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Carcinogenic and non-carcinogenic health risk assessment of river Ganges in different climatic conditions and regions of Uttarakhand, India

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Abstract

Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD), the two most significant physicochemical indicators, we find higher in water samples from plain regions than from hilly regions. Mean levels of As, Pb, Hg, Cd, Cr, Zn, and Ni were 5.48, 1.060, 4.4, 0.728, 3.5, 2.93, 26.56, and 7.68 (µg/L), respectively, in water samples, was within normal ranges, except Arsenic, which was found in higher at shukartal site > 10 µg/L. A marked correlation was observed between the physicochemical quality of water and bacterial density. The presence of specific bacterial strains, e.g. *Enterococcus, Pseudomonas, Klebsiella*, and *Proteus spps.*, in higher concentrations suggests a significant level of faecal contamination in water. The Most Probable Number, *Escherichia coli* count, total coliform count, faecal streptococci count and faecal coliform count were discovered in the regions of Rishikesh, Roorkee, and Shukartaal, indicating that the total bacterial count was higher than the permitted range (GR1, GRR, and GS). The spatial distribution of the Hazardous index (H.I.) in the study area revealed a rising trend of environmental leaching from mountainous parts to plain regions. Children were at a higher carcinogenic risk compared to adults both males and females. The study recommends prevention and safeguarding against anthropometric variables.

1.0 Introduction

Indians consider the River “Ganga” to be the most extensive and sacred due to its enormous traditional, commercial, and conservation aspects. It provides water for approx. 45 crore people, or more than 550 people per square kilometer, and has become the lifeline for millions of people who live along its path (Srinivas et al., 2020).and on the other hand, there are numerous tourist spots, pilgrimage sites, and spiritual landmarks on the riverside where people take a bath to complete religious rites (Kumar et al., 2010).but unfortunalty holy river is being harmed by anthropogenic activities, sewage waste disposals and expansion of urban industrial belts along river banks. The Ganges allows for the release of various wastes into this powerful river environment from twenty-nine class first cities, Twenty-three class II cities, and over 50 towns (Paul D et.,al 2017). For the management of the biota and ecosystems, there is a need to pay close attention to heavy metals and pathogenic microbes including bacteria, fungi, protozoa, and other biological organisms. Direct dumping of home garbage, industrial waste, agricultural runoff, and human activity along a river bank results in an accumulation of pollutants and contamination of the river water. Paint pigment, metals, varnishes, pulp and cotton textiles, paper, rubber, steel plants, thermal power plants, galvanizing of iron products, mining, and the haphazard consumption of pesticides and fertilizer containing heavy metals in the agricultural sector are responsible for the presence of heavy metals in river water (Sinha R et.,al 2012). These wastes include poisonous compounds that are harmful to human health, such as lead, chromium, copper, cadmium, and arsenic salts, which interrelate with the water environment and upset the river ecosystem (Luch, 2012). These pathogenic agents have been linked to several illnesses that have an impact on public health. According to research, these regions have a high prevalence of water-borne illnesses such as dysentery, hepatitis, cholera, and diarrhoea. According to the WHO, consuming potable water contributes to nearly 80% of diseases in developing nations (Khan et al., 2013). Both uncleanliness and poor water quality are responsible for 3.1% of deaths (Pawari MJ, 2015). Use of Contaminated drinking water is the major problem for human health in many cities of India (Chakraborti et al., 2003). Numerous research has been done on threat assessment for human health based on cutaneous exposure, ingestion, and inhalation (Haghnazar et al., 2021). Therefore, assessing both cancer-causing and non-cancerous risks is a helpful and popular way to learn about how hazardous elements (HEs) affect human health (Adimalla, 2020). According to various studies that counted the amount of harmful metals in drinking water Malaysia, Jordan, Turkey, the United States, and Germany had lower levels of these metals than are considered acceptable (Wang et al., 2017). According to the Environmental Protection Agency (EPA) and Agency for Research on Cancer (IARC), inorganic arsenic and toxic heavy metal exposure are important health problems in drinking water, principally due to their carcinogenic and non-carcinogenic effects on human health. The presence of As, Cr, and Cd in drinking water has been deemed a concern to public health in more than thirty countries. There is evidence that drinking 1 liter per day of water with 50µg/L of As and 8.3–51µg/L of Cr can result in lung, liver, bladder, and kidney cancer over the course of a person's lifetime (Chowdhury et al., 2016)(Alidadi et al., 2019). Prolonged exposure of heavy metals can also lead to kidney, Liver and cardiovascular disease and osteoporosis, and gastrointestinal diseases (Saha et al., 2017). To the best of our knowledge, the present study was conducted since there was a lack of comprehensively approachable evidence-based documentation and published literature regarding the Ganges River. But the main purpose of water quality monitoring is to spot issues and come up with solutions to lessen the decline of water class. The goal of current manuscript was to describe the physicochemical and bacterial quality of household water sources and to debate whether or not they meet the standards for drinking water. These wastes comprise harmful toxins that interact with the aquatic environment and affect the river ecosystem, such as salts of chromium, copper, cadmium, arsenic, mercury, and lead. These wastes contain hazardous substances that endanger human health, including lead, mercury, chromium, copper, cadmium, and arsenic salts. These substances interact with the aquatic environment and disrupt the river ecosystem. These wastes contain dangerous substances that endanger human health, including lead, mercury, chromium, copper, cadmium, and salts of arsenic. These substances also cooperate with the aquatic environment and disturb the river ecosystem.

2.0 Material Methods

2.1 Study Locations

Water samples from the Ganga River area in Uttarakhand were obtained for this study. (Gomukh, Gangotri, Uttarkashi, New Tehri, Devprayag, Rishikesh I & II, Haridwar I & II, Roorkee, and Shukartal), which is situated between 30049'59.99"N-79009'60.00"E and 29.48760N-77.98240E (Fig. 1). The river travels 2,510 kilometres from Gomukh to the Bay of Bengal. The river is 1.6–8 km wide and varies in depth from 16–30 m (Sonkar GK,et. al, 2019). With the use of a GPS tracker (Germin-62s, USA), the sampling locations were noted. Before choosing the sampling places, a number of potential factors were taken into account, such as human activities occurring close to the riverbanks (such as farming, harvesting, and swimming) and the geographic closeness of manufacturing units and municipal discharges to this river. The Ganga River serves as the primary source of domestic and irrigation water in India.

2.2 Sample Collection.

Fresh polypropylene bottles (1 L) with double stoppers were used to collect the River water samples. The polypropylene containers were cleaned with detergent, wash away thoroughly under running water, submerged in 5% HNO3 (Made in Germany) for a whole night period, rinsed with distilled water, and lastly dried in the air. The dried bottles were marked with unique identification numbers to distinguish the gathered samples. Between October 2018 and June 2019, samples were taken at a depth of 5 to 10 cm below the water's surface at 11 distinct Ganga river locations (Table 1). Bubble formation and suspended particles were strictly avoided during sampling. The River water samples were put into polypropylene bottles with 0.4% supra-pure Nitric acid (Assay: 65% Merck, Germany) & kept in cold

Table 1
Location of 11 different sampling sites at Ganga River 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
Uttarkashi	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	Triveni 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 like paint, Agriculture runoff
Haridwar I	GH1	Har ki pauri	Latitude:29.945^{0}N Longitude: 78.163^{0}E	1,030 feet	Bathing center, 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.

2.3 Quality control

The target elements' highly pure standard solutions (purity: 99.98%) were procured from Varian Inc. in the USA. We bought many chemicals, including ultra-pure HNO3, from E. Merck in Germany. Numerous working standard solutions were created by diluted with Milli-Q water from a stock solution (concentration of 1000 mg/L). The calibration curves served as the foundation for quantifying the examined metals. By examining the Certified Reference Materials NIST 1640, the analytical procedures' accuracy was evaluated (water matrix). The analysis was satisfied with the earned recovery rate of 90–99%. For each sample analysis, three duplicates were run.

2.4 Physico-chemical 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. Biological oxygen demand (BOD), chemical oxygen demand (COD) Dissolved Oxygen (DO), and total solid solutes were measured by Wrinkle's methods, volumetric analyzer, and titration methods. (APHA, 2005)18

2.5 Heavy Metal Analysis.

Eight heavy metals were analysed in this study. ICP-MS (PerkinElmer Élan 9000; USA) was used to measure the heavy metal content in water Ganga samples at the Indian Institute of Technology Centre Research facility in Roorkee, India. - In order to digest 50 ml of water, 10 ml of pure HNO3 was used. until the solution turned translucent at 80^{o}C (APHA 1998) The solution will be diluted to 50 ml with double-distilled water after being filtered with what man no. 42 filter paper. All collected water samples were subjected to eight metal analysis Cadmium (Cd), Nickle (Ni), Chromium (Cr), Copper (Cu), Lead (Pb), Zinc (Zn), Arsenic (As), Mercury (Hg) and using a standard protocol of Inductively Coupled Plasma-Mass Spectrometry (ICPMS) manufactured by Perkin Elmer. 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 Nitric acid and 2 ml Hydrogen peroxide at ~ 80oC until the solution remains about 5 ml. The solutions were filtered through What man filter paper no. 42 and dilute to 50 ml with double distilled water (APHA (American Public Health Association), 2005). The filter paper was rinsed with diluted nitric acid solution and used to remove the siliceous impurities from the digested solution. 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 ions were then directed to an electron multiplier tube detector after being sorted by the MS based on their mass/charge ratio. On the instrument's display unit, this detector then detected and quantified each ion from the processed water samples.

2.6 Water quality-

The water quality index (WQI), which integrates the various water quality metrics into a single, unit-less integer number, is regarded as an effective way to adequately represent water quality. (Şener Ş, Şener E, 2017). A specific kind of mathematical averaging function converts the raw analytical results of various water quality metrics with varied values and units into a single value. (Cude CG, 2001).

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i}$$

For each parameter considered, the quality rating scale (Qi) was determined using the formula below:

(1)

$$Q_i = \frac{C_i}{S_i} \times 100$$

Finally, the WQI was determined using the formula below.

(2)

$$WQI = \sum_{i=1}^{n} (W_i \times Q_i)$$

(3)

Ci is the normalized value assigned to each parameter, while Pi is its comparative weight. Pi has values from 1 to 4, with 4 indicating the most significant factor for aquatic life and 1 denoting the least significant factor. K is a subjective constant that can range in value from 1.0 to 0.25 based on the researcher's perception of river contamination. The five categories for the WQI are excellent (WQI < 50), decent (50 < WQI < 100), bad (100 < WQI < 200), and extremely poor (200 < WQI < 300). Table showing weight values used in WQI computation.

Table 2

the values of weights for calculation of WQI

Heavy metal	pH	TDS	EC	BOD	COD	DO	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
w_i	4	4	4	4	3	4	5	5	5	2	5	4	5	3

The Nemerrow pollution index (NPI) was determined using the formula 4 provided, where Ci and Si represent the chemical parameters' observed and standard concentrations, respectively, and n represents the total number of chemical parameters (Haghnazar et al., 2021) six levels of the pollution assessment by NPI is defined by six levels as follows: no pollution (NPI < 0.5), clean (0.5 < NPI < 0.7), Very low pollution (0.7 < NPI < 1), low pollution (1 < NPI < 2), medium pollution (2 < NPI < 3), and high pollution (NPI > 3) (Haghnazar H et. al., 2022).

$$NPI = \sqrt{\frac{\left(\left[\left(\frac{1}{n}\right)\sum_{i=1}^{i=n}\frac{C_i}{S_i}\right]\right)^2 + \left(\left[max\left(\frac{C_i}{S_i}\right)\right]\right)^2}{2}}$$

4

2.6.1 Health risk assessment

Individual dangers from a heavy metals Risk assessment is the process of estimating the probability of any given likely quantity of negative health effects over a set period (Bempah & Ewusi, 2016). Each contaminant's health risk assessment is classified as posing either carcinogenic or non-carcinogenic health risks based on an estimation of the risk level (Odum PU et. al., 2021). The Average Daily Intake (ADI) (table No-3), Hazard Quotients (HQ), Hazard Index (HI), and Cancer Risk (CR) were used to estimate the heavy metal contamination and potential carcinogenic and non-cancer health risk brought on by ingestion and dermal absorption of heavy metals in the water of the Ganga river distribution network. Adults made up the study's study group.

$$ADI_{ingestion} = C \times \frac{(IR \times EF \times ED)}{(BW \times AT)} \tag{5}$$

$$ADI_{dermal} = C \times \frac{(SA \times Kp \times ET \times EF \times ED \times CF)}{(BW \times AT)} \tag{6}$$

$$HQ_{ingestion} = \frac{ADI_{ingestion}}{RfD_{ingestion}} \tag{7}$$

$$HQ_{dermal} = \frac{ADI_{dermal}}{RfD_{dermal}} \tag{8}$$

$$HI = HQ_{ingestion} + HQ_{dermal} \tag{9}$$

$$CR = \left(ADI_{ingestion} + ADI_{dermal}\right) \times SF \tag{10}$$

While HI < 1 shows no risk to occupants, HI > 1 indicates the possibility of a non-carcinogenic risk. The values of CR < 10 − 6 show no danger, 10 − 6 < CR < 10 − 4 represent a tolerable carcinogenic risk, and CR > 10 − 4 suggests a threat of cancer.

Table 3
Description and values of exposure parameters for ADI calculation.

Parameter	Description	Unit	Value			References
			Adult male	Adult female	Children	
C	Elements concentration	$\mu g\ L^{-1}$	–	–	–	Present study
IR_{ing}	Rate of ingestion	$L\ day^{-1}$	1.5	1.5	0.7	(Su L et. al., 2016)
EF	Occurrence of exposure	$day\ year^{-1}$	365	365	365	(USEPA D, 1989)
ED	Coverage period	year	30	30	12	(USEPA D, 1989)
CF	Renovation feature	$L\ cm^{-3}$	0.001	0.001	0.001	(Su L et. al., 2016)
BW	Weight of human body	kg	70	55	15	(Su L et. al., 2016)
AT	Average exposure time	day	ED × 365	ED × 365	ED × 365	(USEPA D, 1989)
SA	Skin area	cm^2	18086	15476	6597	(Su L et. al., 2016)
ET	Contact duration	$h\ day^{-1}$	0.4	0.4	0.4	(Wu, J. and Sun, 2016)
Kp	Skin permeability	$cm\ h^{-1}$	0.001 (except for Cr = 0.002)			(USEPA, 2002)

2.6.2 Multivariate statistical analysis

By using principal component analysis (PCA), vast sets of variables are condensed into a small number of linear combinations of the original data. The majority of the contamination in the huge set is still present when using a linear combination, which creates new variables that are orthogonal and uncorrelated to one another. It takes the covariance matrix of the original variables and extracts the eigenvalues and eigenvectors. Principal components (PC) have been extracted from the sampling locations using this methodology, which has also been used to assess potential sources and variations of heavy metals in water samples.

3.0 Results

3.1 Water chemistry of the Ganges River-

The Physico-chemical characteristics of water samples taken throughout the study period from the Ganga River are displayed in Table 4. The World Health Organization standards were used to compare the water eminence detected throughout this study (Cotruvo JA, 2017). The rules for drinking water listed permissible limits (Table-4). Compared to February (7.2) and June (6.4), the river water sample from October (7.4) had the greatest pH concentration (7.2). The average water temperature measured during the study period ranged from 10.5 to 25.05 (°C), with the river water sample recording the greatest mean temperature (20.47 ± 5.02°C) and the reservoir water sample recording the lowest (10.51 ± 7.63°C). In three separate seasons, samples of Ganga water were taken, and the conductivity and TDS content varied greatly from 141.20 ± 31.34 & 239.81 ± 71.34 (μS/cm) and 93.13 ± 18.32-173.72 ± 55.73 mg/L, respectively. The water sample yielded the greatest mean values of DO and BOD (8.95 ± 0.55 mg/L and 3.22 ± 1.38 mg/L, respectively), whereas the water sample also yielded the highest mean value of COD (8.803.15 mg/L).

Table 4
Statistical summary of physiochemical parameters and heavy metals in the Ganga River water samples (unit: µg/L, n = 13)

	October 2018			**February 2019**			**June 2019**			
	Min	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**WHO (2011)**
pH	6.7	7.4	6.96	6.4	7.2	6.79	6.5	7.2	6.89	6.5–8.5
EC	53	267	131	50	287	146	87	299	134	1500
TDS	79.1	399	195	146	390	207	69.7	366	183	1000
BOD	1.2	5.6	2.58	1.9	6.8	2.94	1.1	5.8	2.59	5
COD	3.3	15.1	7.19	5.2	16.6	7.73	3.1	14	6.64	10
DO	8.1	9.4	8.86	6.4	10.5	8.06	6.5	9.2	8.31	5
As	2.5	16.1	6.03	1.24	22.5	4.76	1.45	21.1	5.65	10
Pb	0.008	0.93	0.113	0.014	2.45	0.649	0.38	8.17	2.42	10
Hg	5.16	7.82	6.45	0.352	3.78	1.72	0.25	9.98	5.03	6
Cd	0.004	0.19	0.041	0.142	5.65	1.73	0.176	0.99	0.413	3
Cu	0.319	1.25	0.629	0.57	3.67	1.34	3.15	23.4	8.79	2000
Cr	0.571	7.17	2.61	0.65	5.95	1.92	0.49	18.2	4.26	50
Zn	0.498	9.63	3.09	8.59	38.5	15.7	10.2	224	60.8	3000
Ni	0.734	23.2	5.05	3.46	18.8	8.51	1.95	32.3	9.49	70

First, the limit values established by the WHO, USEPA, and TSE listed in Table 2 were compared to the heavy metal contents of the surface water samples. Table 4 provides descriptive data on metal concentrations for surface water samples taken during three different seasons. Heavy metal concentrations ranged widely; the levels (in µg/L) at October 2018. When compared to WHO values and index calculations, the As concentration was discovered to be quite high in three seasons. In October 2018 and June 2019, the highest Hg content was higher above the WHO-recommended limits. All of the water samples were found to have very low levels of pollution, according to the evaluation of the water quality index (WQI) Nemerow's pollution index (NPI). Figure 2 displays the Nemerow's pollution index and WQI.

3.2 Health risk assessment.

The average daily dose (ADD) of toxic compounds were determined through the consumption of drinking water and dermal absorption pathway because there is no information on the non-carcinogenic effects of heavy metals in the Ganges water in the Uttrakhand region. Assessments of health risks and their effects on environmental health must be done in order to address the public health issue due exposure to heavy metal contamination through drinking water (drinking, dishwashing, swimming, and bathing).

3.2.1 Non-Carcinogenic Risk.

The pathways of exposure to the target species are utilised to estimate the health risk presented by a pollutant because establishing the exposure amount is so crucial. People can be exposed to potentially harmful metals in a variety of ways, and eating vegetables polluted with these substances can have negative health effects. The HI, which depicts the combined impacts of all components, was used to evaluate the health hazards. The table displays the HI of examined metals after comparison between adult, female, and paediatric water consumption. For men, the HI of Arsenic was 3.94E-01, followed by Cd: 4.64E-02, Cr: 3.56E-02, Cu: 1.61E-03, Hg: 3.16E-02, Ni: 9.23E-03, Pb: 1.65E-02, Zn: 1.94E-03, respectively, and for women, it was As: 5.01E-01, Cd: 5.63E-02, Cr: 4.34E-02, Cu: 2.04E-03, Hg: 4.02E-02, Ni: 1.16E-02, Pb: 2.10E-02, Zn: 2.47E-03, respectively while for children As: 8.56E-01, Cd: 9.38E-02, Cr: 7.27E-02, Cu: 3.49E-03, Hg: 6.88E-02, Ni: 1.96E-02, Pb: 3.59E-02, Zn: 4.21E-03 (Table-5).

Table 5

Non-carcinogenic risk assessment via different exposures of heavy metals in water.

	Male			**Female**			**Children**		
	HQ_{ing}	HQ_{derm}	HI	HQ_{ing}	HQ_{derm}	HI	HQ_{ing}	HQ_{derm}	HI
As	3.92E-01	1.99E-03	3.94E-01	4.99E-01	2.17E-03	5.01E-01	8.53E-01	3.39E-03	8.56E-01
Cd	3.13E-02	1.51E-02	4.64E-02	3.98E-02	1.64E-02	5.63E-02	6.81E-02	2.57E-02	9.38E-02
Cr	2.57E-02	9.90E-03	3.56E-02	3.27E-02	1.08E-02	4.34E-02	5.59E-02	1.69E-02	7.27E-02
Cu	1.57E-03	3.79E-05	1.61E-03	2.00E-03	4.13E-05	2.04E-03	3.42E-03	6.45E-05	3.49E-03
Hg	3.15E-02	1.52E-04	3.16E-02	4.01E-02	1.65E-04	4.02E-02	6.85E-02	2.58E-04	6.88E-02
Ni	8.24E-03	9.93E-04	9.23E-03	1.05E-02	1.08E-03	1.16E-02	1.79E-02	1.69E-03	1.96E-02
Pb	1.63E-02	2.62E-04	1.65E-02	2.07E-02	2.85E-04	2.10E-02	3.54E-02	4.45E-04	3.59E-02
Zn	1.90E-03	4.58E-05	1.94E-03	2.42E-03	4.99E-05	2.47E-03	4.14E-03	7.80E-05	4.21E-03

3.2.2 Carcinogenic Risk.

The risk of cancer was determined based on the intake of inorganic As, Pb, and Cr, which may have more potent effects depending on the exposure level. (Garg VK et. al., 2014). Figure 3 depicts the results of the calculations performed on the carcinogenic risks (CR) and cumulative carcinogenic risks (TCR) associated with consuming river water and ingesting As, Cd, Cr, Cu, Hg, Ni, Pb, and Zn. We also demonstrated the spatial distribution of carcinogenic risk of heavy metals (As, Cr, Cd, and Pb) (figure-4) in collected water samples, these substances may induce both non-carcinogenic and carcinogenic effects.

The CR values of As was higher as compared to other tested heavy metals. Spatial distribution of carcinogen risk of heavy metals was higher in children followed by female and male (Fig. 3). Because the CR values was below the US EPA's recommended safety threshold ($1×10^{-4}$), it is possible for both adults and children Fin Mashhad be exposed to carcinogens through dermal contact. According to a new World Health Organization (WHO) report, children are more prone to health concerns, because they consume more food, drink more water, and breathe more air relative to their weight. The Digestive, neurological, reproductive, and immunological systems of children are still developing. Exposure to harmful substances during the early stages of development results in irreparable harm (Peek L et. al., 2018). The finding state that in order to reduce the amount of carcinogenic heavy metals, some interventions, clean-up, and control measures are needed at all stations. To safeguard the citizens' health in this major city, it is recommended that adequate purifying improvement initiatives be put in place.

3.3 Microbiological assessment of river Ganga water.

Total heterotrophic bacterial counts in the investigation varied widely, from $1.2 ×10^7$ to $6.0 ×10^7$cfu/ml. The range of heterotrophic bacteria counts was $1.0 ×10^6$–$3.7× 10^7$ cfu/ml, with $3.6× 10^7$ – $3.3× 10^7$ cfu/ml being the maximum mean value. The maximum mean value of *Klebsiella spp*. was found in river water samples during the summer, when it was $6.43×10^7$± $3.49× 10^7$ cfu/ml, while the highest mean value of *Acinetobactor spp*. was found in river water samples through the rainy season. when it was $1.57× 10^7$ ±$1.14 ×10^7$ cfu/ml. (October-2018). *Pseudomonas spp*. and *E. coli* were reported to have maximum mean concentrations of $4.80 x10^7$ ± $2.11 x 10^7$ and $5.03 x 10^7$ ± $3.21 x 10^7$ cfu/ml, respectively, throughout the summer. (June 2019). *Proteus species* was recorded as $2.92 × 10^7$ ± $1.31 × 10^7$ cfu/ml throughout summer season and *citrobacter spp*. was recorded as $3.00 × 10^6$ ± $3.82 × 10^6$ cfu/ml throughout summer period. The total heterotrophic bacteria count mean values was higher throughout summer period water samples as compared to winder and raining period. Other seasons and area bacterial count are given in the table 6. Biochemical bacterial identification was done by manual detection methods shown in figure.5. Total six kinds of bacteria were identified through the period of study including *Klabsiella spp, Pseudomonas spp, Proteus spp, Citrobacter spp, Escherichia coli*, and *Acinetobacter spp*. *Escherichia coli* had the highest frequency in river water followed by *Pseudomonas spp, Klabsiella spp*.

Table 6

Seasonal variation of bacteriological quality in different area of revere Ganga water samples.

Bacteria	**June 2019**	**October 2018**	**February 2019**
K. pneumoniae CFU/ml	$6.43 \times 10^7 \pm 3.49 \times 10^7$	$2.59 \times 10^7 \pm 2.62 \times 10^7$	$5.13 \times 10^7 \pm 2.28 \times 10^7$
P. aeruginosa CFU/ml	$4.80 \times 10^7 \pm 2.11 \times 10^7$	$2.93 \times 10^7 \pm 1.05 \times 10^7$	$2.74 \times 10^7 \pm 1.07 \times 10^7$
P. mirabilis CFU/ml	$2.92 \times 10^7 \pm 1.31 \times 10^7$	$1.25 \times 10^7 \pm 1.37 \times 10^7$	$2.52 \times 10^7 \pm 1.99 \times 10^7$
C. freundii CFU/ml	$3.00 \times 10^6 \pm 3.82 \times 10^6$	$1.25 \times 10^6 \pm 1.29 \times 10^6$	$2.36 \times 10^7 \pm 1.08 \times 10^7$
E. coli CFU/ml	$5.03 \times 10^7 \pm 3.21 \times 10^7$	$3.86 \times 10^7 \pm 2.32 \times 10^7$	$2.82 \times 10^7 \pm 2.19 \times 10^7$
A. baumannii CFU/ml	$3.91 \times 10^7 \pm 3.26 \times 10^7$	$1.57 \times 10^7 \pm 1.14 \times 10^7$	$2.48 \times 10^7 \pm 1.13 \times 10^7$

3.4 Antibiotic susceptibility testing.

The antibiotic susceptibility pattern was determined against 18 commonly used antibiotics (figure.5) by the Kirby-Bauer disk diffusion methods. According to Clinical Laboratory Institute guidelines (CLSI-2018). Cefotaxime, Cefodoxime, Cefazidime, Aztreonam, Ceftriaxone, Amikacin, Azlocillin, Carbenicillin, Cefepime, Cefoperazone, Cefotaxime, Ciprofloxacin, Ceftazidime, Doripenem, Doxycycline, Gentamycin, Gatifloxacin, Levofloxacin are the antibiotics used in this present study. Antibiotic susceptibility testing was performed for all isolated bacteria. The maximum number strains show rug sensitive patters towards the tested antibiotics. Only *Pseudomonas* and *accinetobacter spp* shows resistance to some of antibiotics. *Pseudomonas* showed resistance to Cefotaxime, ceftriaxone, Ciprofloxacin, and Levofloxacin. *Accinetobacter spp* showed resistance to Ceftriaxone, Amikacin, ciprofloxacin and Levofloxacin (Fig. 5).

3.4.1 Principal Components Analysis.

Principal Component Analysis (PCA) was used to recognize key elements associated with sources in order to understand their multivariate associations, categorise their prospective sources, and determine the metallic concentration's reliable idea of the various sources of heavy metals contributing to the water collected from the Ganga River during altered seasons. Data revealed a substantial positive association between PC1 and the following elements: Cd, Cr, Hg, Pb, Cu, Ni, As, and Zn. PC1 accounted for 75% of the total variability. As (0.491), Cr, and Pb were the next strongest, all of which point to an anthropogenic source.

Table 7

Correlation analysis for physiochemical parameters and heavy metals concentrations in water.

	pH	TDS	EC	BOD	COD	DO	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
pH	1.000													
TDS	-0.310	1.000												
EC	-0.375	0.987	1.000											
BOD	0.008	0.824	0.791	1.000										
COD	-0.273	0.972	0.972	0.801	1.000									
DO	-0.373	0.728	0.710	0.435	0.747	1.000								
As	-0.329	0.934	0.937	0.637	0.968	0.782	1.000							
Cd	-0.416	0.950	0.962	0.747	0.959	0.776	0.933	1.000						
Cr	-0.511	0.947	0.947	0.714	0.901	0.656	0.890	0.932	1.000					
Cu	-0.420	0.858	0.891	0.684	0.913	0.594	0.894	0.929	0.890	1.000				
Hg	-0.587	0.792	0.781	0.517	0.816	0.792	0.836	0.885	0.831	0.842	1.000			
Ni	0.689	-0.112	-0.107	0.297	-0.14	-0.432	-0.288	-0.224	-0.229	-0.206	-0.602	1.000		
Pb	-0.430	0.917	0.926	0.723	0.916	0.599	0.897	0.940	0.962	0.965	0.851	-0.200	1.000	
Zn	-0.329	0.817	0.824	0.629	0.877	0.800	0.872	0.936	0.805	0.892	0.876	-0.267	0.861	1.000

According to earlier studies (Usman K, Al-Ghouti MA, Abu-Dieyeh MH), the concentrations of these elements in Qatar fluctuate across the nation as a result of the most intense human activity in the neighbourhood. Tetraena qataranse, a shrub plant, was used to evaluate the tolerance to and bioaccumulation of cadmium, chromium, copper, and nickel (Usman et al., 2019). PC1 on the other hand showed a weak negative connection to Cu. PC2 demonstrated a moderately negative correlation with Nickel and was responsible for 13.9% of the total variability. The number of PCs is determined using the scree plot. The component plot of the principal component analysis in rotated space and the contribution of the pollution sources as determined by PCA-MLR are shown in Figure.6. The factor loadings, cumulative percentage, and percentage of variance are explained by each factor as indicated in Table.7

4.0 Discussion

4.1 Physico-chemical parameters.

The physicochemical parameters and bacteriological analysis for different domestic water sources discussed in WHO and USEPA guidelines for drinking water quality. The hydrogen ion concentration (pH) of water affects biological and chemical activities that only occur within a specific range serves as evidence of the importance of this parameter (Kolawole OM et. al., 2013). Industrial or home garbage on considerably impacts the pH levels of the nearby waterbodies (Campbell IC, 1978). The pH trend in tap water has been found to be fairly acidic, and the pH range was within acceptable range for drinking water, which is 6.5 to 8.59 (WHO 2011). This outcome approves by (Shittu OB, Olaitan JO, 2008). Who discovered that the pH range of the water used for drinking and swimming in Abeokuta, Nigeria, was the same. Average pH readings below 6.5 are considered to acidic for humans to consume and can lead to health issues, such as infections with acidosis. Synergistically, low pH decreases the toxicity of heavy metals in waterbodies (Effendi H, 2015). Numerous human actions, such as washing, bathing, and using bathrooms close to waterbodies, may also impact on pH levels, air temperature and various chemical and biological processes impact the pH of water bodies (Manjare SA, Vhanalakar SA, 2010). The majority of fish can survive in a pH range of 5.0 to 9.0, and a smaller pH change has no noticeable effects on aquatic life. However, pH changes impact the availability and solubility of different chemicals, exacerbating nutritional issues for aquatic life. Here, it might be inferred that the pH levels of the River Ganga have no appreciable influence on its aquatic life, human population, or plant life. The obtained samples contained levels of total dissolved solids (TDS) ranging from 69.7 to 399 µg/L in each of the three seasons. In October 2018, the highest TDS value was recorded (79.1–399). TDS levels that are too high raise the water temperature impede photosynthesis, and lessen water clarity (Rahman MS, 2014). TDS concentrations, however, were found to be much below the 1000 mg/L WHO guideline limit, which is intended to safeguard fisheries, aquatic life, and domestic water supplies. Electrical conductivity, which determines the number of ions in water, singnificantly impacts and, in turn, user approval of the water (Florescu D et. al., 2011). Each subterranean water sample had an average value within the WHO-acceptable level. Electrical conductivity (EC) is a common way to gauge the total concentration of ionized water elements, and a higher conductivity indicates more water contamination (Wilcock RJ, Stevenson CD, 1981). The EC values of the water samples taken for this study across various seasons were very similar (Table 4). From the physicochemical parameter analysis, it could be concluded that the water of the River Ganga is satisfactory in terms of EC, pH, and TDS values.

The BOD level detected in water samples fell within the range depicted in the table (according to WHO). BOD assesses how much oxygen is used by bacteria and other microbes to oxidize the stuff in the water (Aniyikaiye et al., 2019)(Bhateria & Jain, 2016)(Wondie TA, n.d.). The water samples from October 2018, February 2019, and June 2019 were tested for DO values ranging from 8.1 to 9.4, 6.4 to 10.5, and 6.5 to 9.2 mg/L. These results were compared to WHO acceptable criteria for drinking water. Depending on the water's temperature, very little oxygen is dissolved in warm water compared to cold water (Nduka JK, Orisakwe OE, 2008). Therefore, one of the reasons for the low DO values found in this study could be the high temperature of the water sources. All living things depend heavily on dissolved oxygen, which can enter bodies of water directly from the air or be produced by autotrophs through photosynthesis. The surface water sources' DO readings throughout this study period were within WHO guidelines. The dissolved oxygen content has been decreasing in river water samples, which may indicate that too many bacteria are present (Olajire & Imeokparia, 2001). It has been noted that DO oxidiszes both organic and inorganic compounds, reducing their ability to cause consumer annoyance. Although dissolved oxygen may not directly endanger human health, it may impact other water substances (Chapman, D. and Kimstach, 1996).

4.2 Heavy metals Analysis

Heavy metal concentrations ranged widely; the levels (in µg/L) in October 2018. As: 2.5–16.1, Pb: 0.008–0.93, Hg: 5.16–7.82, Cd: 0.004–0.19, Cu: 0.319–1.25, Cr: 0.571–7.17, Zn 0.498–9.63, Ni: 0.734–23.2. Same as the concentration in February 2019 were As: 1.24–22.5, Pb: 0.014–2.45, Hg: 0.352–3.78, Cd: 0.142–5.65, Cu: 0.57–3.67, Cr: 0.65–5.95, Zn: 8.59–38.5, Ni 3.46–18.8. Furthermore, in June 2019, the concentrations of heavy metals were As; 1.45–21.1, Pb: 0.38–8.17, Hg: 0.25–9.98, Cd: 0.176–0.99, Cu: 3.15–23.4, Cr: 0.49–18.2, Zn: 10.2–224, Ni: 1.95–32.3 (table-2). The As concentration is high in three seasons compared to WHO values and index calculations. The current investigation found that October's maximum concentration of As in the Ganga River water was 16.1 µg/L, slightly higher than the WHO-recommended level (10 µg/L). Islam et al., conducted a comparative investigation on the Korotoa River and discovered As levels of 46 µg/L and 37 µg/L throughout the winter and summer seasons, respectively (Islam et al., 2015). Arsenic (As) has a link to hypertension, and Jolly et al. discovered that the As level in water from the Shitalakhya River was within the allowable range (10µg/L) (Jolly YN et. al., 2018). It effects on the cardiovascular system and may harm the liver. In Bangladesh, they investigated the Shitalakhya River's water. They noted a Pb content of 16 µg/L (Jolly YN et. al., 2018) the seasonal change in Pb concentration and found River Korotoa had a Pb level of 35.0 µg/L in the winter and 27.0 µg/L in the summer (Proshad et al., 2018). In a sample of water taken from the River Buriganga, Ahmad et al. discovered a Pb level of 65.45 µg/L (Ahmad MK et. al.,, 2010). Vehicle exhaust, metal plating, wastewater discharge, fertiliser, etc. are all potential sources of lead (Karrari et al., 2012). Haem biosynthesis and erythropoiesis are impacted by lead (Pb). Chronic Pb exposure causes malignancies and anaemia in adults, damage to male reproductive organs, hormonal imbalances, and IQ decline in early children (Siddiqui MK, Srivastava S, 2002)(Tandon et al., 2001). In October 2018 and June 2019, the highest Hg content was higher above the WHO-recommended limits. All of the water samples were found to have very low levels of pollution, according to the analysis of the Nemerow's pollution index (NPI) and the Water quality index (WQI). Every form of mercury is harmful, and its side effects include kidney, nervous system, and gastrointestinal toxicity (Fernandes Azevedo et al., 2012).

4.2.1 Human health risk assessment.

The risks to human health from the heavy metal contamination in the water distribution network can increase through a number of exposure modes. The current study examined the dangers to human health from skin contact and oral consumption that are both non-carcinogenic and carcinogenic. As, Hg, and Cu had the highest and lowest levels of metal content, respectively. When toxic compounds are present in a contaminated environment, humans may be exposed to them, and the human health risk assessment evaluates the type and severity of adverse health impacts. In the current work, exposure and risk analyses were carried out based on the methodology of the USEPA and APHA. Humans acquire heavy metals mostly through drinking water, food, inhaled aerosol particles, and dust (Díaz-Somoano et al., 2009). The frequency of consumption directly affects how harmful heavy metals are to human health. But this research also took cutaneous absorption and consumption from drinking water into account. This led to the health risk estimation of As, Cd, Cr, Cu, Hg, Ni, Pb, and Zn revealing the mean HQs suggesting an acceptable level of non-carcinogenic deleterious health risk in all samples taken from the river Ganga water distribution network in three different sessions. The mean values of HI through ingestion, cutaneous adsorption, and total HI demonstrate the negligible non-carcinogenic danger to residents and are summarised in Table no. Pb, Cr (VI), Cd, and Ni are examples of heavy metals that may increase the risk of cancer in people (Tani & Barrington, 2005)(Cao et al., 2014). The above table provides the carcinogenic risk assessment for both male and female adults as well as youngsters. This outcome came after multiple investigations. They stated that youngsters received much larger doses of all heavy metals than adults, which was supported by our findings. For instance, in Australia and Thailand, children's populations had average ADI real values that were approximately 1.7 and 2.5 times greater than those of adults, respectively. (Wongsasuluk et al., 2014)(Saha et al., 2017). The findings of this study indicate that the toxins in the area's drinking water posed a danger of cancer to locals through cumulative consumption and skin contact. A related study also supports these findings. (Cao S et al., 2014)(Wcisło et al., 2002)(Yang G et al., 2014).

4.3 Bacterial quality in river water samples.

The mean total bacterial counts in both the reservoir and the river were greater than what the WHO deemed safe for drinking water. The results of this investigation corroborate those of (Doughari JH, Elmahmood AM, 2007). The extraordinarily high total heterotrophic bacterial load in the water indicated that it may be unsafe for human consumption and has been polluted with possibly harmful microorganisms. Changes in the bacterial population's abundance can be used to identify surface water microbial contamination (Kavka, G.G. et al., 2006). The presence of bacteria in surface water not only suggests that the water is contaminated with excrement but also raises questions about potential risks to human health (Baghel VS et al., 2005). Typhoid, diarrhoea, and cholera are the three main diseases that could develop from bacterial pollution of the groundwater and surface water. As water infiltrates through the soil, the water contains little to no bacteria, which could have been eliminated by thorough filtration. (Uzoigwe CI, 2012). The characterisation of the isolates from the water samples from the study's sampling locations, which were heavily contaminated with one or more bacterial pathogens, served as confirmation of this. From river water samples, the high bacterial loads of the species *Klebsiella, Pseudomonas, Proteus, Escherichia, citrobacter*, and *Acinetobacter* were isolated. The significant number of pathogens present in the water sample and the high number of bacteria isolated from it in this investigation point to high faecal contamination and a health risk for human depletion (Schets FM et al., 2005). According to WHO recommendations, there shouldn't be any fecal coliforms in hundred millilitre of drinking water. The reason for the severe pathogen contamination of waters as seen in this study may be related to the river's shallowness and various savage drainage systems, which make it simple for particles from the environment to enter. It could also be a result of the places' unsanitary surroundings (Shittu OB, Olaitan JO, 2008)(Musyoki, A.M. et al., 2013). In Athi River found high number of total coliform count surpassed the WHO allowed limit from water sources in river Ogun (Nairobi River surface water bacterial infections and their effects on downstream people' health). The bacterial species found in the water samples may be caused by farming methods carried out close to the surface water by the habitat of the local population, which may lead to open defecation along the farmland and a tendency for runoff from these farmlands to wash into the River. Human activities including bathing, farming, washing, and human or animal facial seepage run-offs infiltrate the waterbodies and can contaminate the surface water. These activities are capable of spreading a wide range of infectious diseases (Anyanwu CU, 2012). The study's bacterium findings have the potential to infect consumers with urinary tract infections, meningitis and pneumonia. The most common bacteria in water that cause waterborne illnesses like typhoid, dysentery, and diarrhoea, as well as being linked to global mortality, are the coliforms. They are the main bacterial indicator for faecal contamination in water (World Health Organization, 2004). The high abundance of bacteria, including *Klebsiella, Pseudomonas, Proteus, Escherichia, Citrobactor*, and *Acinatobactor spps*, found in the river and reservoir water in this study could be attributed to one or to several sewage effluents, including agricultural run-off and direct faecal contamination from natural fauna (Annous B, Gurtler J, 2012).

High levels of bacteria were found in the summertime water samples, which may be the result of environmental runoff that boosted the microbial burden, particularly coliforms. The discovery is made by Esharegoma OS (Esharegoma OS et al., 2018). A concentration of nutrients brought on by midsummer evaporation of water was postulated as the cause of the observed greater microbial counts in the rainy season compared to the dry season (Juma K et al., 2016). This odd pattern in the occurrence definitely demonstrates that specific seasonal factors in the tropics favour their proliferation. A greater pH and an increase in decomposable organics in the waterbody observed during different seasons, which encouraged an increase in the microbial Contamination, may have contributed to the high microbial load.

5.0 Conclusion

Seasonal fluctuations significantly impact physiochemical variations, heavy metals, and microbiological contaminations, according to the study findings. Mean of TDS, pH, and EC concentrations were found to be within acceptable limits and below the reference range, while the mean values of BOD, COD, and DO were likewise below acceptable limits. However, physicochemical pollution indicators were found to be higher in plain areas than in hilly areas. Except for Hg, the mean concentrations of arsenic, lead, mercury, cadmium, copper, and chromium. Because of industrial pollution, agricultural runoff, and anthropogenic activities, the concentration of As in the water has grown downstream. In the agricultural fields of the Ganga River, a very high ecological danger has been assessed due to high Hg concentration and contribution. The Ganges river water contaminated with heavy metals and microbes could have a serious impact on public health, increasing the risk of chronic metal toxicities, chemical carcinogenesis, and infectious diseases in living beings who rely on the Ganges for their daily activities, as well as many pilgrims who take sacred holy baths regularly. The study strongly advises concerned citizens and the Indian government to plan and implement reductionist approaches to the environmental management of natural water resource facilities by improving anthropogenic sources, managing natural environmental terrestrial soil erosion, and propagating proper Ganga water treatment facilities to improve river water quality for domestic use and have a positive impact on public health.

Declarations

Declaration of Competing Interest

The authors declare that they have no conflict of Interest

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Author's contribution

Prashant Kumar and Ashish Kothari conceived the structure, performed experiments and wrote the manuscript. Prashant Kumar collected environmental samples. Prashant Kumar and Ashish Kothari designed the experiments and helped authors to edit manuscript. Prashant Kumar, Ashish Kothari, Anindita Manda, Shashi Ranjan Mani Yadav, Bhupender Singh, Balram Ji Omar, Ajeet Singh Bhadoria, Pratima Gupta, and Anissa Atif Mirza did data analysis and edited the manuscript. All other authors have approved and finalised the manuscript for final submission.

Ethical approval

Ethics approval and consent to participate: The Ethical Approval has been taken from institutional ethical committee (Reg. No.: 42/IEC/Ph.D./2018).

Date availability

The datasets analysed during the current study are available from the corresponding author on reasonable request.

Supplementary Information

Supplementary excel showing heavy metals of Ganga water in different seasons.

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Figures

Figure 1

Map showing the different location of sample collection site (star mark).

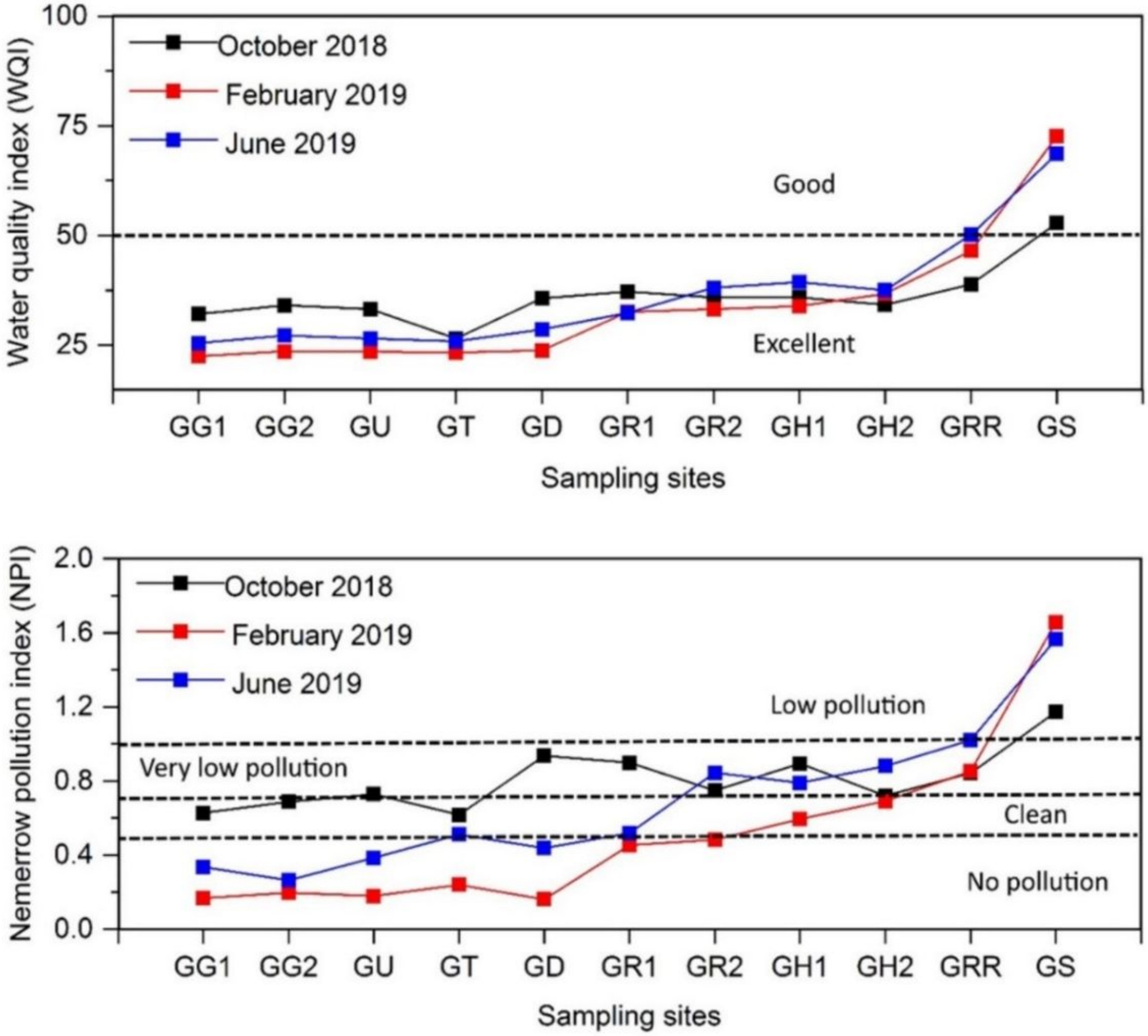

Figure 2

Water quality index (WQI) spatial distribution and nemerrow pollution index spatial distribution (WQI).

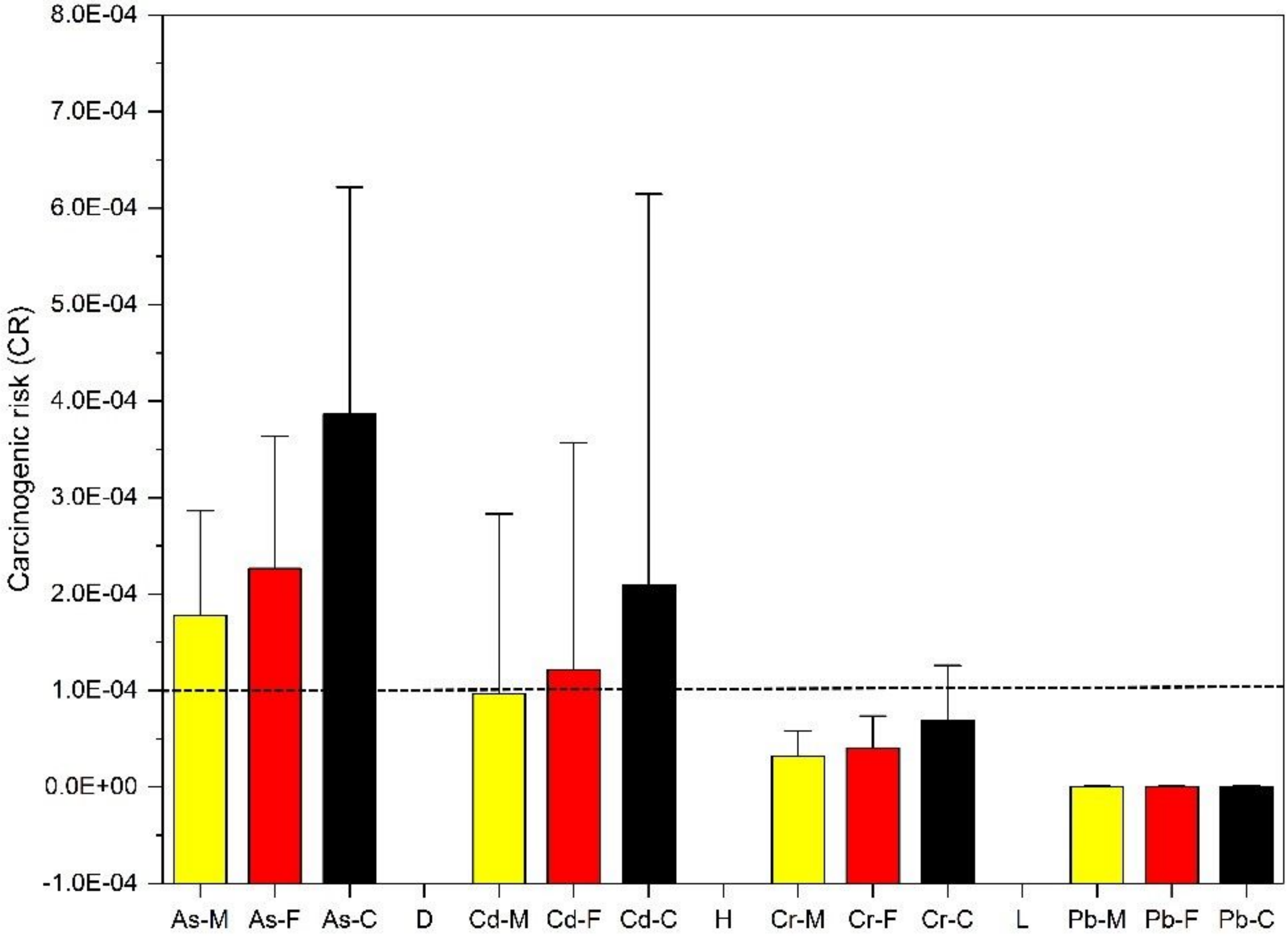

Figure 3

Carcinogenic risk assessment of heavy metals in collected water samples (M: male, F: female, C: children)

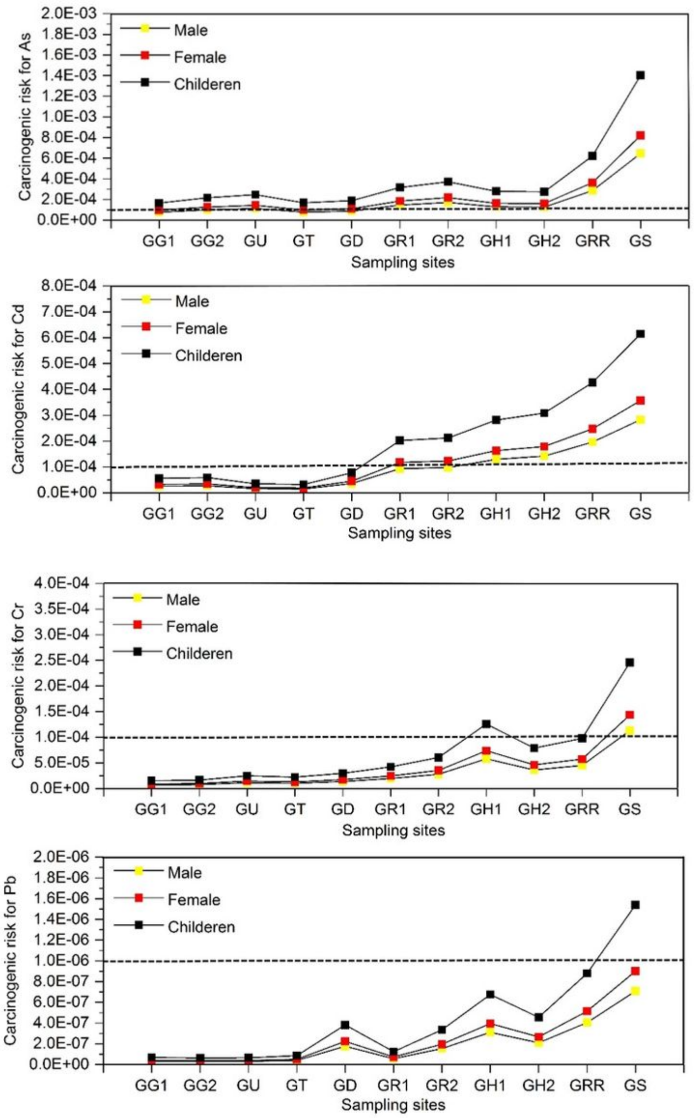

Figure 4

Spatial distribution of carcinogenic risk of heavy metals in collected water samples

Bacteria	Indole	Methyl red	Citrate	Oxidase	Urease	H2S	TSI	Catalase	Coagulase	VP
K. pneumoniae	(-)	(+)	(+)	(-)	(+)	(-)	Y/Y gas	(+)	(-)	(+)
P. aeruginosa	(-)	(-)	(+)	(+)	(-)	(-)	Y/R	(+)	(-)	(-)
P. mirabilis	(-)	(+)	(+)	(-)	(+)	(+)	K/A+gas	(+)	NA	(-)
C. freundii	(-)	(+)	(+)	(-)	(+)	(+)	A/A+gas	(+)	NA	(-)
E. coli	(+)	(+)	(-)	(-)	(-)	(-)	A/A+gas	(+)	(+)	(-)
A. baumannii	(-)	(-)	(+)	(-)	(-)	(-)	K/K	(+)	(+)	(-)

Figure 5

Identification and Antibiotic susceptibility testing of bacteria isolated form water samples from different location. A. showing all tested biochemical test by manual methods. B. Antibiotic susceptibility testing by disc diffusion methods. (TSI; Triple Sugar Iron Test, VP; VogesProskauer test, H2S; Hydrogen Sulfide)

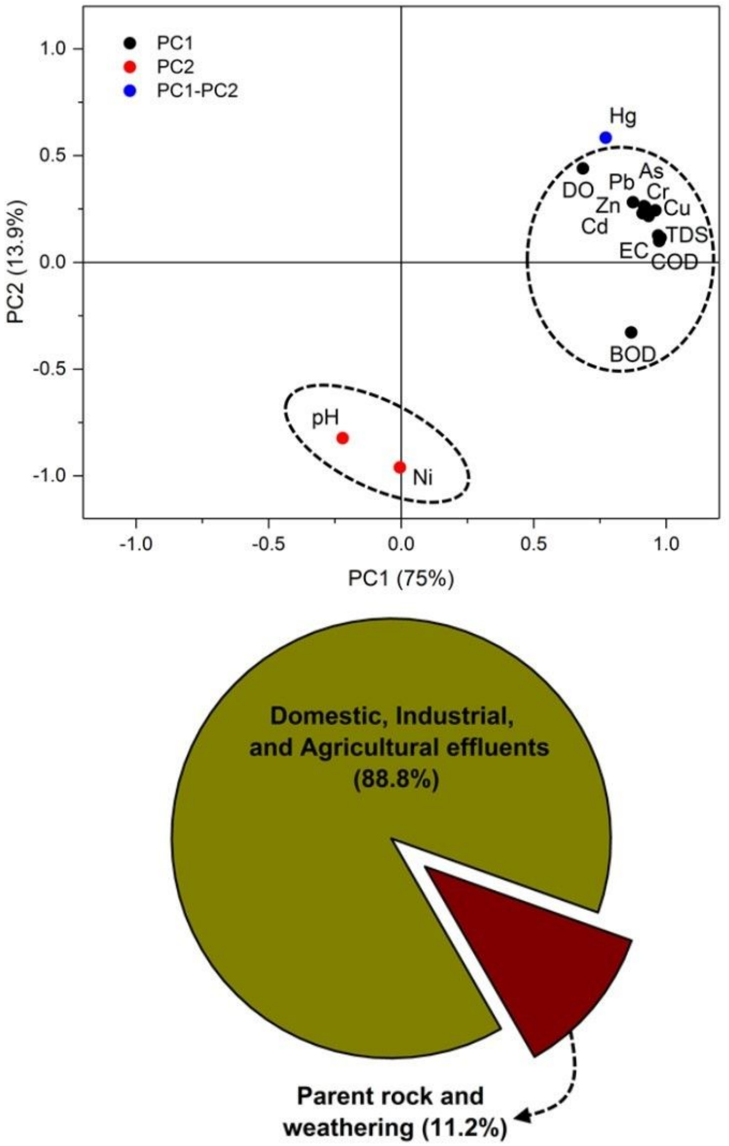

Figure 6

Loading plot of PCA for physiochemical parameters and heavy metals concentrations in water. B. The contribution of the pollution sources obtained by PCA-MLR receptor model

Supplementary Files

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- supplimentarydata.xlsx