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Trace Elements Spatial Distribution in the Groundwater near the Subarnarekha River Basin - Jamshedpur, India

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Abstract

The present study assessed the spatial distribution of trace elements in the groundwater near the Subarnarekha River Basin - Jamshedpur, India. Half of this city's water need (48.11%) relies on groundwater resources. GIS-based maps were constructed using ArcGIS 10.3 software to describe the spatial distribution of Arsenic (As), Barium (Ba), Cadmium (Cd), Chromium (Cr), Cobalt (Co), Copper (Cu), Iron (Fe), Manganese (Mn), Molybdenum (Mo), Nickel (Ni), Selenium (Se), and Strontium (Sr). The concentration of trace elements was investigated in the groundwater sample of 30 wells by the Inductively Coupled Plasma-Mass Spectrometry (ICP-MS). Many samples contained levels of Sr (100 µg/L), Cu (50 µg/L), Co (10 µg/L), and Mn (300 µg/L) that vastly exceeded the limits of the Bureau of Indian Standards (BIS) limit, which may directly affect the human health. The northern region of the study area exhibits higher concentrations of heavy metals. The groundwater table was monitored using a sensor-based

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water level recorder during pre and post-monsoon seasons. A significant fluctuation of 4.9 meters below ground level (mbgl) was observed, indicating potential water scarcity in the summer. The findings of this study offer valuable insights into various sources of contamination affecting groundwater in river basins within industrial regions.

Keywords

Heavy metals; river basin; spatial distribution map; ArcGIS

1. Introduction

Worldwide, groundwater is considered to be one of the safest sources of drinking water, which possesses life preservatives and essential elements [1]. Notwithstanding being more protected than surface water, the groundwater was highly susceptible to contamination with various pollutants [2, 3]. It is unevenly distributed below the earth's surface, mainly depending upon factors like geographical location, permeability of rocks, rainfall, infiltration rate, etc. [3, 4]. In developing nations like India, urbanization, rapid industrial growth, economic expansion, etc., greatly influence the quality of the environment and water. Almost 85% of the domestic water needs of this country (India) are filled with groundwater resources, where many states (Uttar Pradesh, Rajasthan, West Bengal, Jharkhand, Andhra Pradesh, Orissa, and Punjab) are at risk of acute groundwater depletion [5, 6]. Industrial activities like the production of heavy automotive and petrochemicals release pollutants like microplastics, toxic metals, organic pollutants (pesticides), and other emerging pollutants, affecting the quality of groundwater reservoirs [7]. Contaminants from various sources, including industrial discharges, agricultural runoff, and urban development, can introduce heavy metals such as Arsenic (As), Barium (Ba), Cadmium (Cd), Chromium (Cr), Cobalt (Co), Copper (Cu), Iron (Fe), Manganese (Mn), Molybdenum (Mo), Nickel (Ni), Selenium (Se), and Strontium (Sr). The infiltration of these metals into the soil and groundwater can occur through several pathways, including the percolation of contaminated surface water, leachate from landfills, and the weathering of metal-rich geological formations [8, 9]. The accumulation of heavy metals in groundwater affects water quality. It has long-term implications for public health, as exposure can lead to various diseases, including neurological disorders and organ damage [2, 10]. Moreover, heavy metal contamination can harm the environment, impacting soil quality, aquatic ecosystems, and biodiversity.

Jamshedpur is India's first planned industrial city, where half (48.11%) of water needs rely on groundwater resources. This city's other primary water sources include rainwater, the Subarnarekha-Kharkai River, the Sitarampur Dam, and Dimna Lake [11]. The uncontrolled seepage from the sewage network, intensive mining activities, and cultivated and industrial land uses have been identified as other potential sources of contamination in the groundwater resource of this area. The rate at which the groundwater resource is contaminated nowadays by several natural and anthropogenic activities is an alarming concern. Its quality is also increasingly compromised by trace elements, which can have severe health and environmental consequences [12-14]. While significant research has focused on trace element contamination in surface water, there is a lack of data on the presence of these elements in groundwater, especially in rural areas. Moreover, existing regulations often fail to account for the cumulative effects of trace element exposure over time."

Hence, these trace elements' spatial distributions were assessed to reduce the health risk in groundwater near the Subarnarekha River Basin Jamshedpur. No such data has been published on the spatial distribution of trace elements near the Subarnarekha River Basin of Jamshedpur, India. To this end, the present study explored the status and season-wise fluctuations of the groundwater table in the study area. The work also investigated the spatial distribution of trace elements. This study filled the critical knowledge gap by providing comprehensive data on trace element concentrations in groundwater across these regions.

2. Materials and Methods

2.1 Water Sampling and Study Area

To achieve the objective of the present study, groundwater samples were collected from 30 various locations in Jamshedpur city along the Subarnarekha River Basin (Figure 1). After collection, samples were stored in pre-conditioned acid-washed high-density polyethylene (HDPE) bottles at 4°C, till they reached the laboratory for further quality testing [15]. To analyze trace elements, samples were filtered with Millipore filter paper (pore size-0.45 µm) and preserved by adjusting the pH < 2 with 6N ultrapure Nitric acid.

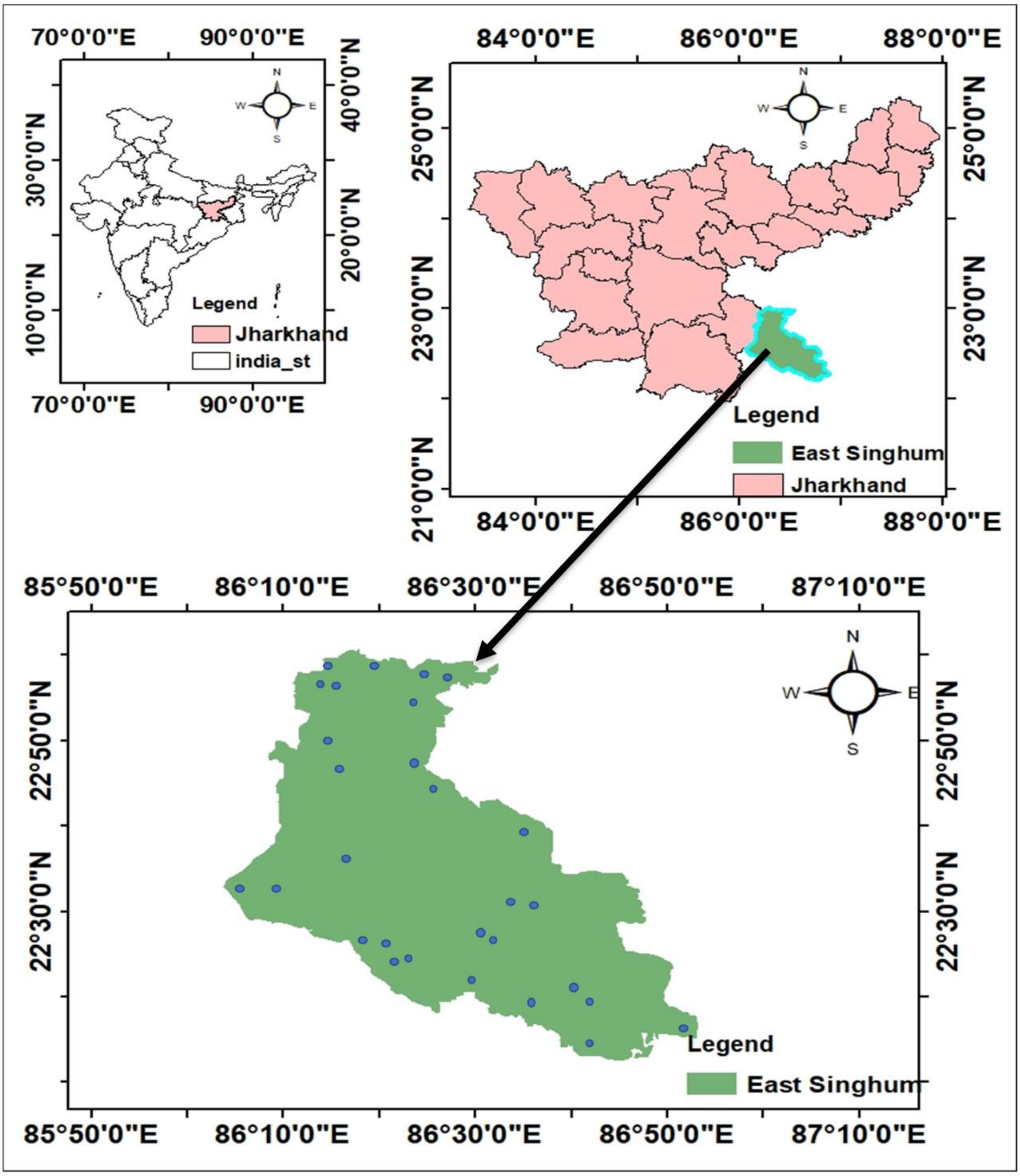

Figure 1 Sampling location of study area.

2.2 Analytical Method

The quality of the collected water sampled was analyzed using the standard methods of the American Public Health Association [16] in the laboratory of the Department of Environmental Science & Engineering IIT (ISM) Dhanbad. The instrument Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) (Model No- ELAN DRCe, Perkin Elmer, United States) monitored Concentrations of trace elements. The wells' water level depth was monitored using a sensor-based water level recorder (Model-K-11107).

2.3 Spatial Distribution Map

To analyze the spatial distribution of heavy metal concentrations in the Subarnarekha River Basin, ArcGIS (version 10.3) was employed. Sampling coordinates were recorded using GPS and maps generated for As, Ba, Cd, Cr, Co, Cu, Fe, Fe, Mn, Mo, Ni, Se, and Sr using the Inverse Distance Weighting (IDW) interpolation method. IDW was selected because it was effective at estimating unsampled values based on proximity and was refined to capture localized spatial trends precisely.

3. Result and Discussion

3.1 Ground Water Table Seasonal Fluctuations

Jamshedpur is well known as its industrial hub, and its population is highly dense, resulting in the overexploitation of groundwater resources. Previous findings revealed that this area's groundwater table has drastically decreased in the last 11 decades [11]. The statistics in Figure 2 signified the occurrence of groundwater as of now, at below 400 feet. No water was found in some places even after digging up to this depth. The season-wise fluctuations in the groundwater table of all selected 30 sampling locations were illustrated in Table 1. The difference in the groundwater table in these two seasons is mainly due to rainwater recharge. Moreover, various factors such as geological formation, impermeability of rocks, and rate of infiltration also greatly influence the groundwater table of this area [3].

Table 1 Season-wise fluctuations in the water table.

Sample ID	Pre-Monsoon (mbgl)	Post-Monsoon (mbgl)	Water Table Fluctuation (m)
W1	17.54	16.79	0.75
W2	23.45	22.77	0.68
W3	11.89	11.05	0.84
W4	15.17	14.25	0.92
W5	11.60	11.16	0.44
W6	14.05	13.50	0.55
W7	14.70	13.81	0.89
W8	15.50	14.31	1.19
W9	11.71	10.60	1.11
W10	18.39	16.99	1.40
W11	13.02	12.47	0.55
W12	10.55	9.74	0.81
W13	17.26	15.48	1.78
W14	14.37	12.64	1.73
W15	11.34	10.24	1.10
W16	14.23	12.25	1.98
W17	11.50	9.51	1.99
W18	10.90	9.32	1.58
W19	15.97	13.15	2.82
W20	11.57	9.34	2.23

W21	17.42	14.82	2.60
W22	16.70	12.50	4.20
W23	21.80	18.05	3.75
W24	14.75	9.85	4.90
W25	14.36	10.01	4.35
W26	19.56	15.46	4.10
W27	12.81	10.13	2.68
W28	20.14	15.89	4.25
W29	17.96	13.52	4.44
W30	22.27	21.22	1.05

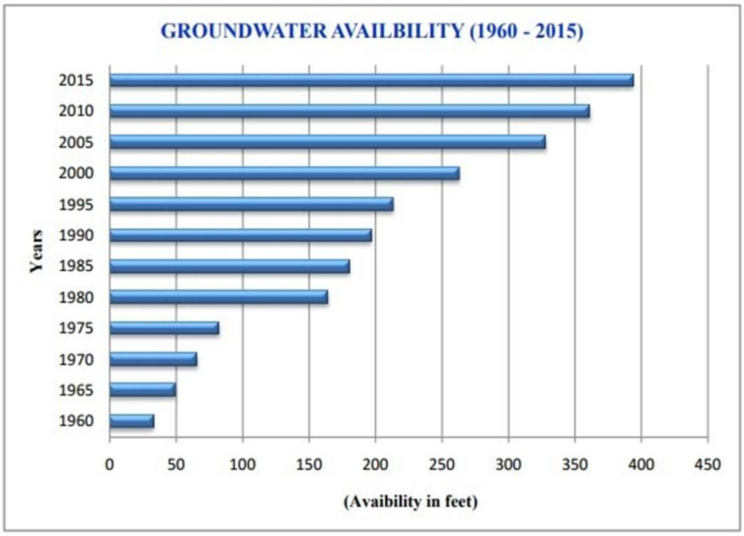

Figure 2 Availability of groundwater [11].

3.2 Trace Elements Spatial Distribution

Significant differences exist in the concentration variance of trace elements in urban groundwater shown in Table 2 [17]. The spatial distribution of heavy metals in the urban groundwater of the Jamshedpur area is shown in Figure 3 and Figure 4. The range value of Arsenic (As) (0.01 to 9.26 µg/L) complies with the Bureau of Indian Standards (BIS) (50 µg/L) specification of Drinking water quality [18]. However, the elevated value within this range was observed in the south-west direction of this region, marked with dark blue color patches (Figure 3a). This may be because the discharge of industrial effluent in the open land of this area causes infiltration of pollutants into the groundwater [2].

Table 2 Concentration of heavy metals in µg/L.

Sl.No	AS	Ba	Cd	Cr	Co	Cu	Fe	Mn	Mo	Ni	Se	Sr
1	0.01	19.3	0.003	0.29	0.15	0.44	3.42	2.02	2.35	1.2	0.35	30.02
2	0.7	26	0.002	0.67	2.55	0.32	379.32	419.65	1.99	8.92	0.06	141.27
3	0.48	175.3	0.151	1.53	0.72	1.66	204	341.11	70.6	4.03	2.77	175.47
4	0.27	118.9	0.066	439	0.72	0.49	561.12	245.19	3.12	9.68	0.7	280.63
5	0.08	20	0.004	0.59	0.78	0.57	1142.76	743.49	1.51	2.75	0.31	55.39
6	0.01	19.3	0.059	0.87	0.33	5.5	1020.6	472.89	0.66	3.04	0.47	147.35
7	9.27	46.9	0.235	715.32	1.27	0.75	391.92	160.38	1.73	8.18	1.52	240.26
8	0.59	71.8	0.225	678	7.14	11.33	307.92	296.56	1.35	8.2	2.62	495
9	0.04	42.1	0.064	0.57	9.22	0.65	264.6	169.62	2.82	11.68	0.31	163.59
10	0.28	53.7	0.004	0.48	0.42	64.62	159	194.37	2.39	3.17	0.31	287.38
11	0.17	24	0.059	79	13.87	0.12	99.84	107.03	152	20.43	0.18	157.7
12	0.01	0.3	0.235	0.64	1.14	0.9	217.44	146.3	1.99	3.62	0.07	106.12
13	1.9	38.3	0.225	0.54	88	36.84	165.24	1454	2.25	11.37	1.41	446.2
14	0.33	8.1	0.064	0.4	190	2.1	163.08	206.03	92	13.78	7.5	186.58
15	1.65	21.6	0.004	0.35	0.59	44.85	170.88	281.71	3.35	2.42	0.31	127.68
16	0.17	116.7	0.169	0.36	255.47	30.59	217.56	362.56	197.72	15.06	0.62	171.95
17	0.18	79	0.005	515	224	3.16	109.08	83.71	7.2	2.78	0.3	140.6
18	0.47	81.5	0.144	1.03	0.31	1.83	301.92	104.39	3.14	6.04	9.2	251.94
19	0.01	56.7	0.059	0.6	0.2	1.18	218.16	134.86	105	3.95	0.4	375.5
20	0.01	55.2	0	0.6	0.79	2.28	690.84	543.4	1.56	3	0.74	95.1
21	1.74	214.6	0.095	0.91	0.34	0.73	137.64	26.18	1.64	6.68	11.9	187.72
22	0.72	38.4	4.82	0.71	0.77	0.45	121.08	397.43	2.03	3.15	0.58	192
23	0.01	32.3	0.006	380	0.42	8.15	57.48	45.98	1.97	1.85	0.39	74.58
24	0.37	67.3	0.011	1.57	0.35	2.19	231.96	129.36	1.54	7.32	0.85	163.78
25	0.01	40.4	0.004	1.7	0.19	0.44	193.68	127.05	1.62	3.71	0.89	296.02
26	3.17	292.7	0.023	0.55	2.76	1.18	826.44	609.29	1.36	7.39	0.62	121.79
27	0.44	97.7	0.005	0.6	0.11	2.3	121.2	47.3	1.81	2.13	5.62	301.91
28	0.2	17.6	0.005	0.7	0.11	1.37	473.64	280.94	128	1.33	0.68	326
29	1.47	116.9	0.014	0.77	0.22	7.81	212.88	168.52	1.59	4	12.07	554
30	0.43	519.4	0.008	1.8	125	2.09	860.52	1185.03	1.27	2.97	0.86	125.5
Avg	**0.84**	**83.73**	**0.23**	**94.17**	**30.93**	**7.90**	**334.17**	**316.21**	**26.59**	**6.13**	**2.15**	**213.97**

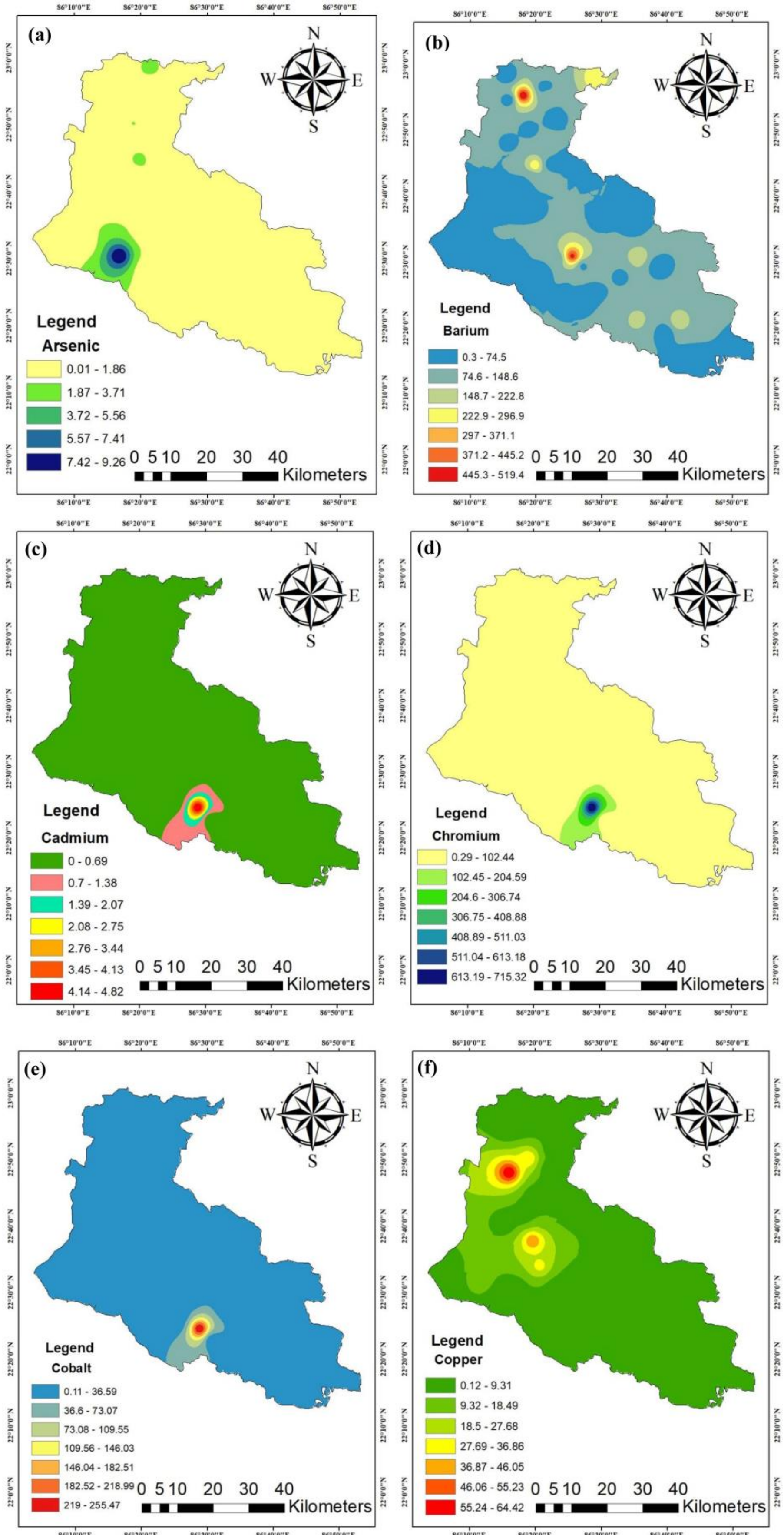

Figure 3 Spatial distribution of (a) As (b) Ba (c) Cd (d) Cr (e) Co and (f) Cu.

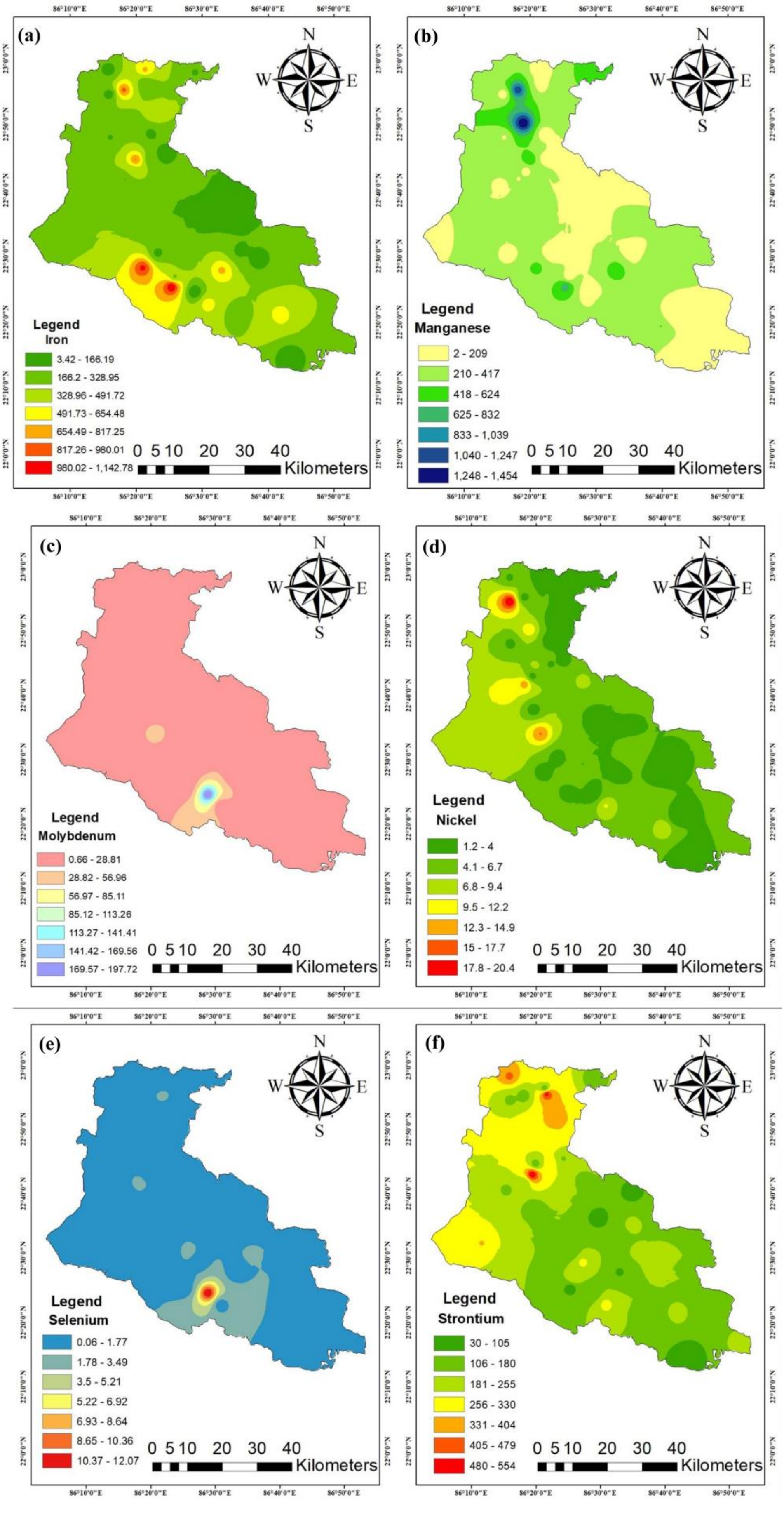

Figure 4 Spatial distribution of (a) Fe (b) Mn (c) Mo (d) Ni (e) Se and (f) Sr.

Barium concentration (Ba) (0.3 to 519.4 µg/L) good complied with the prescribed BIS (700 µg/L) standard. The coal waste dumping and leaching during landfills may support the northwest and central zones of this region to have a higher concentration of Ba as compared to other locations (Figure 3b). Similarly, the Cadmium (Cd) (0.00 to 4.82 µg/L) and Chromium (Cr) (0.29 to 715.32 µg/L) range values were observed to be slightly higher in the south direction (Figure 3c-d). However, they comply with the BIS guidelines, i.e., 10 and 50 µg/L. The Cobalt (Co) (0.11 to 255.47 µg/L) and Copper (Cu) (0.12 to 64.62 µg/L) distribution in groundwater of this area may vary significantly due to the discharge of industrial effluents, chemicals, untreated sewage, mine, and wastewater [18]. The south and west parts of the study area were also dominated by Co and Cu (Figure 3e-f), which also exceeded the regulatory standards of BIS (Co-10 µg/L, Cu-50 µg/L). The crust of the earth contains Manganese (Mn) and Iron (Fe), naturally resulting in severe aesthetic problems in groundwater [13]. In groundwater Fe concentration varied from 3.42 to 1142.76 µg/L, surpassing BIS's guideline value (300 µg/L). The red color patches in southwestern and some northern parts of the study area indicate a higher concentration of Fe in this area (Figure 4a). Simultaneously, the green color signifies the safe zone and potable nature of water with context to Fe. Mn plays a vital role in the human body as an essential nutrient. The intake of Mn in the human body is lower from drinking water than from food [2]. Mn also acts as a component of numerous enzymes and contributes to several significant physiological processes. Mn value in the study area's groundwater varied from 2.0 to 1454 µg/L, exceeding the permissible limit of BIS (300 µg/L). The northern part possesses a high level of Mn; however, the rest of the area is under the safe zone for drinking (Figure 4b). The primary source of Mn in this area is from industrial activities and the mining sector.

Strontium (Sr) is an important radionuclide that can permeate the groundwater system via accidental releases of radioactively contaminated water [19, 20]. Sr is a good substitute for Calcium in the human body and is well known as a pure beta emitter, but it may also damage the bone structure [13]. The range of Sr in the collected groundwater (30 to 554 µg/L) exceeds the permissible limit of BIS (100 µg/L). This element was noticed in the northwest region of the study area (Figure 4f). However, in concert with Sr toxicity, the rest region of the study area comes under the green zone for drinking purposes. The Sr concentration range variation Sr in this area is due to industrial and radioactive activity [13, 21].

In natural water, Mo-VI and Mo-IV are the most stable oxidation states of Molybdenum (Mo) [14]. For adults, with a daily dose of 75-250 µg/L, Mo is considered an essential trace element [14]. The monitored Mo concentration in the study area varied from 0.6 to 197.72 µg/L, which is relatively safe for drinking (Figure 4c). However, the borderline of the south direction possesses a higher concentration of Mo than other locations due to emissions and dust from adjoining steel industries.

Selenium (Se) is an essential nutrient for mankind only in a limited range of daily intake but it will turn into a toxin at elevated concentrations [19]. It possesses anti-carcinogenic properties and prevents heavy metals' effects, especially arsenic toxicity [20]. The Se content in the groundwater ranged from 0.05 to 12.07 µg/L, which complies with the BIS (10 µg/L) guideline. The spatial distribution of Se depicted that the south direction has a higher concentration than other locations (Figure 4e). The weathering and leaching of rocks and dissolution or oxidation of soluble salts in soils of this area may be the reason for Se in the groundwater.

Nickel (Ni) is the fifth most common element on the Earth's surface and is essential for living organisms and plants [7]. It occurs in natural water as a divalent cation in the pH range of 5-9 [22]. Ni concentration (1.2 to 20.4 µg/L) area aligns with BIS standards (20 µg/L) in this region. However, the central zone showed the Ni elevated range within the guideline line of BIS (Figure 4d). In the groundwater nickel's primary source is the leaching of metals [22].

However, future research should consider longitudinal studies to monitor how trace element levels in groundwater change over time, accounting for natural processes and human activities. Additional research is needed to quantify the potential health risks associated with long-term exposure to elevated trace element concentrations, incorporating toxicity thresholds and local consumption patterns.

4. Conclusion

The present research assessed the spatial distribution of trace elements in groundwater near the Subarnarekha River Basin - Jamshedpur. The concentration level of Mn, Sr Co, and Cu was higher than the BIS desirable limit, revealing the leachates of contaminants from various sources. The spatial distribution data showed a high level of Fe dominates the southwestern part of the study area, while the northern part is mostly affected by Ni and Cu. The level of the groundwater table was observed to fluctuate between 0.44 to 4.90 mbgl where the water table was found higher in pre-monsoon season (10.55 to 23.45 mgbl) than post-monsoon (9.32 to 22.77 mbgl). Future work should investigate how climate change-induced shifts in rainfall patterns, groundwater recharge rates, and water table levels may influence trace element distribution in groundwater systems.

Author Contributions

Jaydev Kumar Mahato (first): Literature review, fieldwork, experimental work, and original manuscript writing; Shivam Saw: conceptualization and supervision; Brahmdeo Yadav: Review of the manuscript, validation, and justification; Ajay Kumar: Draft manuscript preparation.

Competing Interests

The authors declare no conflicts of interest.

Data Availability Statement

Data collected and analyzed in this study are available from the corresponding author upon request.

References

1. Saw S, Singh PK, Mahato JK, Patel R, Shikha D. A modeling approach for the suitability evaluation and human health risk assessment of heavy metals dispersion in groundwater resources. Environ Dev Sustain. 2023. doi: 10.1007/s10668-023-04227-4.
2. Khalid S, Shahid M, Natasha, Shah AH, Saeed F, Ali M, et al. Heavy metal contamination and exposure risk assessment via drinking groundwater in Vehari, Pakistan. Environ Sci Pollut Res. 2020; 27: 39852-39864.
3. Bhutiani R, Kulkarni DB, Khanna DR, Gautam A. Water quality, pollution source apportionment and health risk assessment of heavy metals in groundwater of an industrial area in North India. Exposure Health. 2016; 8: 3-18.

4. Egbueri JC. Groundwater quality assessment using pollution index of groundwater (PIG), ecological risk index (ERI) and hierarchical cluster analysis (HCA): A case study. Groundw Sustain Dev. 2020; 10: 100292.
5. Saw S, Singh PK, Mahato JK, Patel R, Deoli V, Singh L. Application of GIS-based DRASTIC model and its validation with solute transport model in the assessment of groundwater vulnerability index: A case study from coal mining region of India. Environ Qual Manage. 2023; 33: 265-276.
6. World Bank. India - Water resources management sector review : Groundwater regulation and management report [Internet]. Washington, D.C.: World Bank; 2010. Available from: https://documents.worldbank.org/pt/publication/documents-reports/documentdetail/372491468752788129/india-water-resources-management-sector-review-groundwater-regulation-and-management-report.
7. Harasim P, Filipek T. Nickel in the environment. J Elementol. 2015; 20: 525-534.
8. Kharina GV, Alyoshina LV. Analysis of the quality of groundwater in the Sverdlovsk region. Hyg Sanit. 2023; 102: 221-228.
9. Prasad D, Singh PK, Mahato JK, Saw S. Hydrogeochemical characterization of groundwater in fire and non-fire zones of Jharia Coal Field, Eastern India, using water quality index (WQI), hierarchical cluster analysis (HCA), and human health risk. Arab J Geosci. 2022; 15: 927.
10. Ayari J, Barbieri M, Agnan Y, Sellami A, Braham A, Dhaha F, et al. Trace element contamination in the mine-affected stream sediments of Oued Rarai in north-western Tunisia: A river basin scale assessment. Environ Geochem Health. 2021; 43: 4027-4042.
11. Pingua SP. Effects of urban activities on underground water of jamshedpur. Int J Appl Sci. 2016; 4: 439-453.
12. Ayari J, Barbieri M, Barhoumi A, Boschetti T, Braham A, Dhaha F, et al. Trace metal element pollution in media from the abandoned Pb and Zn mine of Lakhouat, Northern Tunisia. J Geochem Explor. 2023; 247: 107180.
13. Wallace SH, Shaw S, Morris K, Small JS, Fuller AJ, Burke IT. Effect of groundwater pH and ionic strength on strontium sorption in aquifer sediments: Implications for 90Sr mobility at contaminated nuclear sites. Appl Geochem. 2012; 27: 1482-1491.
14. Smedley P, Cooper D, Ander E, Milne C, Lapworth D. Occurrence of molybdenum in British surface water and groundwater: Distributions, controls and implications for water supply. Appl Geochem. 2014; 40: 144-154.
15. Sudarsan J, Roy RL, Baskar G, Deeptha V, Nithiyanantham S. Domestic wastewater treatment performance using constructed wetland. Sustain Water Resour Manage. 2015; 1: 89-96.
16. APHA. Standard methods for the examination of water and wastewater. 22nd ed. Washington, D.C.: American Public Health Association; 2012.
17. Brima EI. Physicochemical properties and the concentration of anions, major and trace elements in groundwater, treated drinking water and bottled drinking water in Najran area, KSA. Appl Water Sci. 2017; 7: 401-410.
18. Water–Specification, Indian Standard Drinking. New Delhi, India: Bureau of Indian Standards. 2012; 1-12.
19. Kumar AR, Riyazuddin P. Speciation of selenium in groundwater: Seasonal variations and redox transformations. J Hazard Mater. 2011; 192: 263-269.

20. Araúz ILC, Afton S, Wrobel K, Caruso JA, Corona JFG, Wrobel K. Study on the protective role of selenium against cadmium toxicity in lactic acid bacteria: An advanced application of ICP-MS. J Hazard Mater. 2008; 153: 1157-1164.
21. Park Y, Shin WS, Choi S-J. Removal of cobalt and strontium from groundwater by sorption onto fishbone. J Radioanal Nucl Chem. 2013; 295: 789-799.
22. Rajappa B, Manjappa S, Puttaiah E. Monitoring of heavy metal concentration in groundwater of Hakinaka Taluk, India. Contemp Eng Sci. 2010; 3: 183-190.