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SEASONAL ASSESSMENT OF HEAVY METAL CONTAMINATION AND HUMAN HEALTH RISKS IN GROUNDWATER OF MAIHAR REGION, MADHYA PRADESH, INDIA

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ABSTRACT Groundwater contamination by heavy metals has emerged as an important environmental issue due to rapid industrialization, mining activities, urban expansion, and intensive agricultural practices. The present investigation evaluates the seasonal distribution of selected heavy metals and their possible health implications in groundwater of the Maihar region, Madhya Pradesh, India during the year 2024. Groundwater samples were collected from five representative locations characterized by different land-use activities, namely Bharauli (S1), Bhaisasur (S2), Bhadanpur (S3), Sadhara (S4), and the area near Civil Hospital (S5). Sampling was carried out during pre-monsoon, monsoon, and post-monsoon seasons. The concentrations of lead (Pb), cadmium (Cd), nickel (Ni), iron (Fe), and copper (Cu) were determined using Atomic Absorption Spectrophotometry (AAS). The results demonstrated noticeable seasonal and spatial variations in heavy metal concentration. Iron was found to be the predominant metal at all sampling sites, while cadmium and copper occurred in comparatively lower concentrations. Higher metal concentrations were generally observed during the pre-monsoon season, whereas monsoon samples showed reduced levels due to dilution effects caused by rainfall recharge. Mining and agricultural regions exhibited relatively greater contamination compared to residential and institutional areas. A field-based health survey was also conducted to assess the relationship between groundwater quality and public health. The survey findings indicated that most residents were healthy, although a limited number of individuals reported gastrointestinal, neurological, and skin-related problems. The study suggests that groundwater quality in the region is moderately influenced by anthropogenic activities, but current contamination levels do not indicate severe health hazards. Continuous groundwater monitoring, pollution control measures, and sustainable management practices are recommended to prevent future deterioration of water quality.

KEYWORDS : Groundwater Contamination, Heavy Metals, Health Risk Assessment, Seasonal Variation, Maihar Region, Atomic Absorption Spectrophotometry

1. INTRODUCTION

Groundwater serves as one of the most dependable sources of freshwater for domestic, agricultural, and industrial purposes, particularly in semi-urban and rural regions of India. Rapid industrialization, urban growth, mining operations, and intensified agricultural activities have significantly influenced groundwater quality over recent decades. Among different categories of pollutants, heavy metals are considered highly important because of their toxicity, persistence, non-biodegradable nature, and ability to accumulate within biological systems. Even at low concentrations, prolonged exposure to heavy metals through drinking water may produce adverse health effects in humans and other living organisms.

Heavy metals such as lead (Pb), cadmium (Cd), nickel (Ni), iron (Fe), and copper (Cu) commonly enter groundwater through both natural and anthropogenic pathways. Natural processes include rock weathering, mineral dissolution, and geochemical interactions occurring within aquifers. Anthropogenic sources involve industrial discharge, mining activities, excessive application of fertilizers and pesticides, leakage from waste disposal sites, and urban runoff. Continuous consumption of contaminated groundwater may result in neurological disorders, kidney dysfunction, gastrointestinal disturbances, dermatological problems, and other chronic health complications (Yadav, 2023).

Hydrogeochemical investigations play an important role in understanding groundwater chemistry and identifying the factors responsible for contamination. Earlier studies have reported that groundwater composition is strongly controlled by lithology, climatic conditions, recharge processes, and human activities (Hem, 1985; Jalali, 2007). Several researchers have applied hydrogeochemical and statistical approaches to evaluate groundwater suitability for drinking and irrigation purposes (Kumar et al., 2006; Li et al., 2013). Spatial and temporal variations in groundwater quality are also influenced by land-use patterns, industrial development, and agricultural practices (Li & Zhang, 2010; Ravikumar & Somashekar, 2011; Selvakumar et al., 2017).

In India, groundwater contamination due to industrialization and agricultural intensification has become a major environmental concern. Previous studies conducted in industrial and mining regions have demonstrated elevated concentrations of toxic metals in groundwater systems (Saha & Ray, 2008; Shankar et al., 2008). Advanced analytical techniques and multivariate statistical methods have further improved the understanding of contamination sources and hydrogeochemical processes governing groundwater quality (Singh et al., 2017). Sustainable management of groundwater resources therefore requires continuous monitoring and scientific assessment of contamination levels (Yadav et al., 2021).

The Maihar region of Madhya Pradesh represents an environmentally sensitive area characterized by cement industries, mining activities, agricultural operations, transportation networks, and expanding urban settlements. The geological setting of the region contains mineral-rich formations that may contribute naturally to groundwater chemistry, while anthropogenic disturbances further accelerate contamination processes (Geological Survey of India, 2011; Government of Madhya Pradesh, 2019). Previous investigations conducted in nearby regions of Satna district have reported variations in groundwater quality parameters, including fluoride and trace metal concentrations (Yadav et al., 2018).

The environmental behavior of trace metals in aquatic systems has been extensively studied because of their ecological significance and potential health hazards. Spectrophotometric and analytical studies have confirmed that contamination of water bodies by metallic pollutants is often associated with industrial and agricultural activities (Yadav et al., 2012). In addition, agrochemicals and industrial pollutants can alter groundwater chemistry and increase environmental risks through long-term accumulation (Yadav et al., 2021).

Although several investigations have examined groundwater quality in different parts of India, limited information is available regarding the seasonal distribution of heavy metals and their associated health impacts in the Maihar region during recent years. Therefore, the present study was undertaken to evaluate the concentration of selected heavy metals in groundwater during different seasons of 2024, assess spatial variation among different land-use regions, and examine the possible relationship between groundwater contamination and human health conditions in the study area.

2. MATERIALS AND METHODS

2.1 Study Area

The present investigation was conducted in the Maihar region of Satna district, Madhya Pradesh, India. The area is characterized by mixed land-use patterns involving mining operations, agricultural fields, residential settlements, institutional zones, and semi-industrial activities. These anthropogenic activities have the potential to alter groundwater chemistry through discharge of wastes, leaching of minerals, and infiltration of surface pollutants.

Five representative groundwater sampling locations were selected for the study on the basis of population density, land-use characteristics, and dependence on groundwater resources. The selected sites were Bharauli (S1), Bhaisasur (S2), Bhadanpur (S3), Sadhara (S4), and the area near Civil Hospital (S5). Bharauli is influenced mainly by semi-industrial and transportation activities, Bhaisasur is dominated by agricultural operations, Bhadanpur represents a comparatively less disturbed residential region, Sadhara is associated with mining-related activities, while S5 represents an institutional and urbanized zone. These locations were selected to examine the spatial variation of heavy metal contamination under different environmental conditions.

2.2 Groundwater Sample Collection

Groundwater samples were collected during three different seasonal periods of the year 2024, namely pre-monsoon (May 2024), monsoon (August 2024), and post-monsoon (December 2024). Seasonal sampling was carried out to evaluate temporal changes in heavy metal concentration resulting from dilution, recharge, and anthropogenic influences.

Samples were collected from bore wells and hand pumps that are regularly used by local residents for drinking and domestic purposes. Before sampling, the outlets of water sources were allowed to run for several minutes in order to remove stagnant water and obtain representative groundwater samples. Polyethylene sampling bottles of one-liter capacity were cleaned thoroughly using dilute nitric acid followed by repeated washing with distilled water to avoid contamination.

Immediately after collection, water samples were acidified with concentrated nitric acid to maintain pH below 2 and prevent precipitation of dissolved metals. The samples were then preserved at low temperature and transported to the laboratory for further physicochemical and heavy metal analysis.

2.3 Chemicals and Reagents

All chemicals and reagents used during the experimental work were of analytical reagent (AR) grade. Standard stock solutions of lead, cadmium, nickel, iron, and copper were prepared using certified reference materials procured from Sigma-Aldrich. Double-distilled water was used for preparation of standard solutions and dilution purposes.

Nitric acid and other analytical reagents employed during digestion and preservation processes were of high purity grade. All glassware used in the analysis was soaked in dilute nitric acid for 24 hours and thoroughly rinsed with distilled water before use to eliminate possible contamination.

2.4 Analytical Methodology for Heavy Metal Determination

The collected groundwater samples were analyzed for selected heavy metals including lead (Pb), cadmium (Cd), nickel (Ni), iron (Fe), and copper (Cu). Prior to analysis, samples were filtered through Whatman filter paper to remove suspended particulate matter. Heavy metal estimation was carried out using Atomic Absorption Spectrophotometry (AAS), which provides reliable and sensitive determination of trace metal concentrations in water samples.

Calibration curves for each metal were prepared using standard solutions of known concentration. Instrument calibration and analytical procedures were performed according to standard methods for water analysis. Blank samples and standard reference solutions were analyzed simultaneously to verify analytical precision and accuracy.

Each sample was analyzed in triplicate, and the average value was recorded to minimize experimental error. Heavy metal concentrations were expressed in parts per million (ppm). The obtained values were compared with permissible limits prescribed for drinking water quality in order to evaluate the contamination status of groundwater in the study region.

2.5 Health Survey and Risk Assessment

A field-based health survey was conducted to assess the possible impact of groundwater quality on the health status of residents inhabiting the selected locations. Approximately five percent of the local population from each sampling site was included in the survey. The survey mainly focused on individuals regularly consuming groundwater as their primary source of drinking water.

The population surveyed at different locations included 45 individuals from S1, 55 from S2, 38 from S3, 60 from S4, and 44 from S5. Data collection was carried out using a structured questionnaire designed to obtain information regarding water consumption patterns, duration of groundwater usage, and occurrence of health-related symptoms.

Particular attention was given to symptoms commonly associated with heavy metal exposure, including neurological disturbances, gastrointestinal disorders, skin irritation, and fluorosis-related manifestations. The collected information was statistically arranged and correlated with heavy metal concentration data in order to understand the possible relationship between groundwater contamination and public health conditions in the study area.

3.RESULTS AND DISCUSSION

Groundwater quality assessment was carried out to evaluate the concentration and seasonal behavior of selected heavy metals in different parts of the Maihar region during the year 2024. The analytical results revealed noticeable spatial and temporal variation in heavy metal distribution among the sampling locations. Variations in concentration levels were mainly associated with differences in land-use activities, hydrogeochemical conditions, and anthropogenic influences such as mining, agriculture, urbanization, and semi-industrial operations.

The concentrations of lead (Pb), cadmium (Cd), nickel (Ni), iron (Fe), and copper (Cu) were determined for pre-monsoon, monsoon, and post-monsoon seasons. In general, the concentration of heavy metals was comparatively higher during the pre-monsoon season and lower during the monsoon period. This reduction during monsoon may be attributed to dilution caused by rainwater recharge and increased groundwater circulation. A slight increase in concentration was again observed during the post-monsoon season due to stabilization of hydrochemical conditions and gradual accumulation of dissolved ions.

Among all the analyzed metals, iron showed the highest concentration at almost all sampling sites, indicating strong geogenic contribution from mineral-rich geological formations present in the study area. Lead and nickel concentrations were moderate, whereas cadmium and copper were detected in relatively lower amounts. The results also indicated that areas affected by mining and agricultural activities exhibited comparatively higher contamination levels than residential and institutional zones.

The overall groundwater quality of the region suggests the influence of both natural geological processes and human activities. Continuous interaction between groundwater and surrounding rock formations may contribute to the dissolution of metallic ions, while anthropogenic activities such as mining, use of agrochemicals, disposal of domestic wastes, and industrial emissions further intensify contamination levels. Although the observed concentrations were not extremely high, the persistence of heavy metals in groundwater indicates the necessity of periodic monitoring and sustainable groundwater management.

3.1Heavy Metal Concentration in Groundwater: The concentration of selected heavy metals in groundwater samples collected from different locations of the Maihar region during 2024 is presented in Table 1. Considerable variation was observed among different sampling sites and seasons, indicating the combined effect of environmental conditions and anthropogenic activities on groundwater chemistry.

Table 1: Assessment of Heavy Metal Contamination in Groundwater of Maihar Region, Madhya Pradesh, India in Year 2024

Sample Sites	Season (Sampling Month)	Lead (ppm)	Cadmium (ppm)	Nickel (ppm)	Iron (ppm)	Copper (ppm)
Bharauli (S1)	Pre-Monsoon (May 2024)	0.048	0.0064	0.034	0.89	0.023
	Monsoon (August 2024)	0.030	0.0042	0.023	0.63	0.017
	Post-Monsoon (December 2024)	0.038	0.0052	0.029	0.76	0.020

Bhaisasur (S2)	Pre-Monsoon (May 2024)	0.055	0.0074	0.040	0.99	0.027
	Monsoon (August 2024)	0.033	0.0052	0.026	0.72	0.020
	Post-Monsoon (December 2024)	0.043	0.0062	0.032	0.84	0.023
Bhadanpue (S3)	Pre-Monsoon (May 2024)	0.045	0.0062	0.032	0.86	0.022
	Monsoon (August 2024)	0.028	0.0042	0.022	0.60	0.016
	Post-Monsoon (December 2024)	0.036	0.0052	0.028	0.74	0.019
Sadhara (S4)	Pre-Monsoon (May 2024)	0.051	0.0073	0.037	0.94	0.025
	Monsoon (August 2024)	0.032	0.0052	0.025	0.69	0.019
	Post-Monsoon (December 2024)	0.041	0.0062	0.031	0.82	0.022
Near Civil Hospital (S5)	Pre-Monsoon (May 2024)	0.046	0.0062	0.033	0.88	0.024
	Monsoon (August 2024)	0.029	0.0042	0.023	0.62	0.017
	Post-Monsoon (December 2024)	0.037	0.0052	0.029	0.75	0.020

3.2 Health Risk Interpretation

A questionnaire-based health survey was conducted to evaluate the possible influence of groundwater quality on the health status of residents living in different parts of the Maihar region during 2024. The survey included individuals regularly consuming groundwater for drinking and domestic purposes. Information related to neurological disorders, gastrointestinal disturbances, skin irritation, and other water-related health complaints was collected and analyzed. The summarized observations are presented in Tables 2, 3, and 4.

Table 2: Health Impact of Ground Water Pollution

Site	Sample Size	Severe Cases	Moderate Cases	Mild Cases	Healthy Individuals
S1	45	1	2	3	39
S2	55	1	2	3	49
S3	38	0	1	2	35
S4	60	2	2	3	53
S5	44	0	1	2	41

Table 3 Specific Health Problems

Site	Neurological Problems (%)	Gastrointestinal Problems (%)	Skin-related Problems (%)	Fluorosis (%)	Healthy Population (%)
S1	2.22	4.44	6.67	0.00	86.67
S2	1.82	3.64	7.27	0.00	87.27
S3	0.00	2.63	5.26	0.00	92.11
S4	3.33	5.00	8.33	0.00	83.34
S5	0.00	2.27	4.55	0.00	93.18

Table 4: Percentage Representation (Survey Data)

Site	Severe (%)	Moderate (%)	Mild (%)	Healthy (%)
S1	2.22	4.44	6.67	86.67
S2	1.82	3.64	5.45	89.09
S3	0.00	2.63	5.26	92.11
S4	3.33	3.33	5.00	88.34
S5	0.00	2.27	4.55	93.18

The health assessment carried out in the present investigation demonstrates that groundwater contamination in the Maihar region is currently at a moderate stage and has not produced widespread severe health consequences among the local population. Nevertheless, variations in health conditions among the studied locations indicate that anthropogenic activities may gradually influence groundwater quality and associated human health.

The data presented in Table 2 show that the majority of surveyed individuals were categorized as healthy across all sampling sites. Healthy individuals accounted for more than 83% of the total population at each location, suggesting that groundwater remains usable for domestic purposes in most areas. However, a limited number of mild, moderate, and severe cases were recorded, indicating the existence of localized health stress associated with water quality deterioration.

Among all locations, S4 exhibited the highest number of affected individuals. This area is influenced by mining and excavation activities, which may enhance the release of dissolved metals into groundwater systems. Elevated concentrations of iron, nickel, and lead observed at this site during heavy metal analysis support this interpretation. Continuous exposure to such contaminants, even at relatively low concentrations, may contribute to chronic health issues over time. S1 and S2 also displayed noticeable numbers of affected individuals, which could be associated with industrial emissions and agricultural runoff respectively.

The results summarized in Table 3 indicate that skin-related disorders were the most frequently observed health problem among residents. The occurrence of skin irritation may be linked to prolonged use of groundwater containing dissolved metallic impurities and suspended contaminants. Gastrointestinal complaints were also reported at several locations, particularly in S4 and S1. Such problems are commonly associated with the intake of chemically contaminated water and poor sanitation conditions. Neurological symptoms were comparatively less frequent but were observed mainly in S4 and S2, where heavy metal concentrations were relatively higher. Importantly, no cases of fluorosis were detected at any site, indicating that fluoride levels in groundwater remained within acceptable limits during the study period.

The percentage analysis shown in Table 4 further clarifies the distribution of health categories. S5 and S3 recorded the highest percentages of healthy individuals, reflecting comparatively lower environmental stress and reduced anthropogenic interference in these regions. In contrast, S4 showed the lowest percentage of healthy individuals and the highest percentage of severe health cases, emphasizing the potential influence of mining-related contamination on groundwater quality.

Overall, the integrated interpretation of groundwater chemistry and health survey data suggests a positive association between heavy metal concentration and minor health abnormalities. Although the present contamination level does not indicate an immediate public health emergency, the gradual increase in contamination observed in 2024 compared to previous observations highlights the necessity for periodic groundwater monitoring, proper waste management practices, and public awareness regarding safe water consumption. Continuous environmental surveillance and sustainable groundwater management strategies are therefore essential to minimize future health risks in the Maihar region

4. CONCLUSION

The present study provides a comprehensive evaluation of heavy metal contamination and associated health impacts in groundwater of the Maihar region during 2024. The investigation revealed that groundwater quality is influenced by both natural hydrogeochemical processes and anthropogenic activities such as mining, agriculture, urbanization, and semi-industrial operations. Significant seasonal and spatial variations in heavy metal concentration were observed across the selected sampling sites.

Among the analyzed metals, iron was detected in the highest concentration at all locations, indicating a strong contribution from geological formations and mineral dissolution processes. Lead and nickel showed moderate concentration levels, while cadmium and copper remained comparatively low throughout the study period. Seasonal analysis demonstrated that heavy metal concentrations were generally higher during the pre-monsoon season and decreased during monsoon due to dilution by rainwater recharge. Post-monsoon samples showed intermediate values, reflecting gradual stabilization of groundwater chemistry.

Spatial assessment indicated that S2 and S4 were comparatively more contaminated than other sites. Agricultural runoff, mining activities, and human-induced environmental disturbances appear to play an important role in increasing groundwater contamination in these regions. In contrast, residential and institutional areas exhibited relatively lower contamination levels, suggesting reduced anthropogenic pressure.

The health survey findings revealed that the majority of the population in the study area remains healthy, although minor cases of gastrointestinal disorders, skin irritation, and neurological symptoms were observed at some locations. The occurrence of these health problems was comparatively higher in areas showing elevated heavy metal concentration, suggesting a possible relationship between groundwater quality and public health conditions. However, no severe widespread health crisis or fluorosis-related cases were identified during the investigation.

Overall, the study indicates that groundwater quality in the Maihar region is presently under moderate environmental stress but remains largely suitable for domestic use. Nevertheless, the continuous presence of toxic metals in groundwater emphasizes the need for regular environmental surveillance and preventive management strategies. Adoption of proper waste disposal systems, controlled use of agrochemicals, treatment of industrial effluents, and periodic groundwater quality monitoring are essential for protecting water resources and ensuring long-term public health safety in the region.

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