plain region as post-monsoon effects. Physiochemical parameters like pH, TDS, Conductivity were found within the acceptable range. The pH of an aquatic system is a significant sign of the water quality and the extent of pollution in the disaster areas (Kumar *et al.,* 2010). A study conducted by (Matta 2014), testified that the pH of the Ganga River at Rishikesh was in an alkaline range from 7.9 to 8.1. Natural waters hold some dissolved solids due to the dissolution and survival of rock and soil. Waters of high total suspended solids (TSS) are unpleasant and hypothetically harmful (Kumar *et al.,* 2018). Conductivity is the proficiency of a constituent to conduct electricity, the conductivity of water is a more or less linear function of the concentration of dissolved ions. (Kamboj and Kamboj 2019) stated that during Kanwar Mela-2011 at Haridwar, India there are alterations in EC of Ganga river water. Biological oxygen demand (BOD) is a quantity of an amount of oxygen that bacteria will ingest while putrefying organic matter under aerobic conditions. The main attention of wastewater treatment units is to reduce the BOD in the effluent discharged to natural waters (Kumar *et al.,* 2018). In this study, BOD was found to be maximum in Roorkee and Shukartal sample sites due to the high pollution rate. The chemical oxygen demand of Shukartal water was also very high may be due to the influx of industrial wastes. (Singh *et al.,* 2005) reported the mean value of the dissolved oxygen ranging from 1.8 to 5.9 mg/L in River Ganga at Varanasi. The most important heavy metals which have clinical significance to human life and noted as water pollutants are As, Pb, Hg, C

d

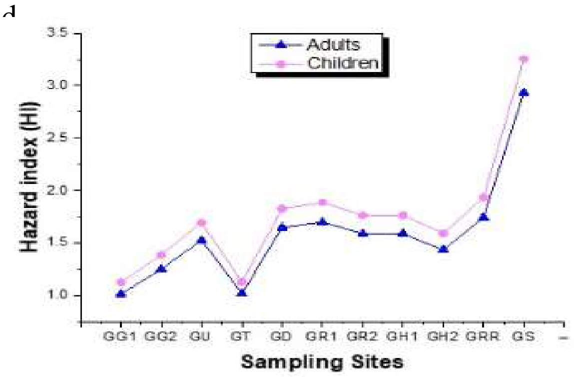

Figure 7: Variation in hazard index (HI) of heavy metals through ingestion of Ganga River water at different sites.

,

Z

n

The present study observed Arsenic and Chromium were found in more concentration in the plane region whereas Zinc and Nickle were found in more concentration in the hilly region due to weathering of rock stones. Chromium utilized in plating, as an inhibitor of corrosion of water, textile dyes, ceramic glazes and refractory (Florea and Büsselberg 2006) may be a source of pollution. The high level of chromium in the plain area due to industrial effluent, untreated water from municipal waste, laundry, and paints. The high level of Cr in water can cause cancer and allergic reaction (Jordão *et al.,* 2002), (Karadede *et al.,* 2004). Exposure to heavy metals has been associated with progressive retardation, cardiovascular disease, osteoporosis, kidney damage, cancer, and even death in cases of very high exposure (Solenkova *et al.,* 2014), (Vaishaly AG 2015). In this study, Mercury contamination was present in all water collection sites above the permissible limits which may be due to its release from local point sources such as from chemicals used in mixed farming, from municipal solid wastes, petroleum combustion, and e-wastes containing compact fluorescent lamps, fluorescent tube lights, mercury vapor lamps, mercury-based cosmetics (skin lightening soaps/creams, mascara, and eye makeup cleansing products), and medical wastes (thermometers, sphygmomanometers, and dental amalgam, *etc*.) (Kamboj and Kamboj 2019) High concentration of Hg values were observed then the permissible limits in 100ground water samples of central Ganga alluvial plain north India (Raj and Maiti 2019) The presence of Arsenic in Shukartal water sample might be due to industrial pollution of Uttarakhand, Haridwar, and Roorkee region. Rivers also contains metals in trace amount and normally are not injurious to health. In this study, the amount of chromium and nickel was found to be high at the Gomukh water collection site because no pollution source is there so this is due to rocks and hills naturally having nickel at the site of water. Nickel concentration was found in more quantity at high altitude Gomukh and Gangotri Ganga water analyzed samples. The present study calculated hazard quotient (HQ) and hazard index (HI) for non-carcinogenic concern related to adult and child by ingestion of Ganga River water showed highest contribution for non-carcinogenic risk to adults and children were caused by Hg followed by As, Ni, and Cd to the value of HI, while rest of the metals contributed least to total HI.

Fig 8: Contribution analysis of each heavy metal towards HI.

Previous studies have documented that heavy metals affect cellular organelles and constituents; cell membrane, lysosome, endoplasmic reticulum, mitochondria, and nuclei. The five elements (Arsenic, cadmium, chromium, lead, and mercury) rank among the priority metals that are of great public health significance. These metals are systemic toxicants and known for multiple organ damage. In the direction of the United States Environmental Protection Agency (U.S EPA) and the International Agency for Research on Cancer (IARC), these metals are also classified as either "known" or "probable" human carcinogens. (Sa´idi 2010 and Ghannam *et al.,* 2015). A high amount of Arsenic can cause skin disease, increase rate of cancer, and different types of circulatory disease. The toxic metals are not only affecting human health by causing severe diseases but also creates an imbalance of the aquatic ecosystem of rivers. Water quality assessment using the overall index of pollution in the riverbed-mining area of Ganga-River Haridwar, India by Nitin Kamboj 2019 concluded that the riverbed mining practice had a negative influence on the surface water quality of the Ganga River in the selected region. Study results of Mohit

Chaudhary 2017 indicated water quality of River Ganga was unsuitable for drinking because an average National Sanitation Foundation Index (NSFWQI) was found to be 53.44 and 43.56, while comprehensive pollution index (CPI) was 2.71 and 2.82 in a post- and pre-monsoon, respectively, river water is severely contaminated due to heavy metals (Heavy metal pollution index-HPI > 3) and indicated the human health risk (RAI > 1).

Bacterial parameters, such as fecal coliform (FC) which assistance as indicators of fecal contamination are also actual significant when human health is a major concern. The precise identification of pathogenic bacteria is tremendously challenging; the coliform group of organisms is used as an indicator of the presence in the wastewater of pathogenic organisms. Coliform bacteria are found in the intestinal tract of human beings. The coliform group of bacteria includes genera Escherichia and Aerobacter. (According to Environmental protection Agency) the contaminant level of the Coliform count should be zero in per 100 ml of water for drinking purposes and for the bathing purpose the fecal coliform should be less than 500 /100 ml of water. So, GR1, GRR *and* GS water collection sites are not good for bathing purposes. Because of the high coliform count present their water samples. But Gomukh and Gangotri Ganga water are pure which can be used for drinking purposes.

The HQ analysis of eight considered metals illuminated the low non-carcinogenic health risk to the consumers of Ganga River water for drinking at all selected monitored locations. However, the HQ generated for Hg crosses the unity value and indicated the high risk to children of Devpryag, Rishikesh, and Haridwar region followed by Arsenic for both adult and child at Shukartal. Being the religious importance, adventure destination and tourist hotspots, over millions of pilgrimages and tourists visit these places every year. Raju *et al.,* (2019) predicted the risk magnitude of dissolved mercury (Hg) at the central Ganga alluvial plain, northern India and found Threefold (high to extreme risk) and twofold (moderate risk) higher dHg concentration values than the permissible limit of WHO due to anthropogenic interferences. The contamination of Hg may be from riverbed, riverbank sediments, industrial, agricultural, sewage, medical products, fossil fuel burning, and cement plant ashes, etc. can affect the gastrointestinal tract, thyroid gland, nervous and reproductive system. Even, exposure to a high dose of Hg may lead to death (Verma *et al.,* 2013) Previous documented studies (Adimalla and Wu 2019) have demonstrated that there will be potential human health risks even water quality indices portrayed suitable water for drinking purpose. The minimum HI values for both considered consumer cases were reported at an upstream location (Gomukh: GG1) of the research area whereas, the maximum HI values were observed at the downstream site (Shukartaal: GS). At Tehri Dam (GT) very close HI values were evaluated as on Gomukh (GG1) for both adult and child cases (Fig. 7). Overall, HI for both adults and children exceeded the threshold limit (HI>1) and indicated potential human health risk by the intake of Ganga River water. The variation in HQ and HI at study locations was due to an unusual geological enrichment or anthropogenic influences.

Conclusion

The study concludes that post-monsoon effects were noted as significant variations in physicochemical, metal pollution, and microbiological indicators of the Ganges affected due to environmental and human mismanagement processes connected to the river. Water quality of the area (Rishikesh, Haridwar, Roorkee *and* Shukartal) sites were found most polluted as all microbiological indicator tests showed positive. Arsenic contamination above the acceptable limit was found in the Ganga water of the Shukartal region. A large number of populations of this region depends on this river water for agriculture and domestic purposes. The present study may be helpful to bring awareness to the population of Uttarakhand regarding the maintenance of health and hygiene. Mercury concentration, 27.2% of all sampling sites elicited high HQ values (>1) for children whereas, HI>1 was recorded for each location and both consumer cases. This evokes the potential human health risk due to the intake of Ganga River water contaminated with heavy metals. The study may give points to improve the planning to reduce the pollution of the river Ganga.

The Ganges river water contaminated with heavy metals and microbes might cause serious impact on public health, which may further increase risks in the development of chronic metal toxicities, chemical carcinogenesis, and infectious diseases in living beings dependent on the Ganges for their routine domestic activities and for many pilgrims who take sacred holy bath on regular basis for the long run. The study strongly recommends to concerned population and government of India to effectively plan and implement reductionist approaches towards environmental management of natural water resource facility through the improvement of anthropogenic sources, management of natural environmental terrestrial soil erosions, and propagate proper water treatment facilities of Ganges to improve quality of river water for domestic use and have a positive impact on public health quality.

Conflict of interest

No conflict of interest

Acknowledgment

We are grateful to Head of Institute Director (AIIMS Rishikesh) Who provided financial support for work on Ganga water Analysis and provided institute vehicle for the collection of a water sample. In addition, we are grateful to IIT, Roorkee and KGMU Lucknow for providing an ICP-MS instrumentation facility.

Funding

Funded by Institute intramural project under Namami Ganga research.

Declaration

Ethics approval and consent to participate: The ethical Approval has taken from institutional ethical committee (Reg. No.: 42/IEC/PhD/2018). All consent was taken from individual who participated in their Research and format of participant consent form uploaded in supplementary details.

Authors Contributions

- Prashant Kumar did all the experimental Research work under the guidance of

Anissa Atif Mirza and Dr Gulshan Kumar Dhingra.

- Data acquisition and interpretation work completed by Ashish Kothari and Avinash Kumar.
- Physiochemical analysis work evaluated and lab support for conducting the research by Gulshan Kumar Dhingra and Bela Goyal.
- Heavy metal Analysis work evaluated by Bhupender Singh, Himani Rathi.
- Microbiological experimental work evaluated by Pratima Gupta.

Competing Interests

The authors declare that they have no competing interests.

Availability of data and materials: Extra data is available by emailing to prash.chauhan40@gmail.com on reasonable request.

References

Adimalla N, Wu J (2019) Groundwater quality and associated health risks in a semi-arid region of south India: Implication to sustainable groundwater management. Human and Ecological Risk Assessment: An International Journal 25:191–216. https://doi.org/10.1080/10807039.2018.1546550

Agarwal AK, Rajwar GS (2010) Physico-Chemical and Microbiological Study of Tehri Dam Reservoir, Garhwal Himalaya, India. 7

American Public Health Association (A.P.H.A) 1998, Standard Methods for the examination of water and wastewater. Twentieth ed. A.P.H.A, 1015 Fifteenth Street, NW, Washington, DC.20005-2605.

APHA, Standard Methods for the examination of water and wastewater (23rd Edn), Washington, D.C., American Public Health Association, 2017.

Behera S., Areendran G., Gautam P. and Sagar V. (2011) For a living Ganga–working with people and aquatic species. New Delhi, WWF-India, 1-84. - Google Search. https://d2391rlyg4hwoh.cloudfront.net/downloads/for_a_living_ganga__working_with_people_and_aquatic_species.pdf.

Buffam I, Turner MG, Desai AR, et al (2011) Integrating aquatic and terrestrial components to construct a complete carbon budget for a north temperate lake district: CARBON BUDGET IN LAKE-RICH REGION. Global Change Biology 17:1193–1211. https://doi.org/10.1111/j.1365-2486.2010.02313.x

Duodu GO, Ogogo KN, Mummullage S, et al (2017) Source apportionment and risk assessment of PAHs in Brisbane River sediment, Australia. Ecological Indicators 73:784–799. https://doi.org/10.1016/j.ecolind.2016.10.038

Florea A-M, Büsselberg D (2006) Occurrence, use, and potential toxic effects of metals and metal compounds. Biometals 19:419–427.

https://doi.org/10.1007/s10534-005-4451-x

Gagan Matta; Amit Kumar; Amit Kumar; Naik, Pradeep K. and Avinash Kumar (2018): Applicability of Heavy Metal Indexing on Ganga River System assessing heavy metals toxicity and ecological impact on river water quality. INAE Letters, An Official Journal of the Indian National Academy of Engineering. (ISSN: 2366-326X: EISSN: 2366-3278) https://doi.org/10.1007/s41403-018-0041-4

Islam MS, Ahmed MK, Raknuzzaman M, et al (2015) Heavy metal pollution in surface water and sediment: A preliminary assessment of an urban river in a developing country. Ecological Indicators 48:282–291. https://doi.org/10.1016/j.ecolind.2014.08.016

Jordão CP, Pereira MG, Bellato CR, et al (2002) [Assessment of Water Systems for Contaminants from Domestic and Industrial Sewages. Environmental Monitoring and Assessment of 79:75–100. https://doi.org/10.1023/A:1020085813555

Kamboj N, Kamboj V (2019) Water quality assessment using an overall index of pollution in the riverbed-mining area of Ganga-River Haridwar, India. Water Science 33:65–74. https://doi.org/10.1080/11104929.2019.1626631

Kanaujia D, Malik D, Gupta V (2017) Risk assessment of heavy metal pollution in the middle stretch of river Ganga: an introspection. International Research Journal of Environmental Sciences 6:62–71

Karadede H, Oymak SA, Ünlü E (2004) Heavy metals in mullet, Liza Abu, and catfish, Silurus triostegus, from the Atatürk Dam Lake (Euphrates), Turkey. Environment International 30:183–188. https://doi.org/10.1016/S0160-4120(03)00169-7

Kumar A, Bisht BS, Joshi VD, et al (2010) Physical, Chemical and Bacteriological Study of Water from Rivers of Uttarakhand. Journal of Human Ecology 32:169–173. https://doi.org/10.1080/09709274.2010.11906336

Kumar V, Chopra AK, Chauhan RK (2012) Effects of Textile Effluents Disposal on water quality of Sub Canal of Upper Ganga Canal at Haridwar (Uttarakhand), India. 7

Kumar V, Kumar S, Srivastava S, et al (2018) Water Quality of River Ganga concerning Physico-Chemical and Microbiological Characteristics during Kanwar Mela 2017, at Haridwar, India: A Case Study. Arch Agri Environ Sci 3:58–63. https://doi.org/10.26832/24566632.2018.030108

Lonergan S, Vansickle T (1991) Relationship between water quality and human health: A case study of the Linggi

River Basin in Malaysia. Social Science *and* Medicine 33:937–946. https://doi.org/10.1016/0277-9536(91)90264-D

Matta G (2014) A study on physico-chemical Characteristics to assess the pollution status of river Ganga in Uttarakhand. /paper/A-study-on-physico-chemical-Characteristics-to-the-Matta/30ae1a6aff20b8e78d2685b789095bdefa78490f. Accessed 15 Jun 2020

Matta Gagan and D. P. Uniyal (2017): Assessment of Species Diversity and Impact of Pollution on Limnological conditions of River Ganga. Int. J. Water, 11(2): 87-102. https://doi.org/10.1504/IJW.2017.083759

Matta Gagan and Laura Gjyli (2016): Mercury, lead and arsenic: impact on environment and human health India. Journal of Chemical and Pharmaceutical Sciences. Vol 9 (2): 718 - 725. (ISSN: 0974-2115)

Matta Gagan, Avinash Kumar, Gulshan K. Dhingra, Singh Prashant, Gjyli Laura, Amit Kumar (2018): Limnological assessment of anthropogenic activities of River Henwal. Journal of Chemical and Pharmaceutical Sciences. 11(1). (ISSN: Print 0974-2115; Online 2349-8552)

Matta Gagan, Sachin Srivastava, R. R. Pandey and K. K. Saini (2015): Assessment of physicochemical characteristics of Ganga Canal water quality in Uttarakhand. *Environ Dev Sustain*. https://doi.org/10.1007/s10668-015-9735-x

Matta, G., Kumar, A., Nayak, A. et al. (2020). Water Quality and Planktonic Composition of River Henwal (India) Using Comprehensive Pollution Index and Biotic-Indices. *Trans Indian Natl. Acad. Eng.* *5*, 541–553. https://doi.org/10.1007/s41403-020-00094-x

Matta, G., Kumar, A., Nayak, A. et al. Determination of water quality of Ganga River System in Himalayan region, referencing indexing techniques. *Arab. J. Geosci.* *13*, 1027 (2020). https://doi.org/10.1007/s12517-020-05999-z

Matta, G., Nayak, A., Kumar, A. et al. (2020). Water quality assessment using NSFWQI, OIP and multivariate techniques of Ganga River system, Uttarakhand, India. *Appl. Water Sci.* *10*, 206. https://doi.org/10.1007/s13201-020-01288-y

Matta, G., Nayak, A., Kumar, A., Kumar, Pawan (2020). Evaluation of Heavy Metals Contamination with Calculating the Pollution Index for Ganga River System. *Taiwan Water Conservancy,* 68(3), https://doi.org/10.6937/TWC.202009/PP_68(3).0005.

Matta, Gagan; Kumar, Avinash; Naik, Pradeep K., Tiwari, A. K. and Berndtsson, R. (2018): Ecological Analysis of Nutrient Dynamics and Phytoplankton Assemblage in the

Ganga River System, Uttarakhand. Taiwan Water Conservancy. 66 (1): 1 – 12. (ISSN: 0492-1505)

Matta, Gagan; Kumar, Avinash; Tiwari, A.K; Naik, Pradeep K. and Berndtsson, R. (2018): HPI appraisal of concentrations of heavy metals in Dynamic and static flow of Ganga River System. Environment, Development and Sustainability, Springer Nature. https://doi.org/10.1007/s10668-018-01182-3.

Matta, Gagan; Naik, Pradeep K.; Machell, John; Kumar, Amit; Gjyli, Laura; Tiwari, Ashwani Kumar and Kumar, Avinash (2018): Comparative study on seasonal variation in hydro-chemical parameters of Ganga river water using comprehensive pollution index (CPI) at Rishikesh, (Uttarakhand) India. Desalination and Water Treatment; 118 (June): 87–95. https://doi.org/10.5004/dwt.2018.22487

Pandey J, Singh R (2017) Heavy metals in sediments of Ganga River: up- and downstream urban influences. Appl Water Sci 7:1669–1678. https://doi.org/10.1007/s13201-015-0334-7

Paul D (2017) Research on heavy metal pollution of river Ganga: A review. Annals of Agrarian Science 15:278–286. https://doi.org/10.1016/j.aasci.2017.04.001

Raj D, Maiti SK (2019) Sources, toxicity, and remediation of mercury: an essence review. Environ Monit Assess 191:566. https://doi.org/10.1007/s10661-019-7743-2

Sankhla MS, Kumari M, Sharma K, et al (2018) Heavy Metal Pollution of Holy River Ganga: A Review. 05:14

Singh KP, Malik A, Sinha S, et al (2005) Estimation of Source of Heavy Metal Contamination in Sediments of Gomti River (India) using Principal Component Analysis. Water Air Soil Pollut 166:321–341. https://doi.org/10.1007/s11270-005-5268-5

Sinha SN (2011) Liquid Chromatography-Mass Spectrometer (LC-MS/MS) Study of Distribution Patterns of Base Peak Ions and Reaction Mechanism with Quantification of Pesticides in Drinking Water Using a Lyophilization Technique. AJAC 02:511–521. https://doi.org/10.4236/ajac.2011.25061

Solenkova NV, Newman JD, Berger JS, et al (2014) Metal pollutants and cardiovascular disease: Mechanisms and consequences of exposure. American Heart Journal 168:812–822. https://doi.org/10.1016/j.ahj.2014.07.007

Vadde K, Wang J, Cao L, et al (2018) Assessment of Water Quality and Identification of Pollution Risk Locations in Tiaoxi River (Taihu Watershed), China. Water 10:183. https://doi.org/10.3390/w10020183

Vaishaly AG MB Krishnamurthy NB (2015) Health effects caused by metal-contaminated groundwater. IntJ Adv Sci Res 60–4

Varol M, Şen B (2012) Assessment of nutrient and heavy metal contamination in surface water and sediments of the upper Tigris River, Turkey. CATENA 92:1–10. https://doi.org/10.1016/j.catena.2011.11.011

Verma DK, Contractor AQ, Parmananda P (2013) Potential-Dependent Topological Modes in the Mercury Beating Heart System. J Phys Chem A 117:267–274. https://doi.org/10.1021/jp3095038

WHO, 1996. Guidelines for Drinking-Water Quality, Health Criteria, and Other Supporting Information. World Health Organization, Geneva.