



Heavy Metal Characteristics and Their Spatial-Temporal Distribution in Trans-Yamuna Aquifer, Palwal District, Haryana, India

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ABSTRACT

The Trans-Yamuna aquifer in Palwal District, Haryana, India, is a vital water source for both agricultural and domestic uses. This study explores the characteristics and spatial-temporal distribution of heavy metals within this aquifer to evaluate potential environmental and health risks. Over the course of one year, water samples were systematically collected from various sites within the aquifer. Heavy metal concentrations—specifically lead (Pb), cadmium (Cd), arsenic (As), and chromium (Cr)—were measured using advanced analytical techniques such as atomic absorption spectroscopy (AAS) and inductively coupled plasma mass spectrometry (ICP-MS). The results reveal notable spatial variability in metal concentrations, with higher levels detected near industrial and agricultural areas. Additionally, seasonal variations were observed, with elevated metal concentrations during the monsoon season, attributed to runoff and leaching. Heavy metal concentrations were generally higher than permissible limits at most sites, ranging from 0.001 to 0.8 ppm, except for iron, which exhibited different behavior. Zinc showed the highest concentration variability, while cadmium had minimal fluctuation. A significant increase in cobalt (Co) and iron (Fe) concentrations, along with a decrease in groundwater quality, was noted in the post-monsoon period. Metal abundances varied, with the following order observed: Fe > Pb > Ni > Zn > Cr > Cd > Cu > Co > Mn in pre-monsoon and Ni > Zn > Fe > Cd > Cu > Pb > Co > Cr > Mn in post-monsoon periods. Rural areas exhibited a marked change in metal abundance patterns. Correlation analysis revealed a stronger relationship among deep groundwater samples in pre-monsoon compared to post-monsoon samples, with the highest correlation found in urban areas. Overall, heavy metal concentrations exhibited a concentric zonal distribution, with higher levels near the urban-rural fringe and decreasing towards the periphery.

Keywords: Heavy Metal, Trans-Yamuna Aquifer, AAS, Health Risks, Anemia, India

1. INTRODUCTION

The trace metals are mainly found in the earth's crust through weathering and erosion process, and they enter into the stream water their become parts of the surface and sub-surface water. It is usually harmless to the organism, but its concentration is increasing throughout the world. In the last few decades, human activities like the use of fertilizers, pesticides, fungicides, burning of fossil fuel, mining activity, leather and footwear industries and some toxic metal production industries directly injecting waste material in the groundwater. It is identified by various researchers that trace metal directly enters the aquatic environments from a different source of point and non-point pollution. Industrial and anthropogenic wastes transport vast amounts of heavy metal in the surrounding environments (Purushotham et al., 2013). The metal contamination of water, soil and environment created many health hazardous effects in the present decades (Erturk et al., 2010; Fan et al., 2012; Haloj and Sharma, 2012). The drinking water quality is degraded by heavy metal, as reported by different researchers (Borah et al., 2009; Das et al., 2009; Sia Su., 2007; Singh, 2004; Chakraborti et al., 2002). According to (MC Neely, 1979; underwood, 1971; USEPA, 1983) the heavy metal concentration creates hazardous health effects in human and other organisms while some researchers found that deficiency of heavy metal cause problem in human metabolism (Athar M. et al., 1995; McLaughim et al., 1999; Noda, M. et al., 1990). In the year 2000, United National Environment Programs (UNEP) announced that the groundwater quality for drinking and other purposes declined due to the growing human population and corresponding economic and industrial development causing eutrophication and heavy metal pollution in the aquatic environment (Peierls et al., 1998; Pekey et al., 2004; Li et al., 2008; Krishna et al., 2009). WHO and UNEP reported the degradation of the water quality due to urbanization, industrialization and anthropogenic activities in different parts of the world (Gems, 1989; Friberg et al., 1986). In India, industrialization is mostly concentrated in and around megacities such as Delhi, Mumbai, Ahmadabad, Kanpur, Calcutta, and Chennai due to the availability of much skilled labor. However, in the last thirty years, because of the scarcity of land in these megacities, the industries have started migrating periphery of the districts. Hence, the new satellite industrial towns have developed, e.g., Ghaziabad, Faridabad, Palwal, Noida near Delhi, Thane, Bhivandi, Kurla Mumra near Mumbai, Mahabalipuram, Chengalpattu, Maraimalai Nagar, Sripurumpudur, Arakkonam, Kanchipuram and Tiruvallur around Chennai. The Palwal district one of the fast-growing industrial cities of Delhi's satellite town marked as one of the industrial hubs adjacent to Yamuna River. The heavy industrialization and predominant agriculture background provide a unique opportunity to assess the impact of this activity on the quality of groundwater. The study performed by several authors revealed a significant problem related to the high total solvent in the area's groundwater.

The current research focuses on the concentration and distribution of heavy metals, sources, and potential hazardous health effects on human population in the study area.

2. STUDY AREA

Palwal is located in the southern part of Haryana and India's western part, and it is a part of the National Capital Region. It shares geographical boundary with Mewat, Aligarh, Gurgaon, Faridabad and Delhi. National Highway-2 passes through the Palwal district. The Kundli-Manesar-Palwal 136 km long Expressway passes through the district. Palwal district is the 21st district of Haryana state in northern India and Palwal City is the headquarter of this district. It is a part of the Braj region and situated 60 km away from (National Capital region) Delhi. It is divided into four blocks; Palwal, Hathin, Hodal and Hassanpur (Fig.1).

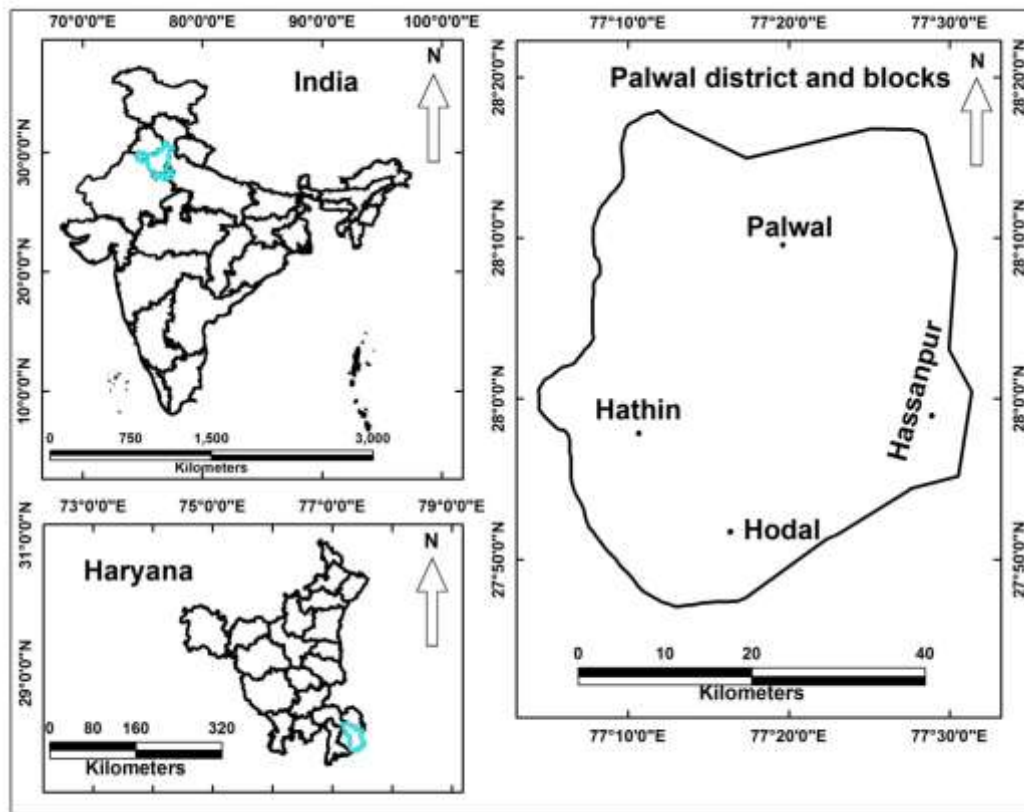


Figure 1. Location map of the study area.

The total geographical area of this district is about 1364.55 sq. km. Palwal district of Haryana lies between 27°47': 28°17'N latitudes and 77°05': 77°33' E longitudes. The area falls in the survey of India's toposheets no.53H/3, H/4, H/7, H/8, H/9, H/12, 54E/5 and E/9.

The area is chosen because few scientific geo-environmental studies were carried out in the Haryana state near Yamuna River, India. In particular, Palwal, due to logistical problems and uneasy access. Since last few years, the study area is considered an industrial hub, particularly in Pirthla and Tatarpur village adjacent to Ballabgarh, Faridabad. The population of the district is growing with time. The ever-growing population and its attendant anthropogenic activities like unplanned growth in urban settlements and huge accumulation of solid wastes in the absence of proper landfill sites resulted in extensive study of this region. Encroachment on the scattered wetlands for habitation and agricultural activities, shifting agricultural practices in the higher reaches, deforestation, and the impacts of the external factors like global warming and climatic change phenomenon are exerting pressure on the geo-environment of the study area. The impacts of these natural and anthropogenic activities manifest in the deterioration quality of water resources, deteriorating health conditions and increasing water and vector-borne communicable diseases. Ignorance about the geo-environment stresses is no less hazardous while planning to mitigate and improve the geo-environmental conditions. This geo-environmental appraisal study will provide information about the factor affecting water quality in the study area.

3. MATERIAL AND METHODS

Fifty-eight representative groundwater samples were collected from the Palwal district covering the whole study area, and the location was chosen on logistic and grid pattern. Sampling was carried out in post-monsoon 2015 and pre-monsoon 2016 using standard techniques (APHA 1995). Water samples were collected in sterile 1 L polyethylene

bottles, and each sample was treated with 10 ml HNO₃ to prevent possible precipitation of heavy metals. The water samples were analyzed for heavy metals according to international standard methods (APHA 1995). The analyses of Cu, Cr, Mn, Ni, Co and Cd were performed in the Department of Geology, Aligarh Muslim University, Aligarh, using Atomic Absorption Spectrophotometer (AAS) (Perkin-Elmer, Analyst 800). In the heavy metal analysis by AAS, quality control was monitored using 10% sample blanks and 10% sample replicates in each sample analysis set.

3.1 Heavy Metal Pollution Index

HPI is a rating method that reflects individual heavy metals' combined effect on the overall water quality. The ranking is between 0 and 1 and represents the relative value of each of the parameters. The weight for each water quality parameter (Wi) selected and inversely proportional to the recommended standard (Si) for the corresponding parameter (Horton, 1965; Mohan et al., 1996; Reddy, 1995; Prasad and Kumari, 2008). The World Health Organization (2017) used for computing HPI (unit of each chemical parameter in mg/l). (Mohan et al., 1996) established the index used and preceded it as below. The first step involved measuring the relative weight of each parameter (Wi) using the equation below.

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

Where the symbols Qi and Wi represents the sub-index and the unit weightage of the ith parameter, respectively, and n is the number of parameters considered.

4. RESULTS AND DISCUSSION

The water samples were analyzed to know the concentration of heavy metals like Cu, Pb, Zn, Ni, Cd, Mn, Fe, Co and Cr in groundwater during the pre-monsoon and post-monsoon time in the study area (Table.1, 2 and 3). The concentrations of Cu are 0.183 to 1.16 mg/l and 0.265 to 0.756 mg/l in pre and post-monsoon, respectively, against the permissible limit of 1.5 mg/l by WHO. In the case of Fe, concentration ranges from 0.609 to 56.480 mg/l during the pre-monsoon and 0.002 to 1.478 mg/l in post-monsoon times. The Pb values in the groundwater range from 0 to 2.34 and 0 to 1.825 mg/l during the pre and post-monsoon season, respectively. While Mn in the pre-monsoon period is 0 to 0.535 and 0.001 to 0.87 mg/l in the post-monsoon. The concentration of Zn during the pre-monsoon is 0.0348 to 3.836 and 0.014 to 3.255 mg/l during the post-monsoon. Ni ranges from 0.232 to 1.345 in the pre-monsoon period and from 0.532 to 1.335 mg/l during the post-monsoon period. The pre-monsoon period's Co value varies from 0.0165 to 0.399 and during the post-monsoon varies from 0.0309 to 0.501 mg/l. Similarly, Cd varies from 0.466 to 0.544 and from 0.47 to 0.567 mg/l in both seasons.

Table 1: Heavy metal concentration in groundwater in Palwal district in (pre-monsoon season 2016). (All the concentration in ppm)

S.no	Long.	Lat.	Mn	Fe	Pb	Cd	Cu	Co	Zn	Ni	Cr
1	28.12	77.4	0.04	1.5	0.66	0.49	0.18	0.05	3.59	0.5	0.85
2	28.14	77.4	0.01	1.36	0.19	0.47	0.25	0.05	0.29	0.58	0.2
3	20.15	77.4	0.01	0.06	0.58	0.48	0.3	0.05	0.35	0.23	0.64
4	28.14	77.3	0.05	0.79	0.74	0.49	0.27	0.07	0.04	0.72	0.78
5	28.14	77.3	0.03	0.06	1.68	0.49	0.32	0.05	0.41	0.64	0.61
6	28.22	77.3	0.12	2.83	0.69	0.52	0.29	0.05	0.43	0.67	0.34
7	28.27	77.3	0.11	1.42	0.86	0.5	0.34	0.04	0.03	0.42	0.37
8	28.27	77.3	0	1.1	0.66	0.49	0.31	0.05	0.4	0.53	0.43
9	28.26	77.4	0	0.61	0.3	0.49	0.38	0.05	0.49	0.64	0.19
10	28.22	77.4	0.02	5.51	0.1	0.49	0.43	0.05	1.72	0.55	0.17
11	28.16	77.4	0.02	6.52	0.02	0.5	0.4	0.07	1.06	0.87	0.88
12	28.08	77.1	0.01	1.29	0.26	0.5	0.44	0.03	0.5	0.55	0.21
13	28.07	77.4	0.01	0.83	1.01	0.49	0.5	0.08	1.37	0.63	0.29
14	28.04	77	0.41	23.09	1.21	0.49	0.48	0.02	1.16	0.57	0.3
15	28.04	77.4	0.16	1.4	1.02	0.51	0.45	0.09	0.78	0.9	0.71
16	28.03	77.5	0.02	0.63	1.24	0.5	0.5	0.08	0.05	0.49	0.45
17	27.98	77.5	0	11.08	0.7	0.47	1.16	0.06	1.62	0.61	0.54
18	27.95	77.5	0.54	56.48	1.01	0.51	0.55	0.1	3.84	0.78	0.75
19	29.91	77.4	0.08	1.44	1.74	0.51	0.48	0.07	0.58	0.83	0.16
20	27.9	77.4	0.03	1.99	0.73	0.51	0.53	0.06	0.54	0.49	0.18
21	27.89	77.4	0.03	1.27	0.75	0.51	0.53	0.12	0.53	0.81	0.57
22	27.9	77.4	0.01	2.11	0.16	0.51	0.49	0.16	0.62	0.41	0.45
23	28.06	77.4	0.01	5.61	0.35	0.51	0.57	0.06	0.59	0.69	0.71
24	28.04	77.4	0	3.31	0.62	0.48	0.51	0.08	0.79	0.7	0.59
25	28.01	77.4	0	1.17	0.46	0.49	0.51	0.19	0.04	0.62	0.43
26	27.97	77.4	0.03	2.68	1.17	0.48	0.52	0.18	0.59	0.54	0.56

27	27.97	77.4	0.02	1.37	0.49	0.51	0.53	0.1	0.54	0.55	0.6
28	27.97	77.5	0.01	5.75	1.43	0.49	0.54	0.2	1.61	0.54	0.48
29	28.01	77.5	0.01	1.72	1.26	0.5	0.49	0.17	0.67	0.55	0.64
30	28.08	77.4	0	1.52	1.55	0.48	0.67	0.1	0.61	0.94	0.55
31	28.14	77.4	0.01	5.62	0.98	0.51	0.5	0.2	1.44	0.84	1.13
32	28.15	77.4	0	1.44	0.51	0.49	0.5	0.02	0.59	0.87	0.44
33	28.19	77.3	0.04	12.75	1.09	0.51	0.59	0.11	0.78	1.05	0.57
34	28.21	77.2	0.01	6.14	0.42	0.52	0.62	0.24	0.74	0.77	0.64
35	28.21	77.2	0.04	0.98	0.9	0.5	0.54	0.18	1.54	0.9	0.4
36	28.23	77.1	0.14	2.16	1.13	0.53	0.52	0.27	0.09	0.87	0.64
37	28.2	77.3	0.07	5.13	0.71	0.53	0.68	0.25	0.98	1.01	0.7
38	28.25	77.3	0.13	3.5	0.07	0.52	0.61	0.27	0.15	1.04	0.75
39	28.23	77.3	0.02	48.33	0.7	0.54	0.61	0.27	1.07	1.03	0.61
40	28.23	77.3	0.31	1.78	0.61	0.54	0.49	0.28	0.5	0.95	0.62
41	28.23	77.3	0.19	1.69	0.76	0.5	0.61	0.26	0.48	0.76	0.65
42	28.23	77.3	0.06	5.65	0.38	0.53	0.61	0.24	0.05	1.03	0.69
43	28.21	77.3	0.03	0.91	0.59	0.54	0.55	0.22	0.05	0.78	0.7
44	28.18	77.3	0.07	1.6	0.86	0.51	0.63	0.33	0.04	1.03	0.6
45	28.18	77.3	0.01	1.06	0.71	0.54	0.58	0.26	0.06	1.09	1.08
46	28.15	77.3	0.05	1.2	1.27	0.53	0.53	0.25	0.92	0.84	0.42
47	28.13	77.3	0.01	3.16	0.43	0.52	0.61	0.27	0.54	0.81	0.18
48	28.14	77.3	0.04	0.72	0.83	0.51	0.6	0.25	0.05	0.94	1.4
49	28.11	77.3	0.07	1.63	1.34	0.51	0.79	0.27	0.06	0.71	0.52
50	28.02	77.3	0.02	0.72	2.34	0.54	0.59	0.32	0.06	1.15	0.92
51	28.02	77.3	0.41	1.63	1.39	0.53	0.56	0.38	0.04	1.06	0.79
52	28	77.3	0.01	1.78	1.01	0.5	0.59	0.27	0.05	0.95	0.53
53	28.02	77.3	0.03	2.91	1.82	0.51	0.44	0.31	0.05	0.92	0.82
54	28.39	77.2	0.02	3.07	1.43	0.52	0.61	0.34	0.57	0.82	0.93
55	28.06	77.2	0.07	3.55	1.37	0.51	0.48	0.33	0.57	1.35	0.75
56	28.07	77.3	0.01	2.1	1.67	0.5	0.51	0.3	0.53	1.03	1.03
57	28.09	77.3	0.05	5.77	1.84	0.51	0.58	0.31	3.16	1.05	1.19
58	28.15	77.4	0.03	3.12	1.99	0.5	0.52	0.4	0.09	0.87	0.83
Average			0.06	4.77	0.91	0.51	0.52	0.17	0.71	0.78	0.61
Max.			0.54	56.48	2.34	0.54	1.16	0.4	3.84	1.35	1.4
Min.			0	0.06	0.02	0.47	0.27	0.02	0.03	0.23	0.16
Std.			0.12	11.98	0.55	0.02	0.15	0.11	0.83	0.22	0.28

Table 2: Heavy metal concentration in groundwater in Palwal district in (post-monsoon season 2015) all the concentration in ppm.

S.no	Long.	Lat.	Mn	Fe	Pb	Cd	Cu	Co	Zn	Ni	Cr
1	28.12	77.4	0.04	0.86	0.4	0.51	0.52	0.36	3.26	0.97	0.03
2	28.14	77.4	0.01	0.67	0.46	0.51	0.48	0.31	0.5	0.94	0.03
3	20.15	77.4	0.01	0.6	0.3	0.49	0.6	0.36	0.01	0.85	0
4	28.14	77.3	0.06	0.82	0.52	0.51	0.48	0.39	0.59	1.08	0
5	28.14	77.3	0	0.66	0.38	0.51	0.49	0.03	0.59	0.8	0.12
6	28.22	77.3	0.16	0.72	0.5	0.5	0.47	0.38	0.48	1.32	0.27
7	28.27	77.3	0.3	0.82	0.52	0.49	0.39	0.35	0.43	0.93	0.21
8	28.27	77.3	0.42	1.4	0.29	0.53	0.48	0.34	1.57	0.83	0.29
9	28.26	77.4	0	0.77	0.42	0.49	0.46	0.4	0.82	0.79	0.23
10	28.22	77.4	0	0.7	0.83	0.49	0.41	0.03	1.57	1.09	0.05
11	28.16	77.4	0.05	1.32	0.34	0.5	0.49	0.36	0.94	0.97	0
12	28.08	77.1	0	0.87	0.06	0.51	0.49	0.36	0.63	0.62	0
13	28.07	77.4	0	0.53	0.1	0.5	0.38	0.39	0.57	1.07	0.09
14	28.04	77	0.11	0.88	0.12	0.49	0.41	0.29	0.58	0.8	0.15
15	28.04	77.4	0.51	1.22	0.55	0.5	0.4	0.38	0.64	1.26	0.07
16	28.03	77.5	0	0.8	0.1	0.5	0.43	0.44	0.53	1.15	0.24
17	27.98	77.5	0.5	0.63	0.63	0.49	0.46	0.34	0.61	0.93	0.08
18	27.95	77.5	0.87	1.19	0.83	0.49	0.32	0.04	0.61	1.25	0.1
19	29.91	77.4	0	0.56	0.06	0.49	0.5	0.4	0.54	1.08	0.43
20	27.9	77.4	0.15	0.6	0.24	0.51	0.49	0.4	0.54	1.1	0.05

21	27.89	77.4	0.04	1.24	0.68	0.5	0.44	0.4	0.51	1.2	0.13
22	27.9	77.4	0	0.81	0.11	0.52	0.36	0.37	0.62	0.6	0.17
23	28.06	77.4	0	0.74	0.69	0.51	0.3	0.48	0.61	1.04	1.64
24	28.04	77.4	0	0.83	1.06	0.49	0.39	0.4	0.53	1.14	0
25	28.01	77.4	0	0.69	0.15	0.51	0.3	0.42	0.44	0.96	0.07
26	27.97	77.4	0	0.52	0.1	0.49	0.42	0.41	1.18	0.72	0
27	27.97	77.4	0.05	0.68	0.26	0.53	0.39	0.43	0.52	1.12	0.13
28	27.97	77.5	0.44	0.68	0.07	0.5	0.43	0.48	1.58	0.64	0
29	28.01	77.5	0	0.68	0.1	0.49	0.44	0.4	0.57	0.73	0.12
30	28.08	77.4	0	0.49	1.41	0.5	0.76	0.39	0.58	0.9	0
31	28.14	77.4	0	0.67	1.84	0.49	0.4	0.44	0.82	0.76	0.26
32	28.15	77.4	0	0.53	0.74	0.5	0.42	0.4	0.6	0.91	0.43
33	28.19	77.3	0.02	0.81	0.46	0.47	0.45	0.38	0.53	0.74	0.4
34	28.21	77.2	0.57	0.55	0.03	0.48	0.34	0.38	0.05	0.81	0.01
35	28.21	77.2	0.03	0.9	0.08	0.49	0.39	0.42	0.59	0.84	0.15
36	28.23	77.1	0.47	0.98	0.1	0.48	0.44	0.47	0.52	0.99	0.59
37	28.2	77.3	0	0.68	0.56	0.48	0.43	0.41	0.61	0.89	0.21
38	28.25	77.3	0	0.77	0.2	0.49	0.32	0.39	0.56	1.08	0
39	28.23	77.3	0.02	0.67	0.34	0.48	0.33	0.5	1.87	1.17	0.53
40	28.23	77.3	0	0.87	0.04	0.47	0.38	0.47	0.81	1.34	0.35
41	28.23	77.3	0.02	0.96	0.1	0.48	0.34	0.42	0.54	0.75	0.67
42	28.23	77.3	0.49	0.8	0.9	0.5	0.36	0.45	1.05	1.06	0.55
43	28.21	77.3	0.04	0.88	1.3	0.48	0.36	0.33	0.6	0.77	0.4
44	28.18	77.3	0	0.94	0.3	0.49	0.33	0.4	0.84	0.8	0.58
45	28.18	77.3	0	0.35	0.39	0.49	0.33	0.41	0.59	1.05	0.39
46	28.15	77.3	0.12	0.59	1.09	0.49	0.27	0.45	0.61	0.94	0.3
47	28.13	77.3	0.01	0.41	0.03	0.57	0.35	0.49	0.57	1	0.55
48	28.14	77.3	0.04	0.66	0.1	0.48	0.32	0.47	0.55	1.23	0.37
49	28.11	77.3	0.04	0.45	0.15	0.48	0.36	0.47	0.82	1.06	0.29
50	28.02	77.3	0.11	1.48	0.66	0.5	0.44	0.36	0.55	1.26	0.29
51	28.02	77.3	0.04	0.06	0.5	0.47	0.37	0.32	0.53	1.14	0.91
52	28	77.3	0.01	0.78	0.25	0.49	0.39	0.38	0.56	0.82	0.38
53	28.02	77.3	0.01	0.34	0.1	0.49	0.39	0.39	0.55	0.88	0.06
54	28.39	77.2	0.01	0	0.1	0.49	0.38	0.48	0.62	1.02	0.32
55	28.06	77.2	0.33	0.8	0.22	0.49	0.43	0.47	1.19	1.23	0.41
56	28.07	77.3	0.01	0.9	0.1	0.48	0.28	0.44	0.56	0.79	0.25
57	28.09	77.3	0.01	0.09	1.01	0.48	0.32	0.44	1.5	1.12	0.44
58	28.15	77.4	0.17	0.07	0.2	0.49	0.33	0.38	1.36	0.53	0.78
Average			0.11	0.72	0.42	0.49	0.41	0.38	0.75	0.96	0.27
Max.			0.87	1.48	1.84	0.57	0.76	0.5	1.87	1.34	1.64
Min.			0	0	0.03	0.47	0.27	0.03	0.01	0.53	0
Std.			0.22	0.32	0.43	0.02	0.09	0.1	0.38	0.2	0.33

Table 3: Average heavy metal concentration in groundwater in Palwal district (all the concentration in ppm)

S.no	Long.	Lat.	Mn	Fe	Pb	Cd	Cu	Co	Zn	Ni	Cr
1	28.12	77.43	0.04	1.18	0.53	0.50	0.35	0.20	3.42	0.73	0.44
2	28.14	77.38	0.01	1.01	0.33	0.49	0.37	0.18	0.39	0.76	0.12
3	20.15	77.36	0.01	0.33	0.44	0.48	0.45	0.21	0.18	0.54	0.32
4	28.14	77.34	0.06	0.80	0.63	0.50	0.37	0.23	0.31	0.90	0.39
5	28.14	77.34	0.02	0.36	1.03	0.50	0.40	0.04	0.50	0.72	0.37
6	28.22	77.30	0.14	1.78	0.60	0.51	0.38	0.21	0.46	1.00	0.30
7	28.27	77.29	0.20	1.12	0.69	0.50	0.36	0.19	0.23	0.67	0.29
8	28.27	77.31	0.21	1.25	0.48	0.51	0.39	0.20	0.98	0.68	0.36
9	28.26	77.35	0.00	0.69	0.36	0.49	0.42	0.22	0.65	0.71	0.21
10	28.22	77.44	0.01	3.11	0.47	0.49	0.42	0.04	1.64	0.82	0.11
11	28.16	77.44	0.03	3.92	0.18	0.50	0.45	0.21	1.00	0.92	0.44
12	28.08	77.14	0.00	1.08	0.16	0.50	0.47	0.19	0.57	0.58	0.11
13	28.07	77.42	0.01	0.68	0.56	0.49	0.44	0.24	0.97	0.85	0.19

14	28.04	77.04	0.26	11.99	0.66	0.49	0.44	0.16	0.87	0.69	0.23
15	28.04	77.44	0.34	1.31	0.78	0.50	0.42	0.24	0.71	1.08	0.39
16	28.03	77.45	0.01	0.72	0.67	0.50	0.47	0.26	0.29	0.82	0.34
17	27.98	77.49	0.25	5.86	0.67	0.48	0.81	0.20	1.11	0.77	0.31
18	27.95	77.47	0.70	28.84	0.92	0.50	0.44	0.07	2.22	1.02	0.42
19	29.91	77.44	0.04	1.00	0.90	0.50	0.49	0.24	0.56	0.96	0.30
20	27.90	77.42	0.09	1.29	0.48	0.51	0.51	0.23	0.54	0.79	0.12
21	27.89	77.38	0.04	1.25	0.71	0.50	0.49	0.26	0.52	1.00	0.35
22	27.90	77.38	0.00	1.46	0.13	0.52	0.43	0.27	0.62	0.51	0.31
23	28.06	77.35	0.01	3.17	0.52	0.51	0.43	0.27	0.60	0.87	1.17
24	28.04	77.37	0.00	2.07	0.84	0.49	0.45	0.24	0.66	0.92	0.30
25	28.01	77.40	0.00	0.93	0.31	0.50	0.40	0.30	0.24	0.79	0.25
26	27.97	77.41	0.02	1.60	0.63	0.49	0.47	0.29	0.89	0.63	0.28
27	27.97	77.44	0.04	1.02	0.37	0.52	0.46	0.26	0.53	0.84	0.37
28	27.97	77.46	0.22	3.22	0.75	0.49	0.48	0.34	1.59	0.59	0.24
29	28.01	77.45	0.01	1.20	0.68	0.49	0.46	0.29	0.62	0.64	0.38
30	28.08	77.40	0.00	1.00	1.48	0.49	0.71	0.25	0.60	0.92	0.27
31	28.14	77.37	0.01	3.15	1.41	0.50	0.45	0.32	1.13	0.80	0.70
32	28.15	77.35	0.00	0.98	0.62	0.50	0.46	0.21	0.59	0.89	0.44
33	28.19	77.25	0.03	6.78	0.77	0.49	0.52	0.24	0.66	0.90	0.49
34	28.21	77.18	0.29	3.34	0.22	0.50	0.48	0.31	0.40	0.79	0.32
35	28.21	77.17	0.04	0.94	0.49	0.49	0.46	0.30	1.07	0.87	0.28
36	28.23	77.13	0.31	1.57	0.61	0.51	0.48	0.37	0.31	0.93	0.61
37	28.20	77.26	0.04	2.91	0.63	0.51	0.55	0.33	0.80	0.95	0.45
38	28.25	77.30	0.07	2.14	0.13	0.51	0.47	0.33	0.36	1.06	0.38
39	28.23	77.29	0.02	24.50	0.52	0.51	0.47	0.39	1.47	1.10	0.57
40	28.23	77.31	0.15	1.33	0.33	0.51	0.43	0.37	0.65	1.14	0.49
41	28.23	77.29	0.11	1.33	0.43	0.49	0.48	0.34	0.51	0.75	0.66
42	28.23	77.29	0.28	3.22	0.64	0.51	0.49	0.35	0.55	1.04	0.62
43	28.21	77.31	0.03	0.89	0.94	0.51	0.46	0.28	0.32	0.78	0.55
44	28.18	77.33	0.04	1.27	0.58	0.50	0.48	0.36	0.44	0.92	0.59
45	28.18	77.32	0.01	0.70	0.55	0.51	0.45	0.33	0.32	1.07	0.74
46	28.15	77.33	0.09	0.90	1.18	0.51	0.40	0.35	0.77	0.89	0.36
47	28.13	77.34	0.01	1.79	0.23	0.55	0.48	0.38	0.55	0.91	0.36
48	28.14	77.33	0.04	0.69	0.47	0.50	0.46	0.36	0.30	1.09	0.88
49	28.11	77.33	0.06	1.04	0.75	0.49	0.57	0.37	0.44	0.88	0.41
50	28.02	77.33	0.06	1.10	1.50	0.52	0.52	0.34	0.30	1.20	0.60
51	28.02	77.32	0.23	0.85	0.94	0.50	0.46	0.35	0.29	1.10	0.85
52	28.00	77.29	0.01	1.28	0.63	0.50	0.49	0.33	0.30	0.89	0.45
53	28.02	77.27	0.02	1.63	0.96	0.50	0.41	0.35	0.30	0.90	0.44
54	28.39	77.23	0.01	1.54	0.76	0.50	0.50	0.41	0.59	0.92	0.63
55	28.06	77.24	0.20	2.17	0.80	0.50	0.46	0.40	0.88	1.29	0.58
56	28.07	77.25	0.01	1.50	0.89	0.49	0.40	0.37	0.54	0.91	0.64
57	28.09	77.26	0.03	2.93	1.42	0.49	0.45	0.37	2.33	1.08	0.82
58	28.15	77.35	0.10	1.59	1.09	0.50	0.42	0.39	0.72	0.70	0.80
Average			0.09	2.75	0.66	0.5	0.5	0.28	0.73	0.87	0.437
Max.			0.7	28.8	1.5	0.55	0.8	0.41	2.33	1.29	1.174
Min.			0	0.33	0.13	0.48	0.4	0.04	0.18	0.51	0.107
Std.			0.15	6.03	0.34	0.01	0.1	0.09	0.49	0.17	0.23

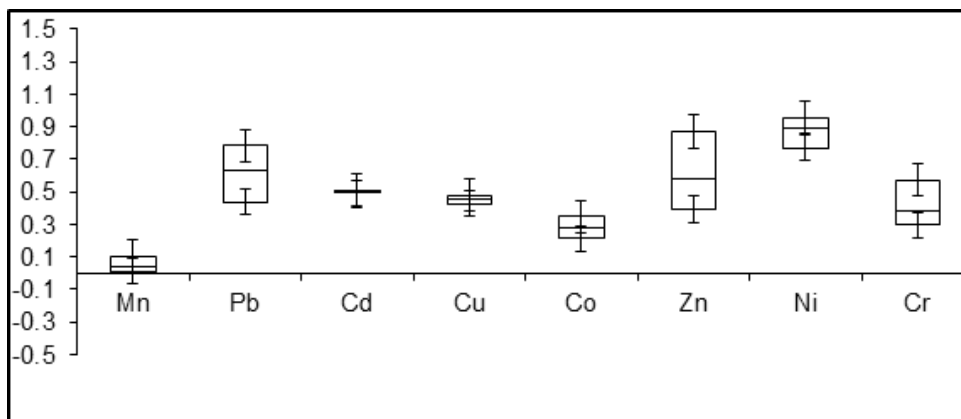


Figure 2: Mean, maximum, minimum and standard deviation of the metal concentrations (ppm) in groundwater in Palwal district.

The average concentration range of heavy metal in groundwater indicates that except Fe, the concentrations for most of the metals range from 0.1ppm for Mn and maximum 0.8 ppm for the Ni. The highest variation is observed for the Zinc and lowest for the Cadmium concentration in groundwater (Fig. 2). It is also observed that most of the samples showing high concentrations of metals against the acceptable standards. A marked variation is observed for the Co and Fe during post-monsoon and impact groundwater quality with season.

Table 4: Samples within Heavy Metal Permissible Limit (ISI).

Heavy metals (ppm)	Mn	Fe	Pb	Cd	Cu	Co	Zn	Ni	Cr
Standard permissible value in ppm	0.3	1	0.05	0.1	1.5	0.3	15	0.3	0.3
Sample over the standard permissible value Pre-monsoon	4	48	56	58	0	8	0	57	49
Sample over the standard permissible value Post-monsoon	9	6	46	58	0	54	0	58	20

In the Comparative study with the other neighboring districts, the average heavy metal content in groundwater was found near the same range (Table. 5). Liberal guidelines and governance by pollution management authority and hydrogeological regimes result in higher levels of heavy metal.

Table 5: Comparison of Heavy metal concentration in groundwater from the nearby areas (all the values in ppm).

	Cd	Cr	Cu	Mn	Ni	Zn	Co	References
Delhi	0.01-0.07	0.01-0.09	0.0-0.08					Agarwal 2014
Ghaziabad	0.019-0.128	0.299-1.143	0.0476-2.037	3.36-62.54		0.013-0.318		Agarwal et. al, 2016
Palwal	0.478-0.545	0.106-1.1735	0.352-0.8115	0.0-0.702	0.506-1.288	0.183-3.42	0.0154-0.409	Present study
Bareilly	0.06-0.303	0.003-1.331	0.011-0.305	0.011-1.36	0.247-1.246	0.75-2.245	0.011-0.624	Nigar et.al,2019
Aligarh	0.00-0.48	0.00-0.33	0.00-0.19	0.00-0.26		0.01- 1.84		Agarwal, 2014
Kanpur	0.001-0.054	0.060-0.085	0.012-0.045		0.01-0.044	0.095-0.380		Agarwal et al., 2016

The impact of seasonal changes on mobilization of metal in groundwater is determined using pH and total metal content in groundwater during pre-and post-monsoon period (Fig. 3).

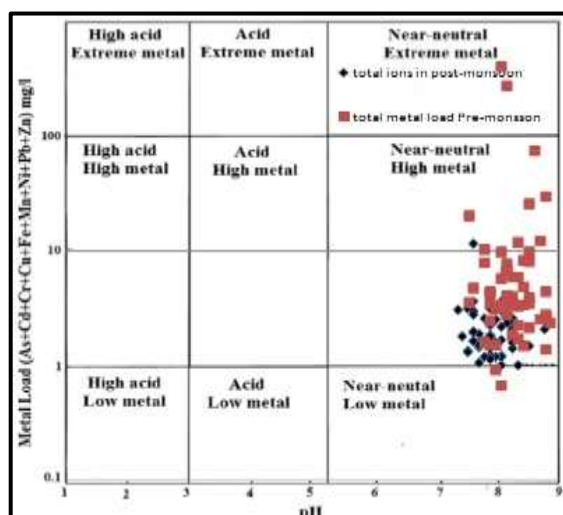


Figure 3: Relationship between pH and total metal load (ppm) in groundwater in Palwal region.

It indicated that the groundwater is characterized by a high concentration of metal content during the post monsoon due to resulting from groundwater recharge along with another pollutant body. The higher concentration of metal observed in post-monsoon is because of movements of metal directly in underground water. The 58 groundwater samples were collected from different locations show seasonal variation in their characteristics during pre-monsoon (June) and post-monsoon (November) in the study area. In the pre-monsoon, average abundance value of metals as Fe > Pb > Ni > Zn > Cr > Cd > Cu > Co > Mn while Ni > Zn > Fe > Cd > Cu > Pb > Co > Cr > Mn in post-monsoon time. The heavy metal behavior was studied based on the variation for the different land use and aquifer type (Table 6). The order of abundance of heavy metals concentrations in shallow are Fe > Pb > Ni > Zn > Cr > Cu > Cd > Co > Mn and Ni > Zn > Fe > Cd > Cu > Co > Pb > Cr > Mn for pre-monsoon and post-monsoon, respectively. In addition, the order of abundance of heavy metals concentrations in deep aquifer are Fe > Pb > Ni > Zn > Cu > Cd > Cr > Co > Mn and Ni > Fe > Zn > Cd > Pb > Cu > Co > Cr > Mn for pre-monsoon and post-monsoon, respectively. The impact of recharge on the ground in different land use and cover shows the dramatic change in heavy metal concentration in rural areas. In this category, Fe is dominated in pre-monsoon while in post-monsoon dominated by Co.

Table 6: Order of abundance of heavy metals in groundwater in pre and post-monsoons and for the different land use and type of aquifer.

Area type	Pre-monsoon	Post-monsoon
Average	Fe>Pb>Ni>Zn>Cr>Cd>Cu> Co>Mn	Ni>Zn>Fe>Cd>Cu>Pb>Co>Cr>Mn
Shallow Aquifer	Fe>Pb>Ni>Zn>Cr>Cu>Cd>Co>Mn	Ni>Zn>Fe>Cd>Cu>Co>Pb>Cr>Mn
Deep Aquifer	Fe>Pb>Ni>Zn>Cu>Cd>Cr>Co>Mn	Ni>Fe>Zn>Cd>Pb>Cu>Co>Cr>Mn
Industrial Area	Fe>Ni>Zn>Cr>Cu>Cd>Pb>Co>Mn	Ni>Zn>Fe>Cr>Pb>Cd>Co>Cu>Mn
Rural Area	Fe>Zn>Pb>Ni>Cd>Cu>Co>Cr>Mn	Ni>Zn>Fe>Cd>Cu>Pb>Co>Cr>Mn
Pei urban Area	Fe>Pb>Ni>Cr>Zn>Cu>Cd>Co>Mn	Ni>Zn>Fe>Cd>Co>Cu>Pb>Cr>Mn
Urban area	Fe>Pb>Ni>Cr>Cd>Zn>Cu>Co>Mn	Ni>Fe>Pb>Zn>Cd>Cu>Co>Cr>Mn

4.1 Elemental alliances

The correlation matrix was derived from determining the familiar sources and the association of heavy metals. Based on the correlations, the matrix identifies the highest significant correlation numbers were found in the pre-monsoon season for the Fe-Mn, Zn-Fe, Cd-Co, and Co-Cr (Table 7). However, a more significant mixing of the groundwater during post-monsoon seasonal recharge is responsible for the disappearing of these alliances in the post-monsoon season. These relationships were showing more significant for deepwater samples than shallow water samples. The higher number of deepwater alliances suggests a greater level of mixing of recharge water at a deeper level than in shallow groundwater aquifer. A comparative analysis of the alliances concerning different landuse cover has been an attempt. It is found that high level of alliances with Fe- Zn, Co in urban areas compared to rural and industrial areas. The Cd alliance with other elements is found in the peri-urban area in the pre-monsoon period.

Table 7: Correlation matrix among dissolved heavy metals in groundwater and HPI of the samples.

Pre- monsoon										
	Mn	Fe	Pb	Cd	Cu	Co	Zn	Ni	Cr	HPI
Mn	1.00									
Fe	0.49	1.00								
Pb	0.10	-0.02	1.00							
Cd	0.23	0.14	0.09	1.00						
Cu	0.00	0.18	0.12	0.20	1.00					
Co	0.08	-0.03	0.41	0.59	0.39	1.00				
Zn	0.25	0.50	0.01	-0.18	-0.01	-0.21	1.00			
Ni	0.14	0.11	0.32	0.57	0.34	0.67	-0.10	1.00		
Cr	0.04	0.04	0.30	0.31	0.15	0.52	0.10	0.50	1.00	
HPI	0.23	0.25	0.95	0.13	0.18	0.43	0.16	0.39	0.43	1.00
Post - monsoon										
	Mn	Fe	Pb	Cd	Cu	Co	Zn	Ni	Cr	HPI
Mn	1.00									
Fe	0.30	1.00								
Pb	0.04	0.05	1.00							
Cd	-0.02	0.13	-0.10	1.00						
Cu	-0.07	0.12	0.13	0.17	1.00					
Co	-0.20	-0.19	-0.19	-0.02	-0.18	1.00				
Zn	0.03	0.02	0.06	0.07	0.04	-0.01	1.00			
Ni	0.13	0.13	0.11	-0.03	-0.08	0.04	-0.03	1.00		
Cr	-0.08	-0.19	0.05	-0.10	-0.40	0.28	0.02	0.06	1.00	
HPI	0.05	0.00	0.97	-0.18	0.02	-0.11	0.05	0.15	0.27	1.00

4.2 Spatio-Temporal Change in Heavy Metal Concentration

The groundwater is the mixtures of various metal concentrations, and their percentage varies according to sources of anthropogenic activities. Different processes suggested metal concentrations in groundwater, but some are spatially distributed and fluctuated in groundwater. Based on this assemblage of heavy metal contained in groundwater has a high concentration of Zinc, Nickel, Manganese, Cadmium, Copper, Cobalt, Chromium due to anthropogenic activities and waste from vehicles, repair shops, galvanising and sewage runoff units, household waste (Sirajudeen et al., 2012, Virha et al., 2010, Bharti et al., 2013, Ravichandaran and Jayaprakash, 2011; Thomas et al., 2011).

4.3 Cadmium

The primary source of cadmium on land in the study area was found near Hodal, Bamnikhera and Pirthla. It is considered an area affected by effluents of industries connected with electroplating, Copper, Nickel alloy, paint nickel-cadmium batteries etc. Cd concentration in the groundwater ranges from 0.50 to 0.55ppm with an average of 0.47 to 0.54ppm in the pre-monsoon period and ranging from 0.47 to 0.57ppm in the post-monsoon period. The higher concentrations of cadmium were found in the study area's central and southeast direction (Fig. 4).

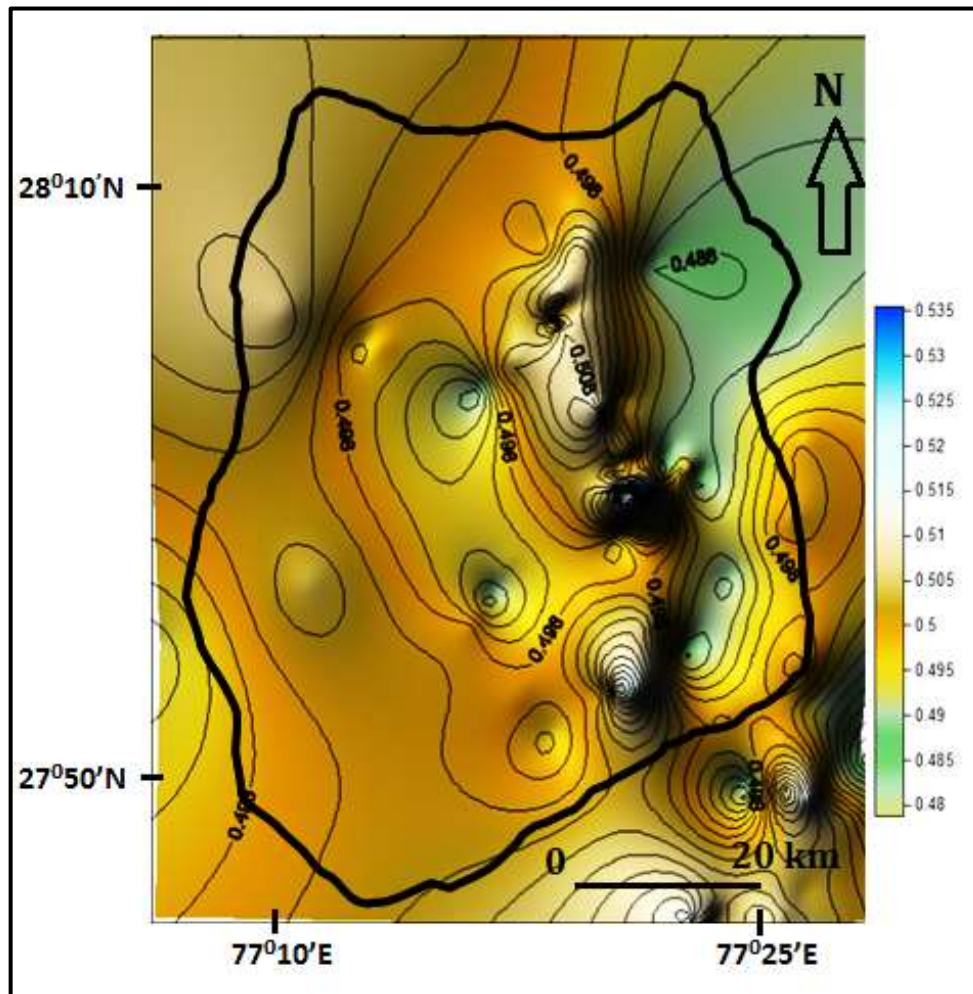


Figure 4: Spatial distribution of the average concentration of Cd (ppm) in the groundwater.

All groundwater samples were taken during the pre-and post-monsoon period showing over the standard permissible limit. A high concentration of cadmium causes adverse effects on the human body. Cadmium has been associated with hypertension and cardiovascular and Itai disease (Schroeder, 1965). Itai disease is characterized by decalcification of bones, significant harmful effects of the human body caused the kidney, liver, and blood damage.

4.4 Zinc

Zinc's primary input to water results from erosion of soil particles containing natural traces of Zinc and major industrial sources of Zinc are including electroplating, smelting, and ore processing (Mirend, 1986). Zn plays a vital role in enzymatic function, protein synthesis, and carbohydrate metabolism (Tylor and Demayo, 1980). It also helps in cell division and growth of cells. The Zn is relatively non-toxic; however, concentration up to 25 mg/l shows few adverse effects (McNeely et al., 1979) deficiently in the results in infantilism and the impaired world (Underwood, 1971). The concentration of Zinc in the study area varies from 0.03 to 3.84 ppm in pre-monsoon and 0.01 to 1.84 ppm in the post-monsoon period. The average concentration ranges from 0.18 to 2.33 ppm. All these samples were collected during the pre and post-monsoons period fall below the standard permissible limit. The Zinc enriches the central-eastern region of the study area close to the Yamuna River (see Fig. 5). The use of ZnSO₄ as a micronutrient to cultivate the crops, especially rice and wheat, owing to the no adsorption of the Zn and reflects its high concentration and less electronegativity than the other elements in the study area. The sample collecting from deep hand pumps shows less zinc concentration than shallow hand pumps and ponds. The primary source of Zinc in the deep zone is likely to be from natural sources as they are clay beds in the intervening layers, which prevent the effects of local pollution.

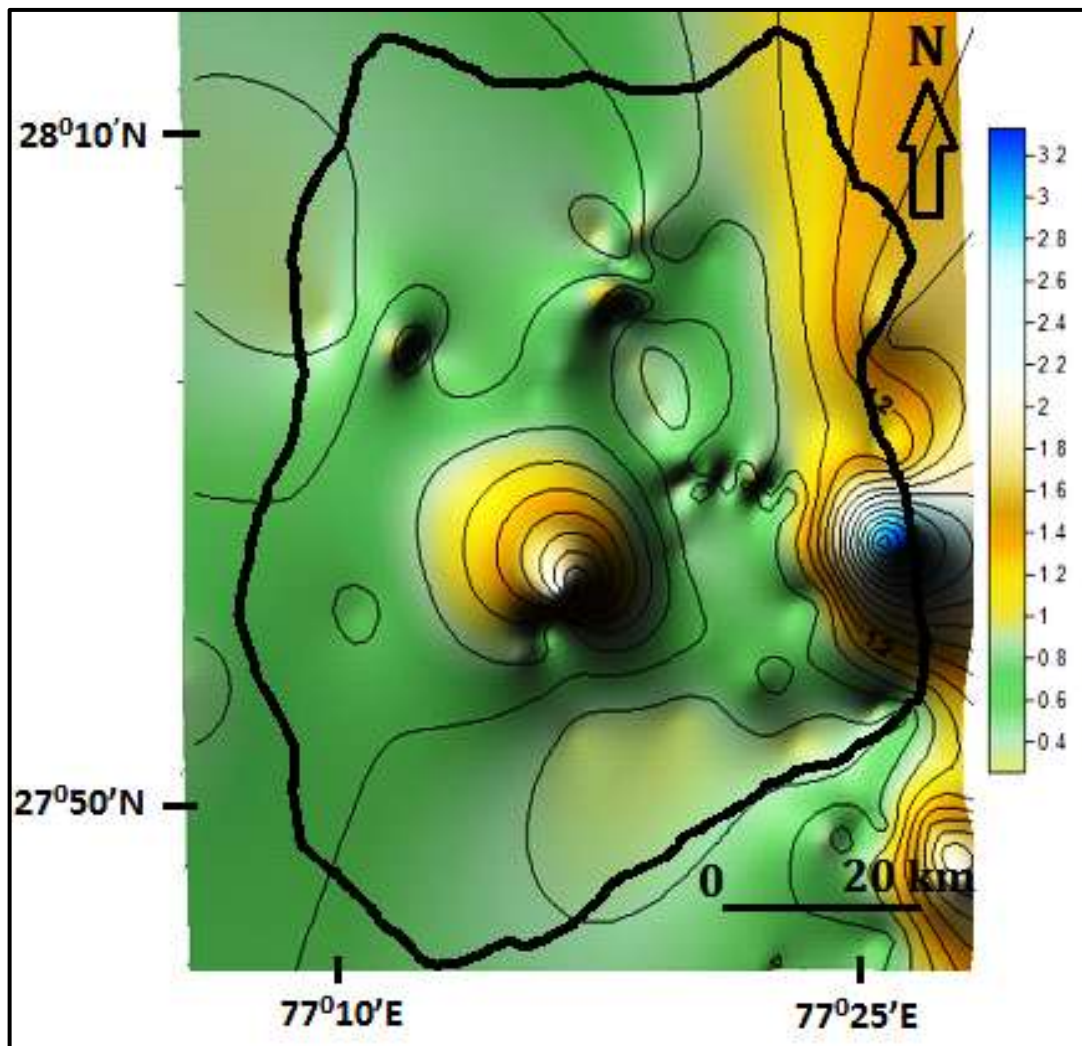


Figure 5: Spatial distribution of the average concentration of Zn (ppm) in the groundwater.

4.5 Cobalt

Natural sources of Cobalt in the environment include volcanic eruption, seawater spray and forest fire. However, anthropogenic cobalt sources to the atmosphere include coal-fired power plants and incinerators and exhaust from vehicles. The production of alloy and chemicals containing Cobalt, sewage effluent, urban runoff, and agriculture runoff is a major anthropogenic contributor of Cobalt to the aquatic environments. Cobalt has also been shown to enhance the growth of some plants at low concentrations. Higher concentration of Cobalt is toxic to humans and terrestrial and aquatic animals and plants. The concentration of Cobalt in groundwater of the study area ranges from 0.04 to 0.41 ppm with an average of 0.17 ppm in the pre-monsoon period and ranges from 0.03 to 0.50 ppm in the post-monsoon period showing a mean value of 0.38 ppm. The spatial variation of average concentration indicates the higher concentration in the north and central parts of the study area. It is found that the cobalt concentration is much higher in the post-monsoon period than the permissible limit. However, most of the samples were found under the permissible limit in the pre-monsoon period. Higher Cobalt concentrations were found in urban and peri-urban areas near Palwal city in the post-monsoon period (Fig. 6). The higher concentration of Cobalt in the study area was found in Bamnikhera, Aurangabad, Kondal, Manpur, Pahari, Baghola and Patikalan. The primary source of Cobalt in the study is considered as the municipal wastes generated in the densely populated parts and dumping locations of untreated waste of industrial plants situated in an adjacent.

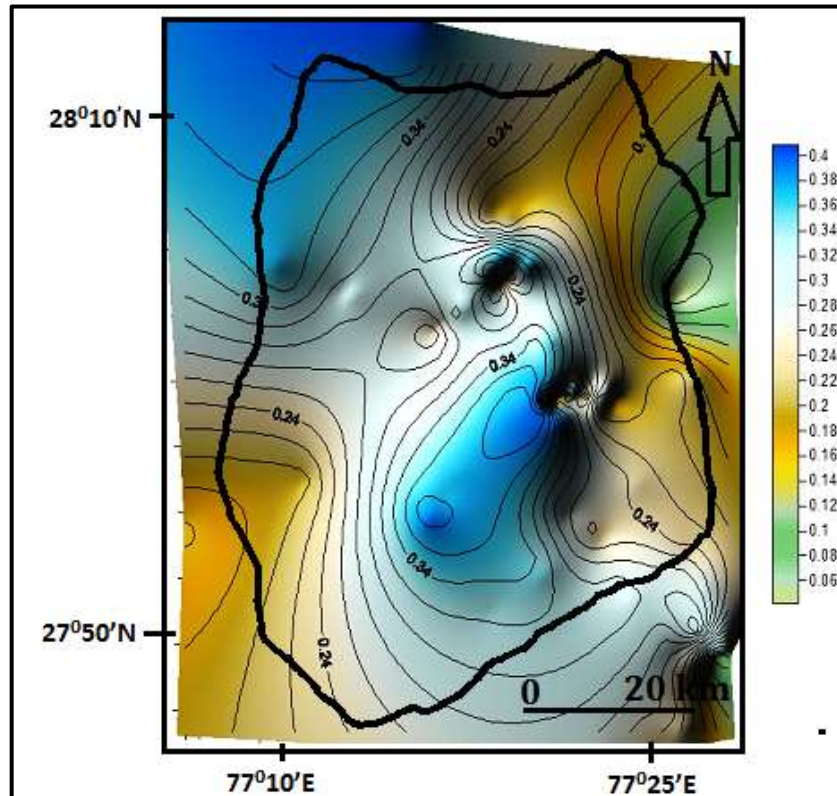


Figure 6: Spatial distribution of the average concentration of Co (ppm) in the groundwater

4.6 Chromium

Chromium in the study area is extensively used in the metallurgical industry to manufacture various alloys and steels. It is also used in electroplating, pigments, tanneries, photographic material, wood preservation and corrosion inhibitors. (Kakar and Bhotnegar, 1981;1983) and (Kakar and Janeshwar, 1981) have reported a higher Chromium level due to pollution from electroplating wastes. The chromium concentration in the groundwater ranges 0.11 to 1.17ppm, with an average of 0.16 in the pre-monsoon period and 0.001 to 1.64 in the post-monsoon period with a mean of 0.27 ppm. It indicates that the spatial distribution map of average Cr concentrations is highest in Ottawa town's central urban regions. (Fig. 7).

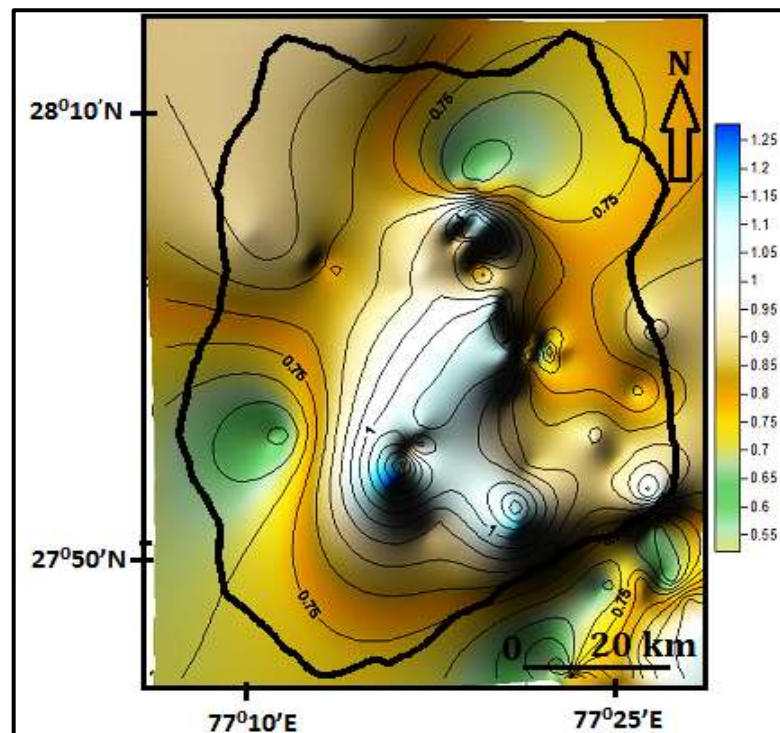


Figure 7: Spatial distribution of the average concentration of Cr (ppm) in the groundwater.

Higher-level Chromium has been observed in the southeast and the central side adjacent to Yamuna River in this study area named as Prithla, Seekri, Pahari, Manpur and Banchari near Hodal. The high concentration of Chromium in groundwater is also due to the percolation of the Yamuna canal's highly polluted water covering large parts of the area.(Fig. 8)



Figure 8: Pollution in Yamuna River (near Gori, Palwal) leads to heavy metal pollution of groundwater.

4.7 Copper

It is an essential micronutrient for all life forms on Earth's land, particularly for plants and human kinds. However, the high concentration of Copper creates hazardous effects on humans and their surrounding environments. It causes stomach and intestinal disease, liver and kidney damage and anemia. Impact on adverse taste and significant, staining to cloth and fixture, and toxic to plants and damage the algae at moderate land and toxic to aquatic life and broad scale. The average of copper concentration in the study area ranges from 0.36 to 0.81ppm and 0.52 ppm in the pre-monsoon period and ranges from 0.27 to 0.76 ppm with 0.41 ppm post-monsoon period. Spatial distribution of average concentration of Copper indicated that a large part of the area shows the lower concentration in the southwest and northeast of the study area (Fig. 9). The lower concentration zone is surrounding the high concentration zone of central Palwal city. All these samples were collected during the pre and post-monsoon period fall below the standard permissible limit (1.5 mg/L; BIS,1991; WHO, 1993).

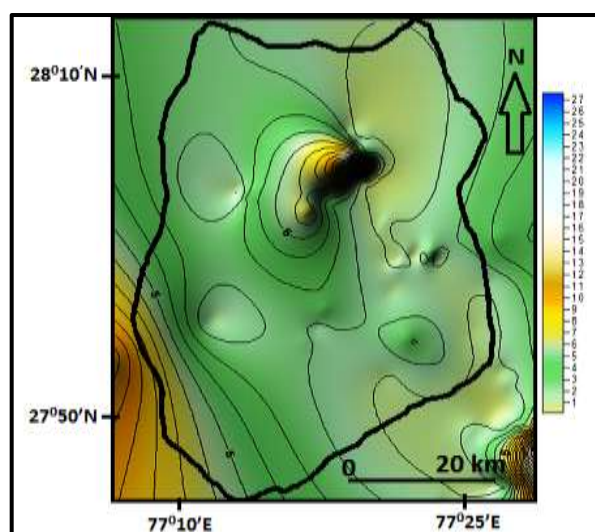


Figure 9: Spatial distribution of the average concentration of Cu (ppm) in the groundwater.

4.8 Iron

It is essential for humans, animals and other living beings, and it is found naturally in freshwater with the range from 0.5 to 50 mg/L (WHO, 1994). The high amount of Fe in groundwater caused bad taste discoloration, staining turbidity and operation problem (Kalicharan, 2007). Fe's major anthropogenic source includes influences from

industries that are manufacture of steel and Iron, and metal plants, and corrosion of pipe and pumps which extent the concentration of Fe in the equalizer water. The concentration of Fe in groundwater ranges from 0.33 to 28.84 (with an average value of 4.77 ppm) in the pre-monsoon period and from 0.002 to 1.48 ppm (0.72 ppm) in the post-monsoon.

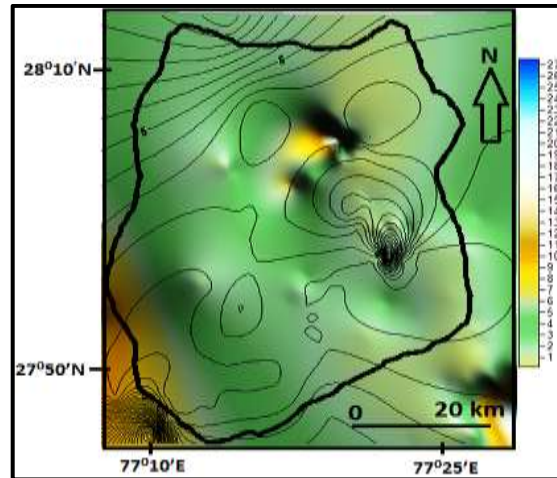


Figure 10: Spatial distribution of the average concentration of Fe (ppm) in the groundwater.

It is found that 48 samples of groundwater out of 58 total samples during the pre-monsoon period show over the desirable limit, but 6 samples in the post-monsoon period are showing the concentration more than desirable limit as per (WHO, 2011; BIS, 2012). The higher permissible limit of Iron was observed in most of the samples in Hasanpur and Prathala. Spatial distribution of the Fe concentration in groundwater, indicating that most parts of the central area are characterized by lower concentration (Fig. 5.8). The highest concentration is found in the industrial area between Palwal and Faridabad as a hot spot in the background of low iron content groundwater. The highest concentration is found in most of the southeastern parts near the Kosi Klan near the Yamuna River.

4.9 Manganese

Manganese plays a significant role in plants and animals, but its higher concentration is undesirable for all kinds of uses (Ballukraya and Ravi, 1999). However, the excess creates a problem with the neurological system (Anon, 1977); it is considered as one of the most toxic elements when its amount increase in groundwater thus can cause growth retardation, fever, fatigue, and eye blindness and affects the reproduction system in human (Tiwari, 2012). Mn's concentration in the groundwater of the area ranges from 0.00 to 0.70 ppm with an average of 0.06 ppm in the pre-monsoon period and ranges from 0.001 to 0.87 ppm with an average of 0.11 ppm in the post-monsoon season. Spatial distribution indicated that most of the region's central part is characterised by a low Mn concentration. Moderate Mn concentrations in groundwater characterise the groundwater in the western part of the study area. However, the southeastern part of the study area is influenced by the Yamuna River draining through Delhi –Faridabad industrial area (Fig. 11).

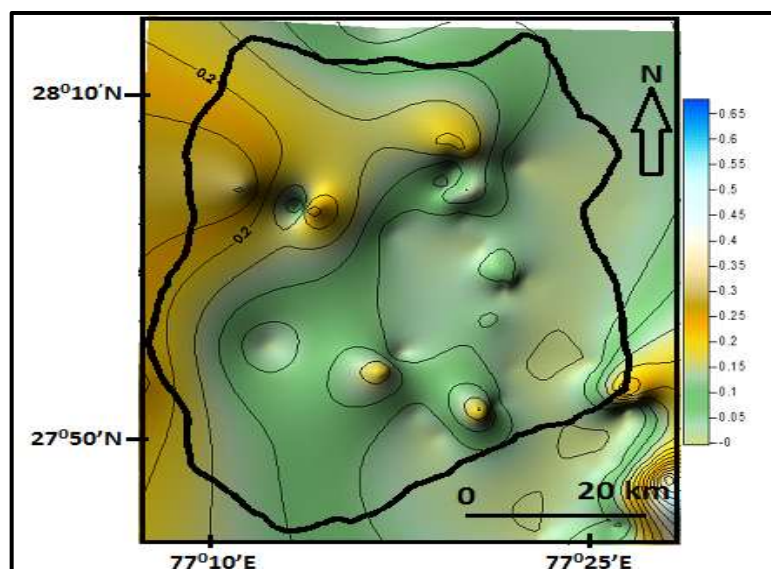


Figure 11: Spatial distribution of the average concentration of Mn (ppm) in the groundwater.

4.10 Nickel

The Nickel is not the naturally occurring element in the earth's crust but is associated with some other metallic elements. Nickel's high concentration in groundwater creates toxic problems in human and animal kinds like lung cancer that affects the T-cells and kills other essential cells in the human body. Nickel toxicity is associated with nausea, vomiting, headache, giddiness etc. (Brazilay, 1999). Repeated inhalation of Ni compound may cause lungs cancer (Mc Neely et al., 1979). Nickel concentrations range from 0.51 to 1.29 ppm with an average of 0.78 ppm during pre-monsoon and 0.53 to 1.34 ppm (0.96 ppm) in the post-monsoon period. Spatial distribution of Ni concentration in groundwater indicated higher concentration in the central urban part of the study area with the highest value in the Uttatwar region. Ni's distribution pattern in groundwater shows the concentric pattern originating from an urban area and moving further away (Fig. 12).

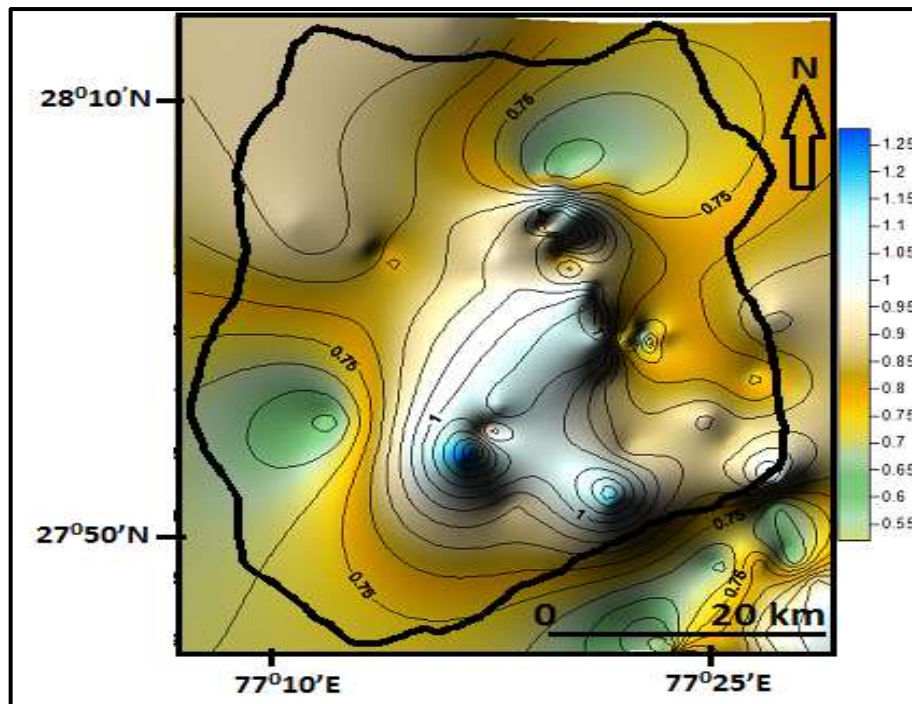


Figure 12: Spatial distribution of the average concentration of Ni (ppm) in the groundwater.

4.11 Lead

Lead is a natural element associated with Zn in the earth's crust and releases in a small amount after watering and erosion of these rock acts as the source of groundwater pollution. The anthropogenic activities like effluents of industrial waste of paints product, storage batteries, printing and dyeing impurities of fertilizer pesticide and insecticide play an essential role in groundwater pollution. The high concentration of Pb in groundwater is a very toxic metal and tends to accumulate into bone skeletal and tissue of men and animals. Lead poisoning causes intestinal cramps, nervous system, anemia, rise in body pressure, irritation, vomiting, etc. The ingestion of lead causes loss of appetite, fatigue, irritation, headache and vomiting (Stephen, 1992) is also a causative factor of hypertension in humans over a large scale.

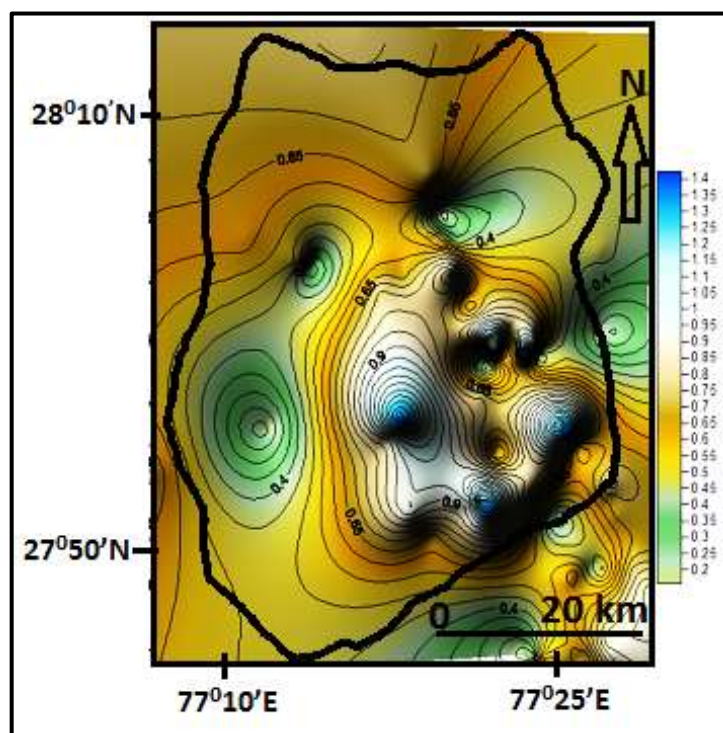


Figure 13: Spatial distribution of the average concentration of Pb (ppm) in groundwater.

Pb concentration ranges from 0.13 to 1.50 ppm, with an average of 0.91 ppm in pre-monsoon and 0.03 to 1.84 ppm with an average of 0.42 ppm in the post-monsoon period. Spatial distribution of average Pb concentration in groundwater shows high concentration at a few points in the study area's central part. These areas are namely, e.g., Gehlab (Hathin), Banchari (Hodal), and Chajju Nagar (Bamdila), Firozpurmisa (Palwal). The distribution pattern indicates the higher concentration in the central part of the study area and decreases as it moves away from the urban areas (see Fig. 13).

4.12 Heavy metal pollution index

The heavy metal index was evaluated the overall pollution content in groundwater. The average HPI in the study area is 55.7, and the highest (86) and lowest values are represented by sample nos. 57 and 12, respectively. The seasonal change in HPI indicated higher average values (66) in pre-monsoon than 44 in the post-monsoon season. In general, a decrease is observed in most cases due to dilution by monsoonal recharged groundwater. However, samples no. 2, 23, 24, 31, 32, 42 and 43 indicate the increase in HPI in the post-monsoon season due to dissolution and mobilization of metal from the surface to the groundwater. The relationship between land use type averages HPI of groundwater has been studied. Samples collected from peri-urban areas have the highest HPI compare to city, urban and industrial areas. A significant level of correlation has been observed between HPI and Pb concentrations for the samples collected in pre and post-monsoon season shown in (Table 7).

5. CONCLUSIONS

The heavy metal analysis in groundwater samples in parts of the trans-Yamuna aquifer in Pawal district inferred the excess concentration of heavy metal in most locations against permissible limits. The concentration ranges from 0.001 to 0.8 ppm for most of the metal except Iron. The highest variation in concentration is observed for the Zn and minimal variation for the cadmium in groundwater. A marked increase in the concentration of Co and Fe concentration and decrease the groundwater quality during post-monsoon. The abundances of metals in groundwater are Fe > Pb > Ni > Zn > Cr > Cd > Cu > Co > Mn and Ni > Zn > Fe > Cd > Cu > Pb > Co > Cr > Mn for pre and post monsoons, respectively. A significant change in the order of abundance of various elements is observed in rural areas. The correlation matrix indicated a significantly good relationship among deep groundwater samples in pre-monsoon than the samples in post-monsoon season. The highest level of correlation was found in the sample from the urban area. A general trend of heavy metal concentration is showing the concentric zonal distribution in the study area. The high concentration is found near the urban-rural fringe in industrial areas and decreases further in the outer part.

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