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Assessment and Monitoring of Seasonal Variation in Metal Levels in Groundwater of Rewari District (India)

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***Abstract*: In the present study, groundwater metal contamination was assessed at fifteen locations in Rewari city of Haryana State during pre-monsoon and monsoon/post-monsoon seasons of year 2024. Water samples were collected from different sites and analyzed for Zn, Fe, Mn, Cu, Cr, As, and Pb using Atomic Absorption Spectroscopy. The obtained results were analyzed and compared with BIS drinking water standards (IS 10500:2012). The findings indicated moderate metal contamination, with some metals showing potential risks of accumulation in soil. Higher metal concentrations were observed during the pre-monsoon period due to evaporation and reduced groundwater recharge, whereas lower concentrations during the monsoon/post-monsoon season were attributed to rainfall induced dilution.**

Keywords: Ground-water quality analysis; Metals contamination; Seasonal variation: AAS

I. INTRODUCTION

Water scarcity and water quality deterioration have become major global concerns, closely associated with increasing water pollution and contamination. Among various pollutants, heavy metal contamination in groundwater has emerged as a significant environmental issue due to its persistence, toxicity, and bioaccumulation potential. Rapid urbanization, expansion of industrial activities, and excessive use of chemical fertilizers in agriculture have contributed considerably to the release of heavy metals into the environment.(Babuji et al., 2023; Hama Aziz et al., 2023; Latif et al., 2024, 2025; Singh et al., 2024; Umeh et al., 2025)

Heavy metals can enter the human body through contaminated drinking water as well as through the food chain, particularly via vegetables and fruits grown in contaminated soils (Choudhury & Mudipalli, 2008; Fergusson, 2014; Rattan et al., 2005). Prolonged exposure to elevated concentrations of heavy metals may disrupt biological and metabolic processes in humans (Hama Aziz et al., 2023; Latif et al., 2024, 2025; Sonone et al., 2020). Furthermore, heavy metals may accumulate in soils as a result of long-term irrigation with contaminated groundwater, eventually reaching toxic levels (Saravanan et al., 2024; Singh et al., 2024; Tariq et al., 2020; Umeh et al., 2025; Zhang et al., 2023). Metals such as chromium (Cr), arsenic (As), and lead (Pb) are well known for their toxic effects and are associated with various severe health disorders (Cheng et al., 2025; Jomova et al., 2025b). Even essential trace elements such as iron (Fe), copper (Cu), manganese (Mn), and zinc (Zn) can become harmful when present in excessive concentrations, affecting both plant growth and human health (Järup, 2003; Plum et al., 2010). Due to their long environmental persistence and potential toxicity, heavy metals pose a serious risk to ecosystem stability and public health (Balali-Mood et al., 2021; Jan et al., 2015; Rahman & Singh, 2019; Renu et al., 2021).

Seasonal variations significantly influence groundwater chemistry and metal concentrations (Giri et al., 2023; Zhou et al., 2025) . Factors such as evaporation, groundwater recharge, and dilution during rainfall events can alter the distribution and concentration of dissolved metals in groundwater systems (Tavakoli & Bayati, 2026). Therefore, seasonal monitoring of heavy metals is essential for understanding groundwater quality dynamics (Sreelesh et al., 2025).

Rewari district, located in the state of Haryana, lies within the National Capital Region (NCR) of India. It has experienced substantial groundwater exploitation and rapid industrial and urban development over the past decade (Malik et al., 2023; Narwal et al., 2024; Panghal et al., 2023; Prajapati, Tanwar, Yadav, et al., 2025). Despite the growing environmental pressures in the region, systematic studies addressing seasonal variations of heavy metal contamination in groundwater remain limited (Fan & Solaimani, 2015; Malik et al., 2023; Prajapati, Tanwar, Yadav, et al., 2025).

Therefore, the present study objectives are (1) Evaluation of heavy metals seasonal variation, (2) Comparative statistical study between two seasons, and (3) Identification of major heavy metals leading to groundwater contamination, if any. In this respect, the present study has been designed to analyze the metal concentrations in the groundwater of Rewari district. Fifteen sites were selected in consultation and guidance with Rewari municipal corporation and public health department experts. Ground water samples were collected for two different seasons (pre- and monsoon/post-monsoon). Seasonal and spatial variation in concentration of metals in groundwater samples have also been studied, and the results statistically analyzed and compared with Indian Standards (IS 10500:2012).

Study area

Rewari district is situated in the southern part of Haryana state in India (**28.19° N latitude and 76.62° E longitude). It** lies in a semi-arid climate zone within the Indian NCR. Groundwater is sourced from a predominant alluvial aquifer and is majorly used for drinking, domestic use and irrigation purposes. There are a number of industrial clusters, urban settlements and agriculture areas which can impact the groundwater quality across the district (Fan & Solaimani, 2015; Malik et al., 2023; Narwal et al., 2024; Panghal & Bhateria, 2021; Prajapati, Tanwar, & Bajar, 2025) .

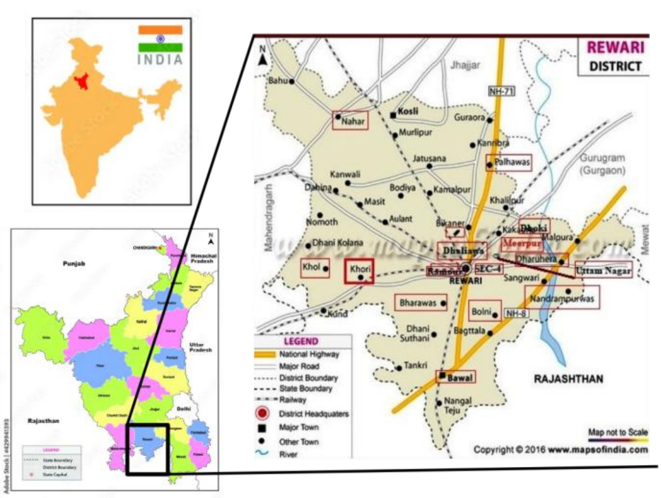

Fig. 1: Rewari Sample sites (red boxes in map of Rewari district). The location of Rewari in Haryana and the full map of India are shown on the left (images courtesy: stock.adobe.com and mapsofindia.com)

II. Materials and Methods

Samples were collected from two types of sources, namely open wells (OW) and borewells (BW), and were coded as S1 to S15, as indicated in **Table 1**. The selected sources represent the commonly used drinking and domestic water supplies in the study area.

TABLE 1

Details of Groundwater Sampling Sites

Sampling stations	Types of water	Sample ID
KHORI	Open well	S1
BHARAWAS	Bore well	S2
KHOL	Bore well	S3
NAHAR	Open well	S4
DHALIWAS	Bore well	S5
RAMPURA	Open well	S6
BAWAL	Bore well	S7
GARHO BOLNI	Bore well	S8
UTTAM NAGAR	Bore well	S9
MEERPUR	Open well	S10
SEC-4	Open well	S11
DARUHEDA	Bore well	S12
DOHEKI	Open well	S13
PAHLWAS	Open well	S14
NANDRAMPUR BAS	Open well	S15

The two pre-monsoon and monsoon/post-monsoon seasons durnig which samples were collected were February to May 2024 and June to September 2024, respectively.

The samples were collected using the grab sampling method, which involves the collection of a single representative sample from a specific location at a particular point in time. Clean, acid-washed 1 L glass bottles were used for sample collection to prevent any potential contamination. Prior to sampling, the bottles were soaked in 10% nitric acid for 12 hours and subsequently rinsed thoroughly with distilled water. For preservation, 1.5 mL of nitric acid was added to each collected sample to stabilize dissolved metals. The samples were properly labelled and preserved in an ice box for analysis (Kumar et al., 2023; Obiri-Nyarko, Asugre, et al., 2022; Obiri-Nyarko, Duah, et al., 2022; Prajapati, Tanwar, Yadav, et al., 2025) .

Metal concentrations were determined using Atomic Absorption Spectroscopy (AAS) with an air-acetylene flame. The obtained data were statistically analysed using the Pearson correlation coefficient to evaluate the relationship among variables and a paired t-test to determine the significance of seasonal variations in metal concentrations (Castejón-Porcel et al., 2018; Narayanan et al., 2025; Yu et al., 2022).

III. RESULTS AND DISCUSSION

The measurement results (**Table 3**) allow for a comprehensive assessment of the concentration of metal ions, namely Zinc (Zn), Iron (Fe), Manganese (Mn), Copper (Cu), Arsenic (As), Chromium (Cr), and Lead (Pb) in groundwater samples S1–S15. These metals are commonly associated with both natural geogenic processes, as well as anthropogenic activities. When present beyond permissible limits, these metals can adversely affect water quality and pose significant risks to human health.

The toxicity of these heavy metals depends on the type of metal, dose, route of ingestion, metabolic pathways, and the duration of exposure. Thus causing a range of acute and chronic effects. Oxidative stress is a primary toxicity mechanism where heavy metals like lead, arsenic and cadmium disrupt the balance between pro-oxidative and anti-oxidative pathways within the cell (Jomova et al., 2025b, 2025a; Kotnala et al., 2025). This happens via depletion of crucial anti-oxidatants like glutathione (GSH) and inactivation of enzymes such as superoxide dismutase (SOD) and catalase, leading to accumulation of damaging reactive oxygen species (ROS) (Chen et al., 2024; Jena et al., 2023). Heavy metals can also interfere with critical cellular processes by mimicking the action of essential metals. For example, lead and cadmium displace calcium, iron and zinc at protein binding sites causing disruption in enzyme functioning, metabolic pathways, as well as cell signaling. The resulting health-effects range from gastro-intestinal and renal dysfunction, neurological impairment to various types of cancers (Chen et al., 2024; Jena et al., 2023; Koyama et al., 2024).

It is also important to distinguish between the beneficial and toxic roles of heavy metals, particularly when their dose or oxidation state exceed or vary from the normal biological limits. For example, iron plays an important role as a component of haemoglobin, myglobin and various enzymes involved in oxygen transport and cellular respiration. However, in excess dosage, it can lead to formation of harmful free radicals that damage the heart, liver, brain and pancrease, and increases the risk of cancer. In a similar manner, copper toxicity leads to oxidative stress, organ damage and neurological damage (Balali-Mood et al., 2021; Jomova et al., 2025a; Naveed et al., 2023). Chromium too is recognised as an essential nutrient for glucose metabolism in its trivalent form (Cr+3), but its hexavalent form (Cr+6) is a potent toxin and a Group-1 human carcinogen, as it easily enters cells and damages DNA. Other heavy metals such as lead, cadmium, arsenic and mercury do not have any known beneficial biological roles and are only known to be toxic in nature. For example, lead poisoning causes neurological damage, cadmium is nephrotoxic and demineralizes bones, mercury is highly neurotoxic, and chronic exposure to arsenic leads to skin lesions, cancer of the internal organs and cardiovascular diseases. Thus, it is necessary to have stringent control and monitoring exposure to these heavy metals (Devoy et al., 2016; Naveed et al., 2023; Ropero et al., 2016).

To evaluate the suitability of groundwater for domestic use, the measured concentrations of heavy metals have been compared with the drinking water standards prescribed by the Bureau of Indian Standards (IS 10500:2012) (**Table 2**) (*Bureau of Indian Standards, Indian Standard Drinking Water Specification (IS 10500:2012). New Delhi, India: BIS, 2012.*, n.d.). The outcomes of this assessment offer valuable insights into the extent of metal contamination and the overall fitness of groundwater resources for drinking and other household purposes (Mazhar & Ahmad, 2020; Sandeep et al., 2012; Singh Yadav & Kumar, 2024) .

TABLE 2

Indian standards (IS 10500: 2012) for studied metal limits. The IS 10500:2012 standard prescribes the requirements and the methods of sampling and test for drinking water (**BIS, 2012**)

Parameters	Indian Standards (10500: 2012)	
	Requirement (Acceptable Limit)	**Permissible Limit (in absence of alternate source)**
Zinc (as Zn), µg/l	5000	15000
Iron (as Fe), µg/l	300	No relaxation
Manganese (as Mn), µg/l	100	300
Copper (as Cu), µg/l	50	1500
Total arsenic (as As), µg/l	10	50
Total Chromium (as Cr), µg/l	50	No relaxation
Lead (as Pb), µg/l	10	No relaxation

Zinc: The values of Zn in the groundwater samples (S1-S15) varied within the 375 to 730 µg/l range during both study periods (Table 3). Zn is essential for the activity of many enzymes and plays a key role in immune system function and protein synthesis. According to IS (10500: 2012) standards (Table 2), the acceptable limit for zinc is 5 mg/L (5000 µg/l) along with a permissible limit 15 mg/L (15000 µg/l) in the absence of alternate sources. All groundwater samples exhibited Zn concentrations within the permissible limits. Overall, Zn levels were very low, indicating minimal contamination.

Iron: Fe metal is important component of hemoglobin, responsible for oxygen transport in blood. The values of Fe varied between 89.83 to 151.79 µg/l in all samples for both study periods (Table 3). Fe concentrations in groundwater samples were found to be well within the acceptable limit of 300 µg/l as prescribed by IS 10500:2012.

Manganese: Mn acts as a cofactor for several enzymes involved in metabolism and antioxidant defense. The values of Mn varied between 1.60 to 10.50 µg/l in all the samples during both study periods (Table 3). These Mn concentrations lie well within the acceptable limit of 100 µg/l as prescribed by IS 10500:2012. The maximum permissible limit for Mn is 300 µg/l (Table 2).

Copper: Cu metal is required for red blood cell formation and proper functioning of enzymes involved in energy production. For both study periods, the values of Cu varied within 1.09 to

50.32 µg/l range in all the samples except S5 (Table 3), well within the acceptable limit of 50 µg/l as prescribed by IS 10500:2012. Sample S5 (Dhaliwas, borewell) recorded the highest Cu concentration (50.32 µg/l), which marginally exceeded the acceptable limit and is quite below the maximum permissible limit of 1500 ppb.

Arsenic: Inorganic As is toxic and can cause skin lesions, cancer, and damage to organs when accumulated in the body. The values of As varied within the 0.34 to 11.50 µg/l range in the groundwater samples (S1-S15) for both study periods (Table 3). Most of the groundwater samples were found to be well within the acceptable limit of 10 µg/l except Only sample S14 (Pahlwas, open well) recording the highest concentration in both seasons (11.50 and 9.40 µg/l), marginally exceeding the acceptable limit during pre-monsoon season (Table 2). The permissible limit for As is 50 µg/l in the absence of any alternate source.

Chromium: The values of Cr varied within 13.27 to 67.37 µg/l in the groundwater samples (S1-S15) during both study periods. Sample S11 (Sec-4, open well) recorded the highest Cr concentration in both seasons (67.37 and 54.01 µg/l), exceeding the acceptable limit of 50 µg/l, indicating localized chromium contamination. All the other samples remained within the prescribed limit (Table 2).

Lead: Pb is highly toxic metal that affects the nervous system and brain development, especially in children. The concentration of Pb varied between 0.12 to 3.88 µg/l in all samples for both study periods. As per IS (10500: 2012) standards (Table 2), the maximum acceptable limit for Pb is 10 µg/l. The concentration in all samples remained well within the prescribed limit, indicating the absence of critical lead contamination in the study area.

TABLE 3

Metal concentrations (µg/l) in pre-monsoon from Feb to May 2024 and Monsoon/Post-monsoon Season from June to Sept. 2024

Sample ID	Zn		Fe		Mn		Cu		As		Cr		Pb	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
S1	510	470	96.7	89.83	2.67	2.50	1.30	1.09	0.35	0.34	26.30	13.27	0.17	0.15
S2	410	375	151.79	140.89	1.72	1.63	1.33	1.16	0.90	0.88	31.35	18.80	0.28	0.24
S3	470	430	125.22	114.11	1.79	1.66	1.72	1.25	0.40	0.39	37.83	26.63	0.18	0.12
S4	670	610	118.95	106.59	10.50	9.60	2.10	1.53	0.50	0.49	30.37	15.56	0.16	0.12
S5	500	460	105.23	97.81	1.68	1.55	50.32	38.21	0.46	0.41	30.88	14.93	3.88	3.71
S6	460	430	135.56	124.66	1.95	1.85	2.15	1.65	1.45	1.37	40.11	29.54	0.15	0.13
S7	730	670	151.52	141.41	1.88	1.70	1.96	1.19	1.05	0.88	46.57	35.37	0.17	0.15
S8	520	480	120.36	112.34	2.45	2.24	3.51	3.15	1.06	0.85	30.54	18.25	0.27	0.25
S9	685	630	125.11	115.72	1.73	1.62	1.46	1.25	1.03	0.79	30.25	17.50	0.15	0.12
S10	555	510	130.34	121.24	1.87	1.77	1.60	1.38	1.55	1.03	36.50	24.25	0.16	0.13
S11	480	440	115.25	108.87	1.70	1.60	1.58	1.37	1.75	1.18	67.37	54.01	0.28	0.22
S12	695	640	125.87	118.32	1.89	1.72	7.22	6.45	0.95	0.73	30.27	17.59	0.43	0.41
S13	530	490	115.35	106.25	1.68	1.58	1.28	1.17	0.52	0.42	38.59	26.85	0.13	0.10
S14	620	570	130.59	124.28	1.75	1.62	18.25	15.03	11.50	9.40	39.36	26.98	0.34	0.31
S15	520	480	125.81	119.23	4.68	4.27	3.25	2.91	0.95	0.60	26.80	15.76	0.58	0.53

Statistical analysis (**Table 4**) indicates a higher concentration of all heavy metals during the pre-monsoon season (February to May 2024) as compared to the monsoon/post-monsoon season (July to September 2024). This reduction in metal concentrations during the monsoon can be attributed to the dilution resulting from groundwater recharge happening during the monsoon rains. Statistically significant seasonal variation in the heavy metal's concentration was revealed by means of paired t- test for Zn, Fe, Mn, Cu, As, Cr and Pb ($P < 0.05$). Copper does not show any significant seasonal variation in any groundwater sample. The visual representations of this data are shown in Fig. 2, 3, 4, 5, 6, 7, 8. Pearson correlation analysis (Fig. 10) also reveals a strong positive correlation between the monsoon and post monsoon concentration of metals in groundwater. This strong correlation indicates a stable spatial distribution pattern. This is turn also suggests a stable geogenic and anthropogenic source control. Spatial variation in metal distribution was also assessed by comparing groundwater samples from open wells and borewells across different sampling locations. No particular trend was observed for metal concentrations with regards to spatial distribution (Fig. 9). This highlights the influence of well type, depth of aquifer, and local hydrogeological conditions on groundwater quality.

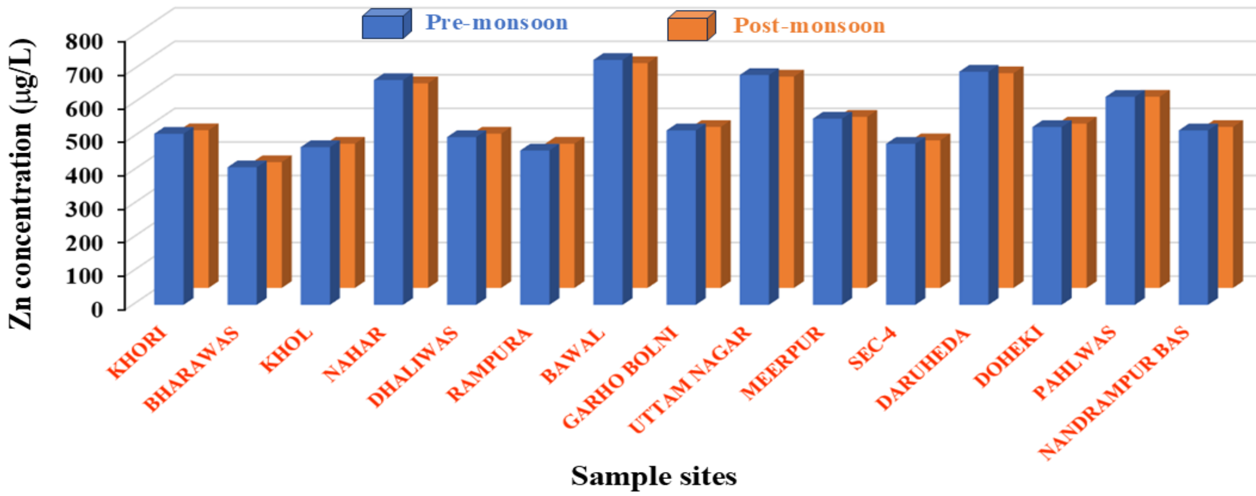

Fig. 2: Spatial distribution of Zn concentration during pre-monsoon and Monsoon/post Monsoon seasons

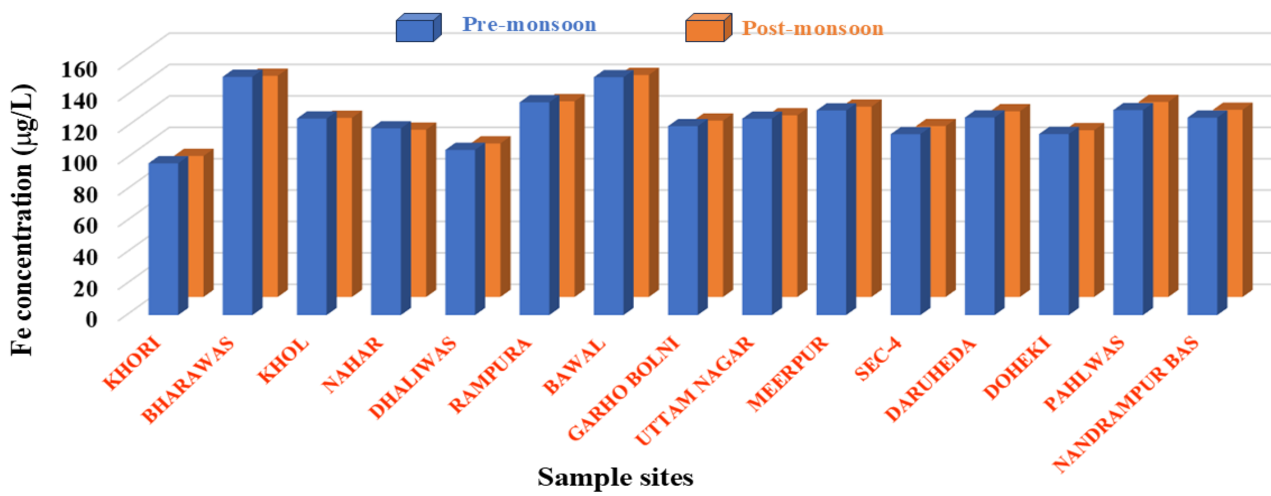

Fig. 3: Spatial distribution of Fe concentration during Pre-monsoon and Monsoon/post Monsoon seasons

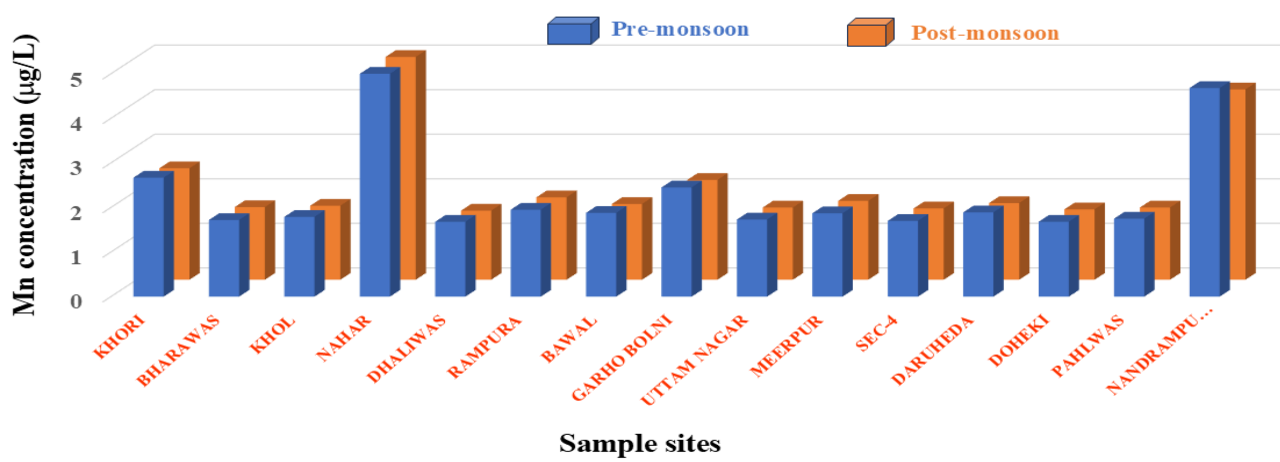

Fig. 4: Spatial distribution of Mn concentration during Pre-monsoon and Monsoon/post Monsoon seasons

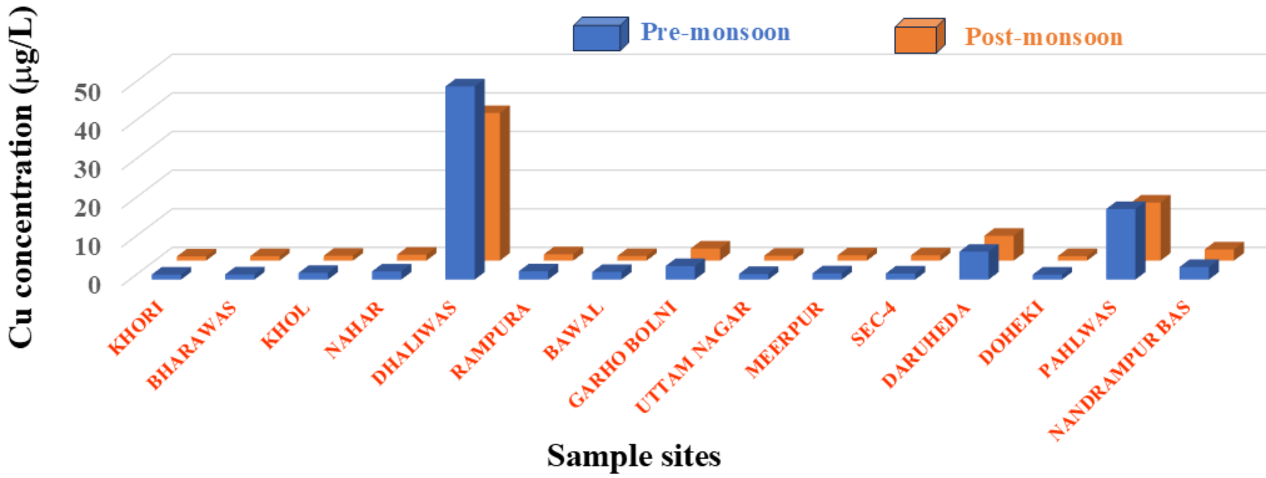

Fig. 5: Spatial distribution of Cu concentration during Pre-monsoon and Monsoon/post Monsoon seasons

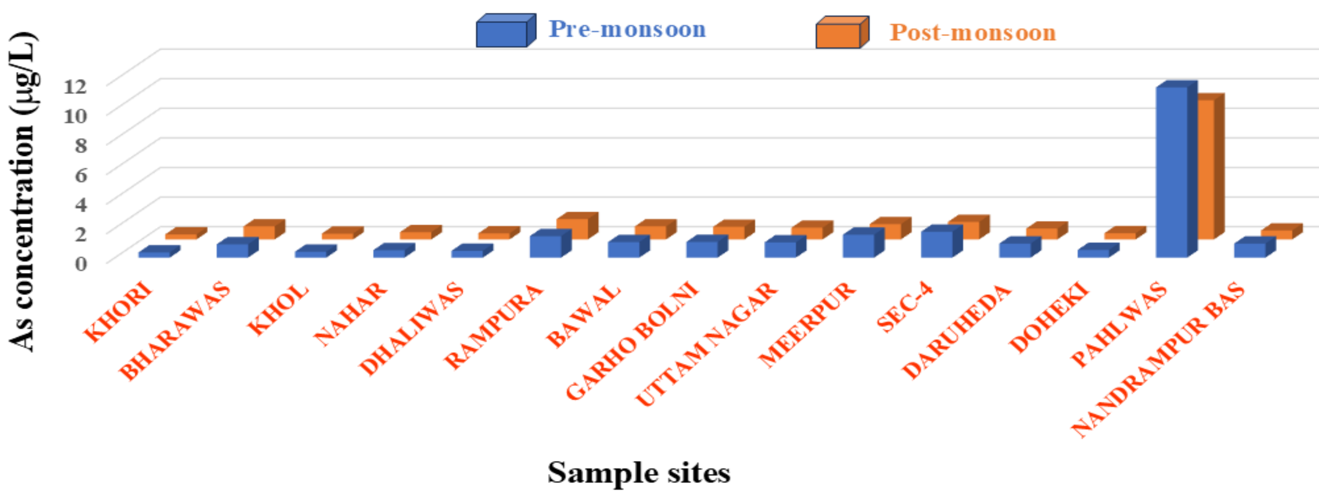

Fig. 6: Spatial distribution of As concentration during Pre-monsoon and Monsoon/post Monsoon seasons

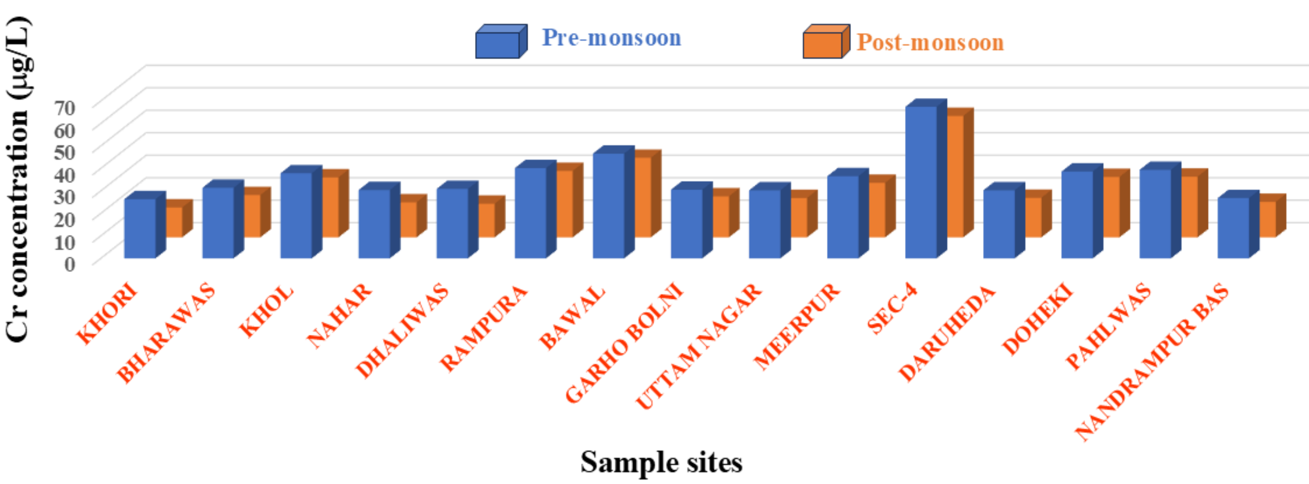

Fig. 7: Spatial distribution of Cr concentration during Pre-monsoon and Monsoon/post Monsoon seasons

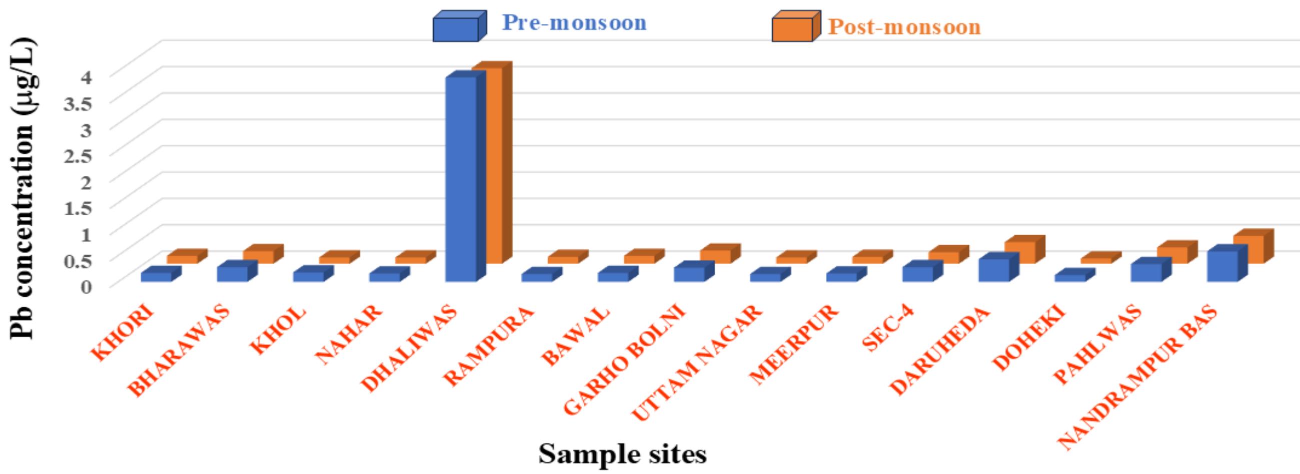

Fig. 8: Spatial distribution of Pb concentration during Pre-monsoon and Monsoon/post Monsoon seasons

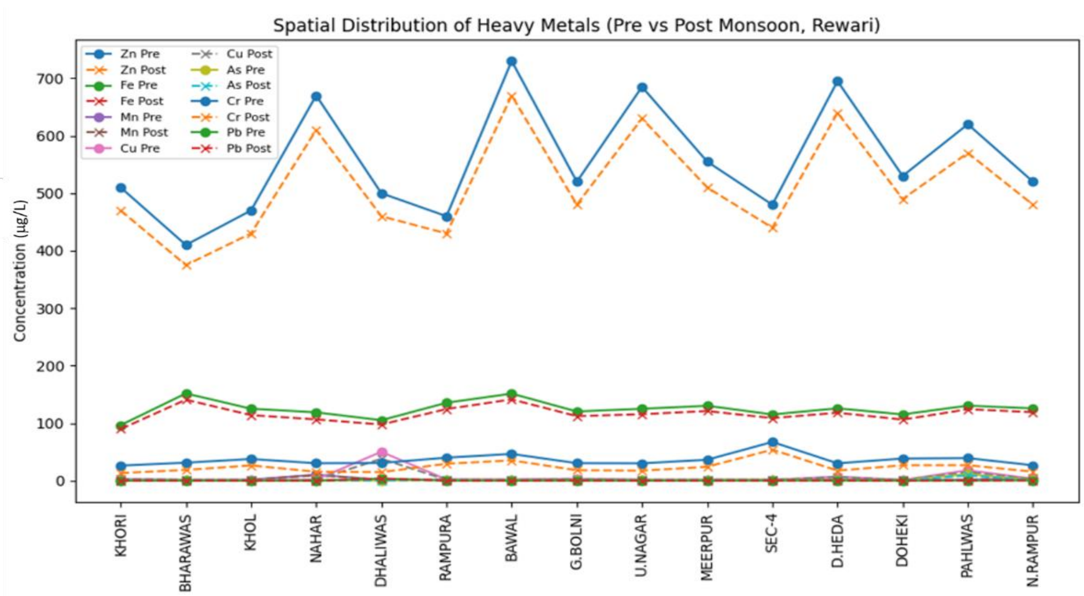

Fig. 9: All Metal's compiled Spatial distribution

TABLE 4
Statistical analysis

Metal	Pre-monsoon (Mean ± SD)	Monsson/Post-monsoon (Mean ± SD)	t-value (paired)	p-value	Significance	Pearson (r)	Correlation strength
Zn	557.00 ± 98.39	512.33 ± 89.70	18.90	2.32×10^{-11}	Significant ↓	0.9995	Very strong positive
Fe	124.91 ± 14.72	116.10 ± 13.94	17.39	7.09×10^{-11}	Significant ↓	0.9921	Very strong positive
Mn	2.66 ± 2.30	2.46 ± 2.09	3.74	0.0022	Significant ↓	0.9999	Very strong positive
Cu	6.60 ± 12.86	5.25 ± 9.82	1.70	0.111	Not significant	0.9992	Very strong positive
As	1.63 ± 2.76	1.32 ± 2.26	2.29	0.038	Significant ↓	0.9984	Very strong positive
Cr	36.21 ± 10.31	23.69 ± 10.57	34.11	7.06×10^{-15}	Highly significant ↓	0.9910	Very strong positive
Pb	0.49 ± 0.95	0.45 ± 0.91	4.36	0.00065	Significant ↓	0.9999	Very strong positive

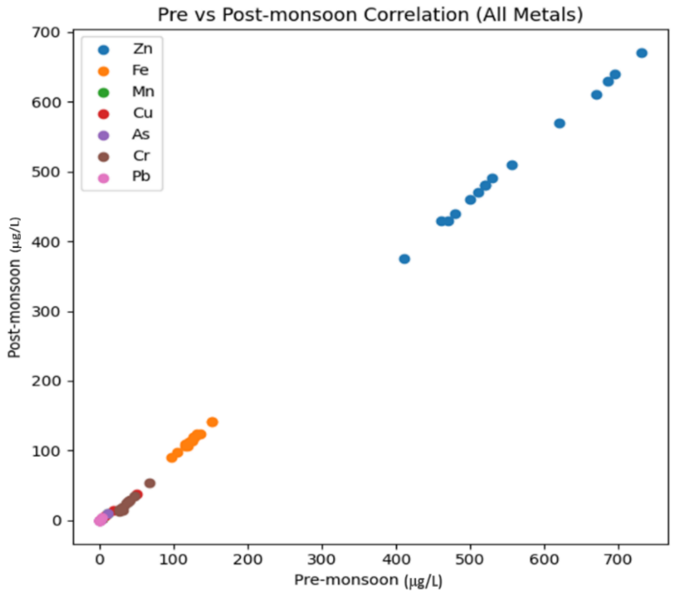

Fig. 10: Correlation pre-monsoon vs. monsoon/post-monsoon

IV. Conclusions

The assessment of groundwater quality with respect to BIS permissible limits reveal that concentrations of zinc (Zn), iron (Fe), manganese (Mn), copper (Cu), arsenic (As), chromium (Cr), and lead (Pb) remained within acceptable limits at most sampling locations during both seasons, indicating minimal heavy metal contamination and no immediate health risk. Seasonal variations showed comparatively higher metal concentrations during the pre-monsoon period, whereas a dilution effect was observed during the monsoon/post-monsoon season due to groundwater recharge. Spatial variations in metal concentrations were influenced by factors such as well type, aquifer depth, local lithology, and limited anthropogenic activities. However, Cu and As concentrations exceeded permissible limits at Dhaliwas borewell (S5) and Pahlwas open well (S14), while localized Cr contamination was observed at Sector-4 open well (S11) during both seasons, suggesting possible site-specific anthropogenic influences. Overall, the groundwater quality of the study area is largely safe with respect to the investigated heavy metals. However, regular monitoring and sustainable groundwater management practices are recommended to ensure long-term water quality protection and safeguard public health.

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