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Assessing the Heavy Metal Contamination Prevailing in Groundwater at Rishipur Village, West Bengal, India

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Abstract

The recent surge in interest surrounding water contamination has prompted a study to evaluate the water quality of groundwater in Rishipur village, Malda District, West Bengal, India. The area's groundwater is crucial for drinking, residential, and irrigation purposes due to its proximity to agricultural fields, where most local residents live. The intended purpose of the study is to comprehensively appraise the groundwater quality of a dug well, specifically analysing the intensities of different heavy-metals existing in the water, resulting in valuable insights into its quality. The native residents rely on the usage of this groundwater for drinking and domestic purposes without any purification. However, potential contamination may be present due to nearby agricultural activities. Thus, the study will enable us to make recommendations for mitigating any identified contamination. Exemplary samples of water from a well were consistently collected near the agricultural region over the course of a year, from April 2021 to March 2022. The groundwater samples were analysed for the presence of heavy elements: iron; zinc; copper; manganese; nickel; chromium; cobalt and lead to evaluate the water excellence. To ascertain the overall water eminence status, the Heavy-Metal-Pollution-Index; (HPI), was calculated, which is considered an efficient and reliable technique for water eminence assessment. In this study, the value of HPI; 101.66 in January, indicates high heavy-metal pollution, although it remained within the desired range for the rest of the months. In the analysis of the descriptive statistical data, both substantial positive and negative relations were observed, which were illustrated in a correlation coefficient matrix. Furthermore, the interaction of heavy-metal variables was also explored by utilising the R-Square values derived from the multiple linear regression analysis, which allowed to gain insights into how these variables interplayed with one another. The investigation conclusively established that the eminence of water is deemed appropriate for consumption alongside other domiciliary purposes, with the exception of January.

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Introduction

Water is an essential component for all forms of floral and visceral life, obtained from two principal resources from nature: surface water (e.g., freshwater lakes, streams, rivers) and groundwater (boreholes, wells, etc.).[1-2] Human activities are a significant source of metal pollutants in water sources, contributing to one of the most pressing environmental challenges today: groundwater contamination.[3] Heavy-metal poisoning of water may result from both human activity and natural processes like improper disposal of agricultural and domestic waste directly into the land and water systems, the mobilization of heavy-metals to natural processes such as rock weathering, volcanic eruptions, biological activity, and geochemical interactions. Although metals: copper; selenium etc. are imperative for humans and their increased frequencies have perverse influence on living creatures. Conversely, chromium; and lead metals are very poisonous, even at very low concentrations[4] and are found to be very deadly contaminants[3] Thus, heavy-metals, among the many pollutants impacting water excellence, pose a precise concern owing to their high poisonousness, even at modest concentrations.[5]These toxins accumulate in the bodies of animals and humans, potentially causing serious diseases such as cancer.[6] Contaminants such as heavy-metals, arsenic, fertilizers, chemical pesticides, and more are introduced into groundwater through activities like mining, solid biomass removal in landfills, improper industrial waste disposal, and agrochemical leaching.[7] We are still not very aware of any studies on the groundwater quality of this studied area. It is imperative to thoroughly assess the groundwater quality in the area to ensure its suitability for drinking and to safeguard it from contamination.[8] Krishnandu Kumar Pobi *et al*., in their research conducted in the Durgapur Industrial Zone, documented the occurrence of heavy-metals in the surrounding soil as well as water settlement, along with an initial estimation of their extent. In instances where the concentration of heavy-metals deviates frequently from the specified standard, either exceeding or falling below the desired levels, special attention is warranted.[9] However, there is currently some researches available on the prevalence of various heavy-metals in potable water across West Bengal.[10] Furthermore, extensive research has been undertaken on the seasonal alterations of heavy-metal congestion in the groundwater of Greater Kolkata, West Bengal. There has been limited research on the existence of various heavy-metals in distinct regions of West Bengal. Nevertheless, researchers have shown considerable interest in the prevalence of arsenic in different areas of West Bengal.[11-12]

The reason for the present study is the valid concerns raised by local residents regarding the quality of their drinking water source. Furthermore, there has been a noteworthy surge in the utilization of chemical pesticides and fertilizers compared to previous practices. The residents hold the belief that the water they used for household purposes was of inferior quality due to various reasons. They have noticed changes in the water's colour, smell, taste and density and have experienced several waterborne diseases and skin ailments indicating an overall decline in groundwater quality. Therefore, an investigation was carried out to inform the local community about the groundwater's excellence. The lack of existing studies on groundwater quality makes this evaluation all the more crucial. The current investigation attempts to comprehensively assess the amount of iron:Fe; zinc:Zn; copper:Cu; manganese:Mn; nickel:Ni; chromium:Cr; cobalt:Co and lead:Pb to determine, extent of contamination embedding month wise distinctions in quantity of the Environmentally Sensitive Elements (ESE) present in groundwater in the course of the assessment period of April 2021 to March 2022. The most effective approach for analysing the excellence of the experimental water is the Heavy-Metal-Pollution-Index; (HPI). Recent studies have shown that statistical methodologies in engineering, as well as the interpretation of symmetric or asymmetric distributions of the generated data, are gaining popularity in surface water chemistry investigations. These statistical techniques provide valuable data for analysis.

In this study, a detailed descriptive statistical analysis, including correlation coefficients and regression analysis, was conducted, to accurately predict the variation and dissemination pattern of experimental heavy- metals present in the groundwater samples in the research region. The study aims to conduct a thorough examination of heavy-metal levels in groundwater to ensure strict adherence to permissible limits. This will involve the application of advanced statistical techniques to assess groundwater dispersion. The results will be crucial in enabling the delivery of top-quality water for drinking and agricultural use to households and farms, and they will also provide valuable insights for developers and government agencies to determine the current contamination levels and adapt management strategies accordingly.

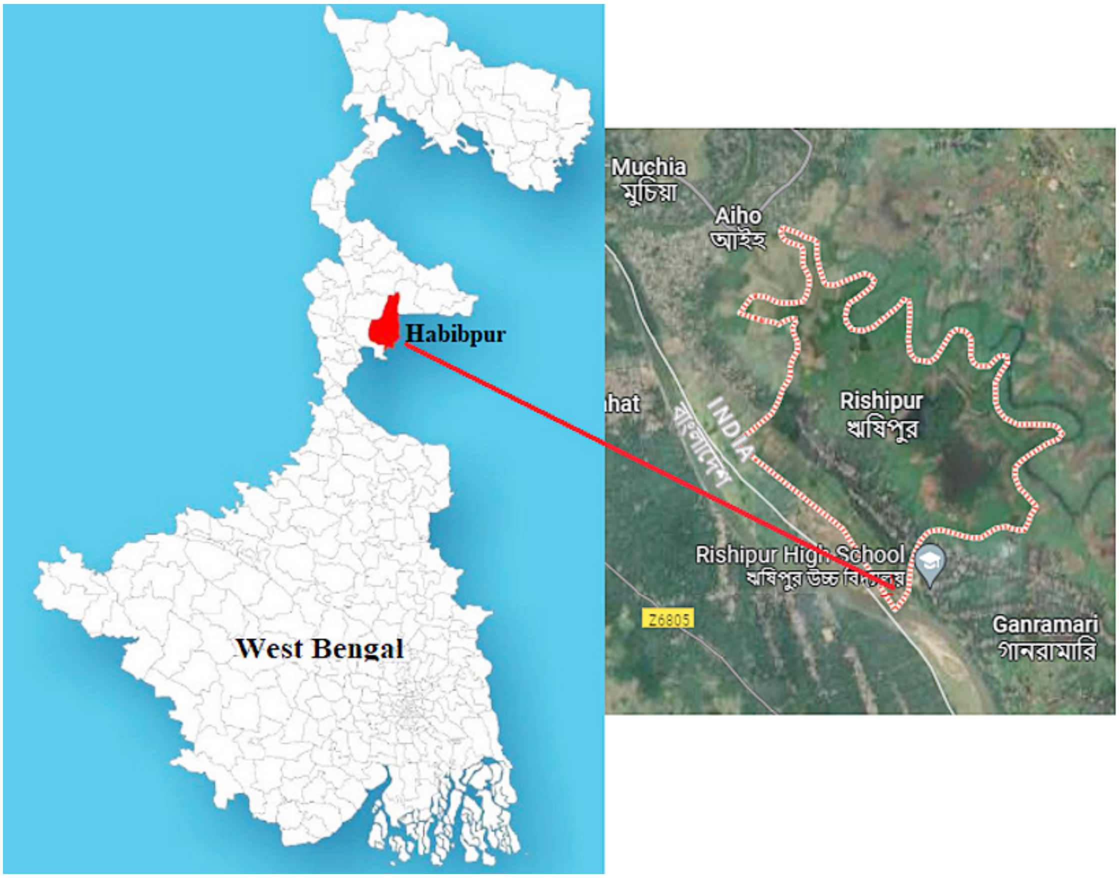

Fig. 1: Map of studied Location

Materials and Methods

An assortment of 12 groundwater samples were extracted from a single dug well located in the study area. The sampling location, housing a dug well in the residential vicinity with close proximity to agricultural activities, was selected for a study aimed at assessing water quality. Sampling took place monthly, covering both the dry and rainy seasons from April 2021 to March 2022. The study area is situated at 24° 55' 45.3"N and 88° 15' 16.6"E at Rishipur village, West Bengal, India, as depicted by Figure 1.

The samples of water were collected in Borosil glass bottles. The glass bottles were dried out using a hot air furnace at 800°C for four hours prior to collecting the samples. The experimental water samples were filtered with the help of Grade 42; Whatman® filter paper, available from GE- Healthcare Companies; UK. The water samples were acidified with 2 ml of HNO_3 to preserve them and stored in an icebox for future analysis. The analysis of groundwater samples was performed for the occurrence of heavy-metals by APHA,[13] 1992 and Trivedy and Goel[14] (1986).

Also, a thorough descriptive statistical analysis of the data was conducted, using methods such as regression and correlation coefficients, to accurately predict the changes and heavy-metal dispersion in the groundwater specimens of the research field.

Assessment of Water Quality

Numerous academics and organisations are actively researching the existence of pollutants in water and studying their consequence on both the ecological system and animals. Through the determination of the heavy-metals' quantity in the groundwater, crucial water quality characteristics are being ascertained. Researchers are generating valuable insights into water quality through a multitude of experimental results, while the degree of heavy-metals is very significant for the considerable reseach. Heavy-metal-pollution-index; (HPI), measurement has been appeared to serve as an advantageous approach for determining water integrity.

Through the HPI we can know about the overall water quality. This pollution index is calculated through equations mentioned below.

$$Qi = \sum_{i=1}^{n} \frac{[Mi(-)\ Ii]}{Si - Ii} \text{ x } 100$$

Mi indicates the measured value that is determined for the ith variable. Ii denotes the greatest intended value or the ideal value used for the ith variable. Si stands for the standard or allowed value associated with the ith variable. The (-) symbol signifies the statistical variation in value between the two, disregarding the semantic (-) symbol.[15-17]

$$HPI = \frac{\sum_{i=1}^{n} WiQi}{\sum_{i=1}^{n} Wi}$$

Qi implies the subindex that is calculated for the ith variable, Wi specifies the unit weight allotted to the ith variable, n denotes the number of variables taken into account for the study. The experimental samples' weight is established based on the significance of the variables allocated between one and zero. It is also perceived as inversely proportional to the standard value of every single constituent.[15-22] Further, water with a contamination index value exceeding 75 is unsuitable for consumption.

Water excellence based on HPI[15]

HPI Range	Water excellence
< 100	low level of heavy-metal contamination
>100	high level of heavy-metal contamination
=100	Heavy-metal contamination on the threshold menace

To evaluate the HPI of the experimental water samples, the values of the heavy-matal content were considered using unit weight (Wi) and a standard acceptable value (Si) for the duration; April 2021 to March 2022.

In conducting the data analysis, various descriptive statistics were performed to thoroughly establish the distribution pattern of heavy-metals. Additionally, Pearson's correlation coefficients were utilised to investigate the source and association viewpoints. Furthermore, Multiple Linear Regression (MLR), a potent statistical method, was carried out to effectively assess the correlation between variables to provide information about distribution trends and patterns. The statistical test results were derived from a series of linear regression equations, as outlined below:

$$Y = a+b_1X_1+b_2X_2+\ldots+b_nX_n$$

Where Y denotes a dependent variable, a signifies a constant, and b_1, b_2 indicates regression coefficient, and X_1, X_2 designate independent variables.

Results and Discussion

The current study has identified varying quantities of heavy-metals reported across different months of the year. These concentrations have been compared to the allowable limits set by WHO and BIS (Table 2). Table 1 precisely illustrates the month-to-month contents of experimental heavy-metals in the samples of groundwater. However, all investigated heavy-metals failed to meet their appropriate limits,[23-27] potentially resulting in health-related issues, including chronic diseases. Figure 2 visually represents the monthly variation in heavy-metals found in the water sample.

Iron is a crucial nutrient for humans, requiring a recommended daily intake of 5 mg. Due to this, many countries have classified drinking water as having a secondary limit for iron-based aesthetic issues (secondary maximum contaminant level, -SMCL). The groundwater sample analysis shows iron concentrations ranging from 0.081 ppm in September to 0.099 ppm in August, with an overall average of 0.089 ppm during the study period. In nations like Greece, Iran, Canada; the iron (Secondary Maximum Contaminant Level) SMCL in potable water is 0.30 mg/l.[28] The occurrence of iron in the samples of groundwater is an immediate manifestation of its inherent abundance in subterranean rock/soil developments and the water from precipitation that permeates across such developments. Water surges across rocks and soil, dissolving iron, accumulating in aquifers, and eventually becoming a source of groundwater. The iron concentration remains below the WHO standard of 1.0 ppm. Iron in groundwater is primarily ferrous or bivalent (Fe^{++}), or insoluble. Additionally, when water is allowed to stand, the presence of iron causes the water to develop a brownish-to-reddish hue.[29] A surplus amount of iron also has an impact on the bacterial abundance in groundwater.

Table 1. Month wise quantity of existing heavy-metals in the groundwater

Heavy metals (ppm)	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
iron	0.093	0.089	0.091	0.087	0.099	0.081	0.083	0.095	0.089	0.085	0.090	0.084
zinc	0.057	0.051	0.053	0.016	0.001	0.013	0.046	0.054	0.059	0.054	0.048	0.053
copper	0.021	0.029	0.023	0.018	0.016	0.041	0.051	0.058	0.068	0.071	0.085	0.089
manganese	0.054	0.074	0.051	0.048	0.037	0.028	0.02	0.028	0.031	0.034	0.041	0.043
nickel	0.068	0.067	0.059	0.074	0.062	0.059	0.043	0.036	0.039	0.035	0.036	0.033
chromium	0.051	0.048	0.038	0.032	0.018	0.025	0.038	0.031	0.038	0.04	0.042	0.048
cobalt	0.009	0.010	0.008	0.005	0.012	0.004	0.007	0.008	0.011	0.006	0.008	0.007
lead	0.009	0.005	0.011	0.007	0.009	0.008	0.012	0.01	0.01	0.014	0.009	0.010

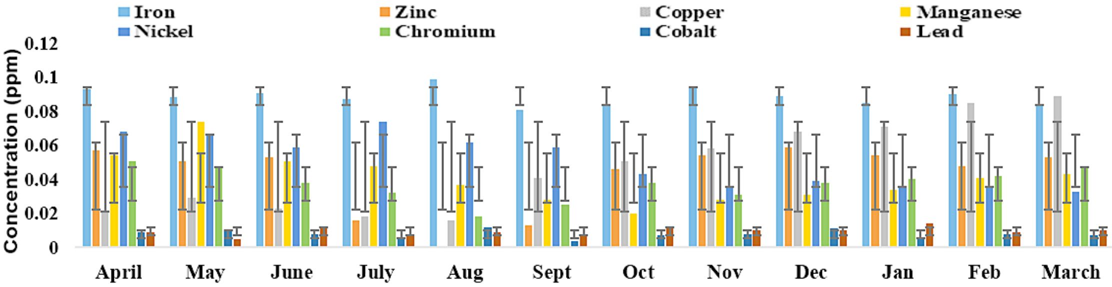

Fig.2: Month wise variation of quantities of existing heavy-metals in the groundwater

Zinc is a crucial factor in promoting human health, especially during prenatal and perinatal development, and its deficiency is linked to various health issues such as depression, weakness, diarrhea, alopecia, eye and skin problems, reduced appetite, compromised immune function, inefficient carbohydrate utilization, and reproductive issues in spermatogenesis.[30] The zinc concentrations in the experimental water samples fluctuated from 0.001 ppm in August to 0.059 ppm in December. These variations can be attributed to a combination of natural factors and human activity. Zinc Sulphate, present in water at levels exceeding 3 mg/l, can cause an unpleasant taste. However, zinc concentrations in drinking water seldom surpass 0.1 ppm. Zinc is introduced into the air, water, and soil through a range of natural and human-induced processes. Waste from zinc and other metal manufacturing and chemical companies, as well as residential use and runoff from zinc-rich soil, are sources that release zinc into streams. Elevated zinc levels in local groundwater can be contributed by sludge, fertilizers, and chemical pesticides.

Copper is a crucial heavy-metal in trace amounts, but when its concentration exceeds permitted levels, it poses a threat to aquatic life and humans. Based on the research conducted, the copper concentrations in the research area varied from 0.016 to 0.089 ppm. The lowest concentration was detected in August, while the highest value was recorded in March, resulting in an average concentration of 0.048 ppm for the study year. The peak copper concentration in March may be attributed to copper intrusion from chemical enterprises, waste disposal from neighbouring manufacturing units, and domestic waste. It's worth noting that the copper concentration remains well below the WHO's acceptable range of 1.0 ppm.[24]

Manganese, similar to iron, is classified as a secondary priority chemical contaminant. The ingestion of manganese-contaminated water has been proven to cause neurotoxicity in both humans and animals. The utmost level of Mn was obtained in May at 0.074 ppm and in October; it reached at the lowest: 0.020 ppm, both well below the WHO permitted range of 0.5 ppm. Mn contamination can be attributed to domestic waste, natural geological sources, and industrial wastewater.[31] High levels of manganese in drinking water can pose a significant health risk, especially for infants, who are more vulnerable to adverse neurological impacts. This element can be found in surface and groundwater, resulting from environmental causes and various human interferences, such as mining and industrial waste. When water enters soil and rock, it can dissolve minerals, including manganese, which then becomes part of groundwater.

The nickel values in the water samples analysed ranged from 0.033 to 0.074 ppm, with the highest concentrations detected in July. It is worth noting that nickel is commonly found in human tissues, and prolonged contact can substantially elevate its levels, which is important to consider.[32-33] The contribution of nickel consumption through air and drinking water is generally less significant compared to dietary ingestion. Absorption is the most important mode of exposure to nickel. In animals, 1-10% of dietary nickel is absorbed through the gastrointestinal system. It is indispensable to recognise that the method of nickel absorption can significantly impact its bioavailability.[34]

Chromium is naturally found in trace concentrations. Elevated chromium levels beyond the permissible limit can be concerning. The significantly elevated quantity of chromium in contaminated water may be attributed to the presence of chromium in soaps and detergents used for washing and bathing.[35] Exceeding the WHO limit for chromium levels poses an imminent threat to the health of people in the affected area. Anthropogenic activities can lead to chromium pollution in the environment, particularly from natural occurrences during the hexavalent process.[36] Hexavalent chromium, classified as a human carcinogen, is a hazardous industrial waste, and its presence is a result of both regulating and non-regulating activities.[37-38] The experimental water samples showed a variation in chromium concentration, ranging from 0.018 ppm in August to 0.051 ppm in April, averaging 0.037 ppm over the course of the trial year. These values consistently remained below the WHO 2007 guidelines.[25]

Cobalt exists in nature in the composition of the exterior layer of earth and consequently in the earth's soil. It is found at the lowest levels in saltwater, surface water, and groundwater.[39] When cobalt is released into the water, it can be absorbed by particles and eventually settle in the sediment. Elevated levels of cobalt in groundwater are often associated with human endeavours such as mineral extraction, treatment of cobalt-bearing mineral deposits, employing cobalt-bearing sludge material, phosphate fertilizers, dumping of cobalt-containing pollutants, the sizzling of fossil fuels, and combustion and refinement of metals.[39] The water samples analysed showed cobalt concentration values ranging from 0.004 to 0.012 ppm, exhibiting a mean concentration value of 0.008 ppm over the study period. It's important to note that the standard authorised limit for cobalt content in drinking water is 0.05 ppm.[23] It's also worth mentioning that cobalt concentrations in groundwater could be significantly greater in mining and farmland regions. While cobalt is crucial for human health by means of a constituent of vitamin B12, high cobalt concentrations may exert detrimental effects on human health, including respiratory symptoms, nausea and vomiting, visual issues, dermatitis, thyroid damage, severe heart harm, and even cancer.

Lead is usually toxic and accumulates in the kidneys and skeletons of animals. Children up to 6 years of age and pregnant women are most prone to its hostile effects.[40] Groundwater samples collected in June, October, and January showed lead levels exceeding the WHO limit of 0.05 ppm. This could be attributed to the usage of leaded petroleum in cars, generators, and some mechanic shops near the study area, especially battery chargers.[41] Furthermore, lead pollution of groundwater can also result from industrial effluent, old plumbing, home sewage, agricultural runoff including phosphate from fertilizers, and human and animal.[42] In the present study in January and May, the lead levels in the water sources peaked at 0.014 ppm and bottomed out at 0.005 ppm, respectively, with an average of 0.010 ppm over the course of the study year. Symptoms of acute lead intoxication encompass a range of manifestations including dullness, restlessness, irritability, allergies, stiffness, hyperactivity, mood swings, queasiness, impassiveness, loss of focus, and convulsions. The heightened presence of lead (Pb) in the water sources may be linked to lead weathering and leaching from waste rocks, dumps, agricultural fields, domestic sewage, and other neighbouring areas.

Based on the findings, it is evident that the heavy-metal dispersion varies throughout the year. As depicted in Figure 2, the presence of iron outweighs that of other metals, peaking in the month of August. Additionally, it is worth noting that the average metal concentration in this particular area adheres to a specific order: cobalt < lead < chromium < manganese < copper < nickel < zinc < iron, in the studied year. The analysis presented in Figure 2 and Table 1, which reflect the WHO's recommendations regarding acceptable levels of examined heavy-metals, indicates that cobalt and lead are the least prevalent heavy-metals in the sampled water due to the remote location of the studied area, distant from industrial zones and urban centres, leading to the absence of significant human inputs such as ignition of fossil fuel, waste emissions, vehicular; aircraft exhaust, and cobalt and cobalt-containing alloys production. Moreover, there is reduced utilization of cobalt fertilizers and agricultural chemicals. However, the likelihood of lead contamination escalates when these materials are utilized and come into contact with water, but, in the studied residential and rural settings, the presence of lead-containing materials such as water pipes or minerals is uncommon and not typically associated with water sources. However, it is noteworthy that in the present study, lead concentrations exceeded the WHO's threshold in June, October, and January. The heavy-metal pathway entails a progressive buildup of Pb in the soil, stemming from the improper disposal of household and agricultural waste on the ground in particular months. Subsequently, rainfall, including irrigation, fosters the transport of these metals into the groundwater, amplifying the environmental impact. Additionally, chromium (Cr) levels exceeded permissible limits in April, likely due to the consequence of excessive use of Cr based agricultural chemicals and the improper disposal of waste in both the soil and water systems, while nickel (Ni) concentrations were found to be in excess of allowable thresholds in July as rainfall-driven soil leaching can result in the transportation of nickel contamination to groundwater. Alternatively, nickel can be directly redistributed from the atmosphere and soil to surface water sources through deposition and runoff. On the other hand, iron, zinc, copper, and nickel, were all within permitted limits throughout the months under study, which stem from the combination of suitable human conduct and environmental elements. All the heavy-metal levels were assessed against the specified thresholds, as outlined in Table 2.

Table 2. Standard specifications for drinking water

Heavy Metals	Standard value (ppm) as per [WHO: 1993, 2003, 2007, 2008]	Standard value (ppm) as per [BIS:2012]
iron	0.30	0.30
zinc	3.00	15.0
copper	1.00	1.50
manganese	0.40	0.30
nickel	0.07	0.02
chromium	0.05	0.05
cobalt	0.05	0.05
lead	0.05	0.01

Further, as the HPI values represented in Table 3, are considered an excellent convenient aid in assessing the overall effluence of water bodies in terms of pollution with regard to several heavy-metals present in the water, the values of HPI in this current investigation designate that except for the months of May, July, August, September, November, and February, the samples of groundwater are relatively critically contaminated in terms of heavy-metals that can be analysed through Figure 3.

Table 3. Monthwise Heavy-Metal-Pollution-Index of the groundwater samples

Heavy metals	Wi	Qi	WiQi	HPI	Wi	Qi	WiQi	HPI
Apr					**May**			
iron	0.003333	31.0000	0.10333	78.21	0.003333	29.5000	0.09833	52.01
zinc	0.000067	49.4300	0.00330		0.000067	49.4900	0.00330	
copper	0.000667	2.00000	0.00133		0.000667	1.44830	0.00097	
manganese	0.003333	23.0000	0.07667		0.003333	13.0000	0.04333	
nickel	0.014286	96.0000	1.37143		0.014286	94.0000	1.34286	
chromium	0.020000	102.000	2.04000		0.020000	96.0000	1.92000	
cobalt	0.020000	2.50000	0.05000		0.020000	0.00000	0.00000	
lead	0.100000	90.0000	9.00000		0.100000	50.0000	5.00000	
Jun					**Jul**			
iron	0.003333	31.0000	0.10333	86.12	0.003333	29.0000	0.09667	63.46
zinc	0.000067	49.4700	0.00330		0.000067	49.8400	0.00332	
copper	0.000667	1.86210	0.00124		0.000667	2.2069	0.00147	
manganese	0.003333	24.5000	0.08167		0.003333	26.0000	0.08667	
nickel	0.014286	78.0000	1.11429		0.014286	108.0000	1.54286	
chromium	0.020000	76.0000	1.52000		0.020000	64.0000	1.28000	
cobalt	0.020000	5.00000	0.10000		0.020000	12.5000	0.25000	
lead	0.100000	110.000	11.0000		0.100000	70.0000	7.00000	
Aug					**Sep**			
iron	0.003333	31.0000	0.10333	69.48	0.003333	27.0000	0.09000	65.73
zinc	0.000067	49.9900	0.00333		0.000067	49.8700	0.00332	
copper	0.000667	2.34480	0.00156		0.000667	0.6207	0.00041	
manganese	0.003333	31.5000	0.10500		0.003333	36.0000	0.12000	
nickel	0.014286	84.0000	1.20000		0.014286	78.0000	1.11429	
chromium	0.020000	36.0000	0.72000		0.020000	50.0000	1.00000	
cobalt	0.020000	5.00000	0.10000		0.020000	15.0000	0.30000	
lead	0.100000	90.0000	9.00000		0.100000	80.0000	8.00000	
Oct					**Nov**			
iron	0.003333	27.6667	0.09222	90.03	0.003333	31.6667	0.10556	74.38
zinc	0.000067	49.5400	0.00330		0.000067	49.4600	0.00330	
copper	0.000667	0.06900	0.00005		0.000667	0.55170	0.00037	
manganese	0.003333	40.0000	0.13333		0.003333	36.0000	0.12000	
nickel	0.014286	46.0000	0.65714		0.014286	32.0000	0.45714	
chromium	0.020000	76.0000	1.52000		0.020000	62.0000	1.24000	

cobalt	0.020000	7.50000	0.15000		0.020000	5.00000	0.10000	
lead	0.100000	120.000	12.0000		0.100000	100.000	10.0000	
Dec					**Jan**			
iron	0.003333	29.6667	0.09889	76.26	0.003333	28.3333	0.09444	101.66
zinc	0.000067	49.4100	0.00329		0.000067	49.4600	0.00330	
copper	0.000667	1.24140	0.00083		0.000667	1.4483	0.00097	
manganese	0.003333	34.5000	0.11500		0.003333	33.0000	0.11000	
nickel	0.014286	38.0000	0.54286		0.014286	30.0000	0.42857	
chromium	0.020000	76.0000	1.52000		0.020000	80.0000	1.60000	
cobalt	0.020000	2.50000	0.05000		0.020000	10.0000	0.20000	
lead	0.100000	100.000	10.0000		0.100000	140.0000	14.0000	
Feb					**Mar**			
iron	0.003333	30.0000	0.10000	70.76	0.003333	28.0000	0.09333	78.14
zinc	0.000067	49.5200	0.00330		0.000067	49.4700	0.00330	
copper	0.000667	2.41380	0.00161		0.000667	2.68970	0.00179	
manganese	0.003333	29.5000	0.09833		0.003333	28.5000	0.09500	
nickel	0.014286	32.0000	0.45714		0.014286	26.0000	0.37143	
chromium	0.020000	84.0000	1.68000		0.020000	96.0000	1.92000	
cobalt	0.020000	5.00000	0.10000		0.020000	7.50000	0.15000	
lead	0.100000	90.0000	9.00000		0.100000	100.000	10.0000	

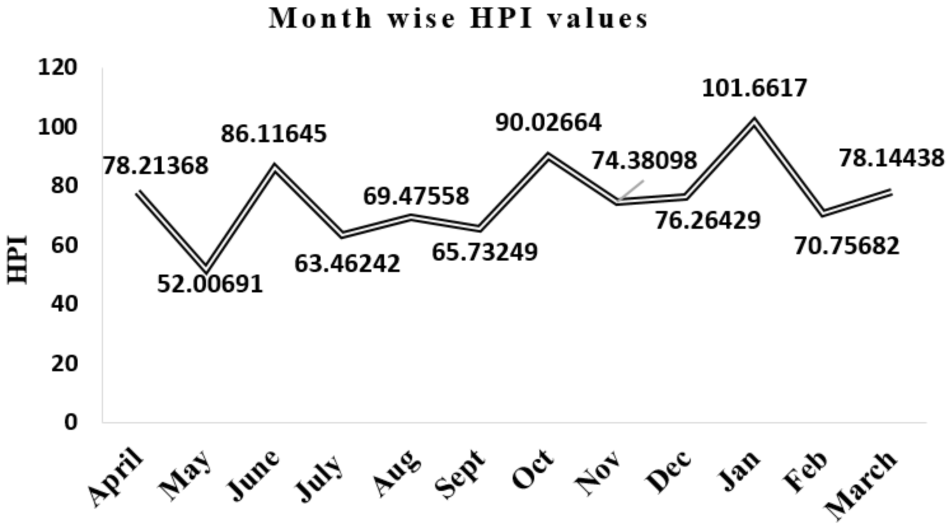

Fig.3: Month wise variation of HPI values of the groundwater samples

The assessment of water quality using HPI values reveals that a value exceeding 100, such as the 101.66 recorded in our present study in January, signifies a high level of HPI. In this context, it's worth noting that the cultivation of vegetables and various cereals in adjoining agricultural fields can lead to increased heavy-metal pollution due to overexposure to pesticides, fertilizers, and sewage sludge. Additionally, the disposal of domestic and agricultural waste in ground areas near drinking water sources may also contribute to higher levels of heavy-metal-pollution-index. In contrast, measurements below

100 were recorded in several months throughout the year. But if the increasing trend persists, it has the potential to disturb the intricate harmony of the ecosystem, leading to adverse impacts on the environment and its inhabitants.

Table 4. The consequences of descriptive statistics of the existing heavy-metals in the groundwater

Statistical Variables	iron	zinc	copper	manganese	nickel	chromium	cobalt	lead
Stand. Error	0.002	0.006	0.008	0.004	0.004	0.003	0.001	0.001
Mean	0.089	0.042	0.048	0.041	0.051	0.037	0.008	0.010
Med	0.089	0.052	0.046	0.039	0.051	0.038	0.008	0.010
Stand. Dev.	0.005	0.020	0.027	0.015	0.015	0.010	0.002	0.002
Var.	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000
Kurt.	-0.213	0.186	-1.461	1.183	-1.853	-0.004	-0.379	0.944
Skewn.	0.420	-1.328	0.291	0.912	0.161	-0.555	0.119	0.000
Ran.	0.018	0.058	0.073	0.054	0.041	0.033	0.008	0.009
Min	0.081	0.001	0.016	0.020	0.033	0.018	0.004	0.005
Max	0.099	0.059	0.089	0.074	0.074	0.051	0.012	0.014

Descriptive Statistical Analysis

The distribution of heavy-metal concentrations demonstrates significant geographical variations, likely attributed to the diverse geological and topographical features of distinct regions.[43] Skewness values serve as a measure to evaluate the symmetry or asymmetry of element distributions. A skewness value exceeding zero specifies a right-skewed (positive) distribution, although a value underneath zero directs a left-skewed (negative) distribution, signaling asymmetry.[43] The descriptive statistics for the groundwater specimens are outlined in Table 4.

The analysis ranks the metals in descending order of average concentration as follows:

Fe > Ni > Cu > Zn > Mn > Cr > Pb > Co

Table 5 implies the correlation matrix for the studied metals was generated using the Pearson correlation method, and the consequences.

Table 5. Outcomes of Pearson's correlation-coefficients of the heavy-metals detected in groundwater samples

Parameters	iron	zinc	copper	manganese	nickel	chromium	cobalt	lead
iron	1.000							
zinc	-0.085	1.000						
copper	-0.373	0.491	1.000					
manganese	0.203	0.152	-0.396	1.000				
nickel	0.197	-0.505	-0.927	0.570	1.000			
chromium	-0.240	0.803	0.317	0.512	-0.152	1.000		
cobalt	0.736	0.145	-0.153	0.255	0.035	0.033	1.000	
lead	-0.133	0.351	0.430	-0.618	-0.644	0.006	-0.142	1.000

Correlation is significant at 0.05 level

In the course of the investigation into the connections among the different elements, the study has revealed robust correlations, which are characterized by a prominent association between interconnected elements. In thirteen instances, negative and inverse associations were identified, including Zn – Fe, Cu – Fe, Mn – Cu, Ni – Zn, Ni – Cu, Cr – Fe, Cr – Ni, Pb – Fe, Pb – Mn, Pb – Ni, and Pb – Co. The intriguing observation is that every notable positive correlation among the heavy-metals suggests a clear interconnectedness of their origins. When there is a strong and meaningful link between these parameters, it is reflected in the high correlation they exhibit and the considerable similarities they share.[44] Furthermore, this increases the likelihood that there are shared human-influenced origins or like causes. Thus in the present study, the substantial correlation coefficients among the heavy-metals indicate their similar geochemical properties and shared input sources. However, their negative association may stem from disparities in their origins, characteristics, and groundwater input. The strong positive correlation between the heavy-metals, approaching nearly one, suggests that an intensification of the amount of one metal is likely to result in a corresponding upsurge of the other metals' content. This phenomenon may be attributable to household and agricultural waste seepage into groundwater.

Analysis of multiple-linear-regression was also employed to evaluate the impact of specific heavy-metal variables on each other. The R-Square values presented in Table 6 exhibit a considerable range, spanning from 0.649 for Ni to an impressive 0.987 for lead. Additionally, Figure 4 illustrates the comparative analysis of the R-Square values that serve as a crucial indicator of the precision and trustworthiness of the findings, showcasing a substantial and strong association between each of the dependent and independent variables. The values demonstrate a strong and identifiable linear association, affirming the capacity to achieve meticulous and reliable results in heavy-metal concentration analysis for each sample. The findings underscore the profound influence of each individual heavy-metal variable on the others, indicating substantial percentage increases. The findings of the comprehensive multiple regression-analysis unequivocally demonstrate the substantial impact of the independent variable on the value of each heavy-metal, pointing to the interconnectedness and complexities within the system.

Table 6. Multiple-linear-regression: significance of heavy-metals to groundwater excellence

R value	R-Square value	R-Square adjusted value	Stand. Error
Fe to water quality			
0.935	0.874	0.581	0.00344
Zn to water quality			
0.952	0.906	0.687	0.01137
Cu to water quality			
0.989	0.978	0.593	0.00718
Mn to water quality			
0.962	0.925	0.750	0.00735
Ni to water quality			
0.994	0.987	0.958	0.00306
Cr to water quality			
0.976	0.952	0.842	0.00364
Co to water quality			
0.806	0.649	-0.170	0.00264
Pb to water quality			
0.891	0.793	0.311	0.00201

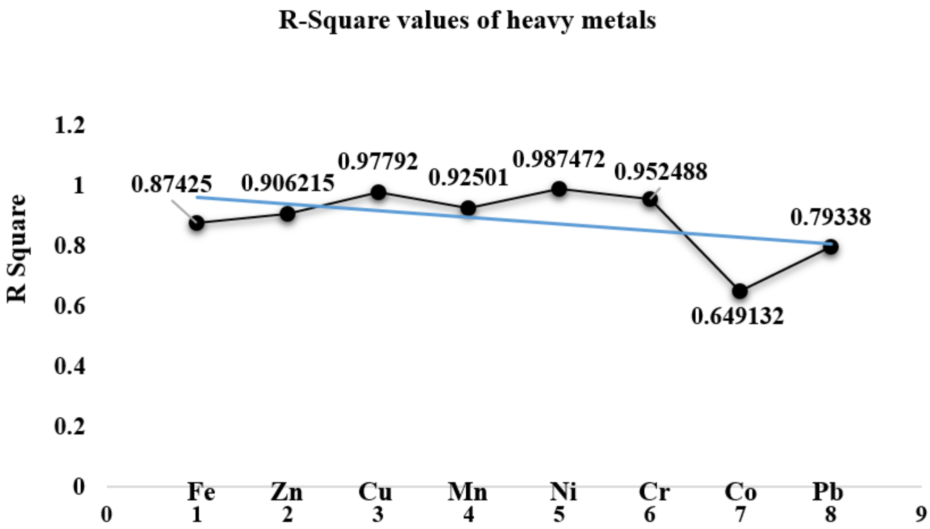

Fig. 4. Variation of R-Square values of heavy-metals to water quality

Conclusion

The main contributor to anthropogenic activity-related water quality effluence in the research area is the discharge of waste from households, including chemicals and organic matter, as well as agricultural pollutants such as fertilizers and pesticides. Groundwater can also become polluted due to various activities that take place on the surface, such as improper disposal of waste. Additionally, contamination can occur due to leakage from underground storage tanks or septic systems. Structures such as wells that are below the water table can also contribute to groundwater contamination, as can the presence of contaminated recharge water. Continuous monitoring of water samples is required, as the results indicate contamination levels that can determine the integrity of imbibing water. It is imperative for individuals to be cognizant of the probable threats allied to the consumption of contaminated water. An increased awareness of the detrimental impacts of consuming contaminated groundwater is strongly advised. Furthermore, the dissemination of knowledge to farmers on mitigating wastewater leaching, along with the promotion of prudent pesticide application, is essential to prevent groundwater pollution. Agricultural activities should be located away from residential regions to uphold environmental integrity. Certain fertilizers, herbicides, insecticides, rodenticides, fungicides etc., have the potential to persist in water and soil for extended periods, ranging from several months to years, resulting in contamination of groundwater by leaching process. Groundwater contamination may also result from animal waste originating from agricultural feedlots seeping into the soil. To mitigate these issues, it is essential to regularly remove and properly manage waste from feedlots to evade environmental pollution. Besides that, identification of heavy-metals based on HPI criteria, which were only detected in January, extremely high levels of heavy-metal contamination that could potentially impact the local ecosystem were observed. This characterisation of the water samples provides insight into the presence of pollution in water bodies, particularly heavy-metals, and can guide future management strategies aimed at preventing such contamination.

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Conflict of Interest

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Data Availability Statement

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Ethics Approval Statement

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