academicJournals

Vol. 5(7), pp. 380-386, July 2013
DOI: 10.5897/IJWREE2012.0408
ISSN 2141-6613 © 2013 Academic Journals
http://www.academicjournals.org/SRE

International Journal of Water Resources and Environmental Engineering

Full Length Research Paper

Study of major and trace elements in groundwater of Birsinghpur Area, Satna District Madhya Pradesh, India

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Accepted 4 June, 2013

The present paper deals with major and trace elements geochemistry from the groundwater of Birsinghpur area, Satna district, Madhya Pradesh, India. Geologically, the area comprises sandstone and shale formations of the Proterozoic Upper Vindhyan Supergroup. The study reveals that the water is hard to very hard (The classification as hard to very hard is possibly based on incorrect analytical data); the elevated hardness is attributed to the calcareous nature of the aquifer. The concentrations of cations are characterized by Ca >Mg> Na> K. Elevated concentrations of calcium (possibly incorrect analytical data) in some localities are related to the aquifer lithology. Concentrations of magnesium, sodium and potassium are generally within the permissible limits. The concentration of anions are characterized by HCO_3 > SO_4 > Cl > NO_3 >F. Bicarbonate and sulphate concentrations exceed the permissible limits in a few samples; elevated concentrations appear to be related to the aquifer lithology. The fluoride concentration exceeds the desirable limit in some areas; the elevated fluoride values are attributed to the application of chemical fertilizers in agriculture and to the occurrence of fluoride bearing minerals in shale formation. Six trace elements (Fe, Cu, Ni, Pb, Mn, Cd) were also analysed. The iron concentrations ranged from 0.27 to 2.98 mg/L, exceeding the permissible limit in drinking water in 4% of the samples mainly in lateritic aquifers Nickel, and cadmium concentrations are well within the permissible limits. The manganese concentrations ranged from 0.20 to 0.282 mg/L, 30% of the samples exceeding the desirable limit: the elevated manganese concentrations are associated with iron ores (?) as well as lateritic mining. The elevated concentrations of trace elements are combined effects of geogenic sources as well as of mining activities and excessive use of chemical fertilizers. It is recommended to control anthropogenic activities adequately in order to minimise the pollution problems.

Key words: Major and trace elements, groundwater, Birsinghpur, Satna, Madhya Pradesh, India.

INTRODUCTION

Water is one of the most vital resources for the sustenance of human, plants and other living beings. It is required in all aspects of life and health for producing food, agricultural activity and energy generation. Groundwater is rarely treated and presumed to be naturally protected, it is considered to be free from impurities, which are associated with surface water, because it comes from deeper parts of the earth. In India, almost 80% of the rural population depends on untreated groundwater for potable water supplies. Due to rapid growth of population, urbanisation, industrialization, water resources of our country are now getting stressed with declining per capita availability and deteriorating quality. The groundwater used for drinking should be free from

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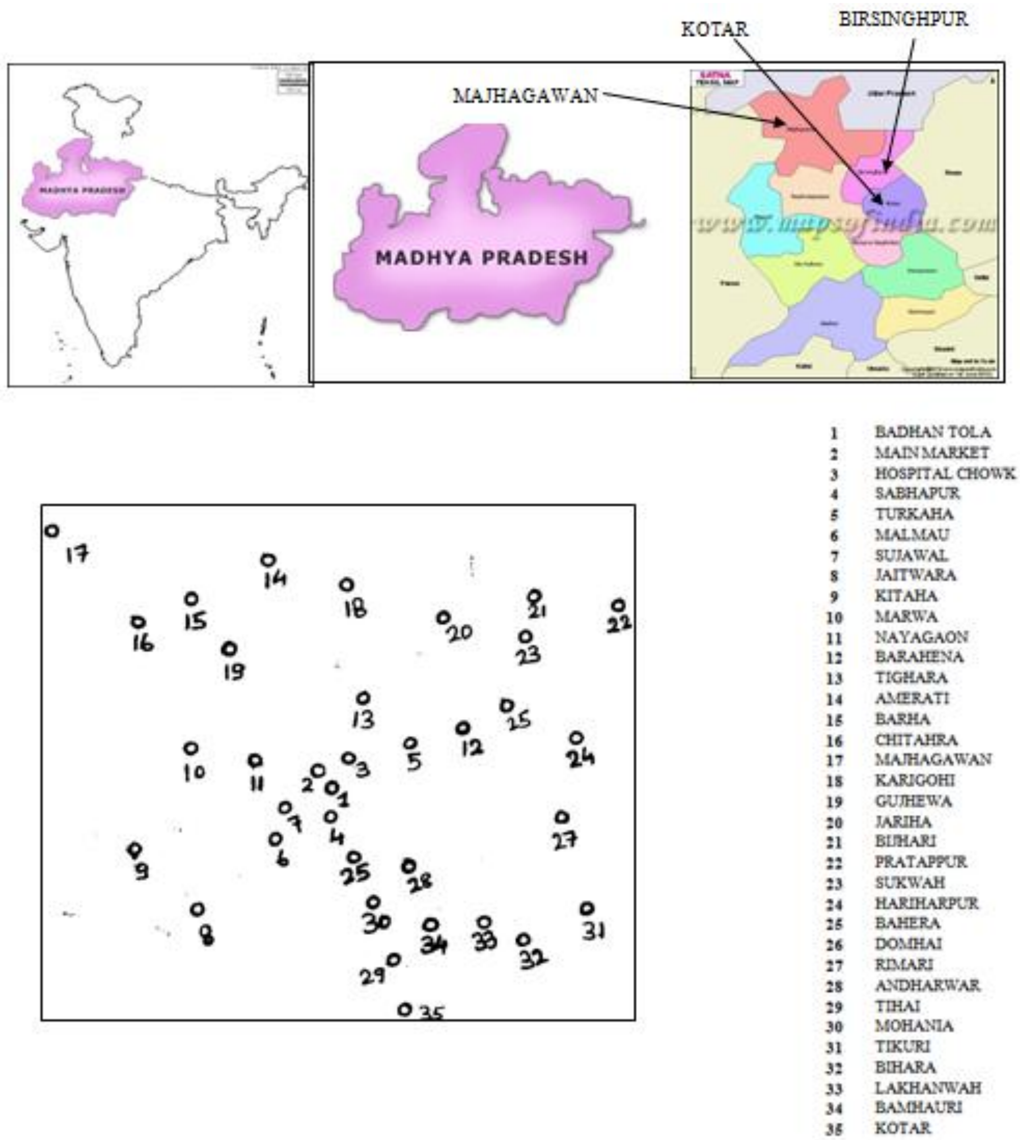

Figure 1. Location Map of the Study Area Showing Ground Water Sampling points

any toxic elements, living and non living organisms; and excessive amounts of minerals that may be hazardous to health. Assessment of groundwater quality requires determination of ion concentrations which decide the suitability for drinking, agricultural and industrial uses (Tiwari, 2011). Some heavy metals are very essential in human health, but they may cause various health problems, if present in higher concentrations. The contamination of groundwater by heavy metals and pesticides may cause problems due to their generally non biodegradable nature (Eugenia et al., 1996). The study of major and heavy metals contaminations in groundwater from different parts of world was carried out by various workers (Henphem et al., 1983; Applin and Zhao, 1989; Barzilay, 1999; Sharma et al., 2000; Dixit et al., 2003; Sudhakhar and Mamta, 2004; Subba Rao, 2006; Chiman and Jiu, 2006; Demirel, 2007; Khan et al., 2010; Madhulakshmi et al., 2012; Nag and Ghosh, 2013). The prime objective of this study is to analyse the major and trace elements present in groundwater in the Birsinghpur area and their comparison with WHO (1993) and ISI (1991) standards for drinking purposes. Besides, the prime cause of elevated concentrations of dissolved constituents and remedial measures is also discussed by the authors.

Study area

The present study is carried out at Birsinghpur area of Satna district, Madhya Pradesh which is geographically bounded by 24°40' to 24°50' N latitude and 80°45' to 81' E longitude covering an area of above 900 km^2 (Figure 1). The area is historically and mythologically well known and famous for lord Gabinath (Shiva) temple and is rich in natural resources namely: bauxite, laterite, flagstone and Ramraj (a type of clay used in paint). Accordingly, intensive mining activities have been carried by various agencies. The waste materials of mining area are dumped on the spot causing pollution problems. The region receives 900 mm average rainfall from the south west monsoon during the months of June to September and the climate is sub-humid. The temperature varies from 42°C (summer season) to 4°C (winter season).

Geologically, the area comprises formations of the Proterozoic Vindhyan Supergroup. The main rock types are Kamour sandstone and shales of Upper Vindhyan. Bauxite and laterite are associated with the Rewa Group of Vindhyan Supergroup. The general geological succession of the area is given in Table 1. Hydrogeologically, the study area belongs to the Precambrian hard rock province. The groundwater occurs in semi-confined to confined conditions. The water level fluctuations are generally 3 to 4 m.

MATERIALS AND METHODS

A total number of 35 groundwater samples were collected in 1 L polythene bottles from different borewells and handpumps from the study area in the month of May 2012. The pH, EC and TDS have been determined with portable kits. Total hardness as $CaCO_3$ was analysed by EDTA. The major cations and anions were analysed per standard methods.

For the determination of heavy metals, the collected water samples were immediately acidified with HNO_3 to bring the pH below 2 to avoid the precipitation of the metals. The samples were concentrated and subjected to nitric acid digestion. Selected trace elements such as Fe, Pb, Mn, Cu, Ni and Cd were analysed per standard method.

RESULTS AND DISCUSSION

Major elements

The pH of the groundwater samples ranges from 6.8 to 8.5 indicating weakly acidic to slightly alkaline conditions (Tables 2 and 3). The electrical conductivity (EC) which is a measure of water's capacity to conduct electric current varies from 244 to 816 μS/cm. Total hardness of groundwater of the study area varies from 166 to 885 mg/L, 70% of the samples are categorized hard to very hard (Possibly incorrect analytical data) (Sawyer and McCarty, 1967). The hardness of the water is caused by the presence of alkaline earth such as calcium and magnesium. The hard water is marginally suitable for drinking, cooking, cleaning and laundry jobs and may needs proper treatment (Categorization as hard to very hard is possibly based on incorretc analytical data).

The cation composition of the groundwater shows an order of Ca > Mg>Na > K. The calcium of groundwater varies from 39.7 to 215 mg/L (possibly incorrect analytical data); about 60% of samples exceed the desirable limit of 75 mg/L (BIS, 1991). The continuous high intake of calcium may cause stone problem which is also noticed in the area. The sources of calcium are limestone and calcareous sandstone present in the area. The concentration of magnesium varies from 8.4 to 70.4 mg/L (possibly incorrect analytical data). The mica rich shale and micaceous sandstone are the main source of magnesium. The sodium and potassium are within permissible limits and their source rocks are K and Na feldspar (orthoclase and microcline) associated with shale and sandstone. The anion composition of the groundwater is characterized by $HCO_3 > SO_4 > Cl > NO_3 > F$. The bicarbonate concentrations ranges from 53 to 305 mg/L; about 10% of samples exceed the desirable limit of 200 mg/L. Bicarbonate is usually the primary anion in groundwater and is derived from the carbon dioxide released by the organic decomposition in the soil (Todd, 1985).

$$CO_3 + H_2O \rightarrow HCO_3 + H^+$$

The sulphate concentrations varies from 60 to 305 mg/L. About 40% of samples exceed the desirable limit of 200 mg/L. The source of sulphate in the groundwater are gypsiferous bands associated with shale formation at higher depth. Elevated sulphate concentration may cause laxative effect. Being a hydrous sulfate of calcium, gypsum gets dissolved by circulating groundwater, thus imparting the water a permanent sulphate hardness. Also, gypsum is reduced by anerobic organisms in the deeper parts of the aquifer (Tiwari, 2011). The resulting reduction, leads to the formation of hydrogen sulphide gas (H_2s) which is easily soluble in groundwater and gives it an unpleasant odour. This peculiar odour is also noticed in a few localities. The concentrations of chloride and nitrate are within the permissible limits. The chemical fertilizers used by farmers are the main source of nitrate whereas industrial effluents may be the source of chloride. The concentration of fluoride ranges from 0.37 to 1.53 mg/L, exceeding the maximum desirable limit (1 mg/L, BIS, 1991) in a few localities. The sources of fluorides are chemical fertilizers as well as micaceous shale.

(b) Trace Elements (Tables 2 and 3) Iron

Iron is an essential element in human body (Moore, 1973) and is found in groundwater all over the world; higher concentrations of iron cause bad taste, discoloration, staining, turbidity, esthetic and operational problem in water supply systems (Dart, 1974; Vigneshwaran and Vishwanathan, 1995). Deficiency of iron results in hyochromic macrobiotic anemia; one of the world's common health problems.

The limit of concentration of iron in drinking water ranges between 0.3 (desirable limit) to 1.0 mg/L (permissible limit). In the study area, a minimum value

Table 1. General geological succession of the area.

Supergroup	Group	Formation	Thickness (m)
	Recent	Alluvium	4
	Pleistocene	Laterite, Bauxite	45
	Rewa	Upper Rewa sandstone	120
		Jhiri shale	18
Vindhyan (Proterozoic)	Kaimur	Kaimur Sandstone	180

Age	Supergroup			
Recent Pleistocene			Alluvium	4
			Laterite, Bauxite	45
Proterozoic	Vindhyan	Rewa	Upper Rewa sandstone	120
			Jhiri shale	18
		Kaimur	Kaimur Sandstone	180

(0.27 mg/L) of iron is observed in Hariharpur whereas the maximum value (2.98 mg/L) has been observed in Lakhanmah area. In about 45% of the samples, the maximum permissible limit of iron in water is exceeded; the elevated iron concentrations are derived from laterite and ferruginous sandstone (Tiwari and Dubey, 2012). Besides natural sources, the corrosive nature of casing pipe used for water supply might contribute to the elevated iron concentration.

Copper

Copper is an essential element, concentrated in several enzymes, and its presence in trace concentrations is essential for the formation of hemoglobin. An over dose of copper may lead to neurological complication, hypertension, liver and kidney dysfunctions (Krishna and Govil, 2004; Khan et al., 2010). Ingestion of copper causes infant death, short lived vomitting diarrhea etc (Barzilay, 1999). In the present study its value ranged from nil to 0.134 mg/L which is within the permissible limit as suggested by WHO (1993) and BIS (1991).

Nickel

Nickel is present in a number of enzymes in plants and microorganism. In the human body, nickel influences iron adsorption, metabolism and may be an essential component of the haemopoiitic process. Acute exposure of nickel in the human body is associated with a variety of chemical symptoms and signs such as nausea, vomiting, headache, giddiness etc. (Barzilay, 1999).

The BIS (1991) has recommended 0.02 mg/L as maximum permissible concentration in drinking water. In the study area, Ni concentrations range from nil to 0.025 mg/L. The primary source of nickel in drinking water is leaching from metals in contact with drinking water such as pipes and fittings. However, it may also be present in some ground waters as a consequence of dissolution from nickel ore bearing rocks. The geogenic source appears to be responsible mainly for the nickel concentrations in groundwater of the study area (Tiwari and Dubey, 2012).

Lead

Lead occurs geologically in association with sulphide minerals and may be present in generally elevated concentration in areas with ores and coal (Reimanne and Decarital, 1998). Lead is toxic to the central and peripheral nervous system causing neurological and behavior effects. The consumption of lead in higher quantity may cause hearing loss, blood pressure and hypertension and eventually it may be prove to be fatal.

In the present study, lead concentration ranged from 0.007 mg/l to 0.065 mg/l. It is observed that all groundwater samples except sample no. 8 (Jaitauara) and sample no. 21 (Bijhari) have lead values within the permissible limit (BIS, 1991). The comparatively higher concentrations in a few localities are attributed to the chemistry of aquifer.

Manganese

Manganese is one of the most abundant elements in the earth's crust, it usually occurs together with iron and is widely distributed in soil, sedimentary rocks and water. The most abundant compounds of manganese are sulphide, oxide, carbonate and silicate. In the present study, the concentration of manganese ranged from 0.020 to 0.282 mg/L. About 30% of samples exceed the desirable limit however they do not exceed the permissible limit (0.3 mg/L). Higher concentrations are related to the geology of the area (Tiwari and Dubey, 2012)

Table 2. Analytical Results of Groundwater Samples of the Study Area.

S. No.	Sampling locality	pH	EC	TDS	TH	Cl	F	SO4	NO_3	HCO_3	Pb	Fe	Mn	Cu	Ni	Cd	Ca	Mg	Na	K
1	Badhan tola	7.4	584	365	448	28.6	0.85	31.4	10.45	140	0.010	0.56	0.055	0.085	0.012	0.0032	160.3	62.5	12.2	2.4
2	Main market	7.9	536	335	568	32.4	0.87	34.1	8.35	110	0.024	0.66	0.035	0.058	0.013	0.0036	147.2	50.6	22.1	3.2
3	Hospital Chowk	7.9	525	328	582	33.1	0.72	20.2	7.88	60	0.019	0.73	0.042	0.053	0.012	0.0021	175.3	35.5	15.5	3.4
4	Sabhapur	7.9	597	373	567	33.6	0.94	39.7	7.40	142	0.021	0.91	0.062	0.070	0.015	0.0038	158.3	41.7	4.8	0.8
5	Turkaha	7.4	430	268	320	26.8	0.68	29.4	8.76	145	0.012	0.53	0.042	0.047	ND	0.0024	80.2	30.0	5.3	0.8
6	Malmau	7.2	244	152	310	21.3	0.99	30.9	6.95	135	0.013	0.64	0.048	0.042	0.015	0.0028	59.2	43.0	6.7	1.2
7	Sujawal	7.6	413	258	282	25.8	0.78	29.2	6.90	117	0.015	0.28	0.049	0.028	ND	ND	75.8	23.0	15.0	2.2
8	Jaitwara	7.4	432	270	349	33.7	0.92	30.5	10.27	68	0.065	1.63	0.127	0.042	0.025	0.0049	94.6	28.6	19.1	12.2
9	Kitaha	7.7	389	243	253	26.8	0.88	35.4	8.36	103	0.018	0.76	0.070	0.041	0.016	0.0030	65.1	22.6	17.0	3.5
10	Marwa	8.5	364	227	256	36.6	1.21	33.3	7.40	105	0.015	0.63	0.049	0.045	0.017	0.0022	56.5	28.7	18.0	4.0
11	Nayagaon	7.6	365	228	235	24.9	1.26	33.2	6.48	107	0.007	0.47	0.024	0.040	0.018	ND	46.4	29.8	16.0	2.8
12	Barahena	7.5	468	292	462	24.2	0.57	33.7	6.10	82	0.009	0.29	0.045	0.046	0.014	0.0054	100.1	53.5	25.2	3.3
13	Tighara	7.0	349	218	252	27.8	0.72	25.2	6.88	62	0.016	1.35	0.083	0.049	ND	0.0026	58.4	26.8	15.2	4.1
14	Amerati	7.0	301	188	196	27.9	0.75	16.2	3.56	80	0.032	0.53	0.213	0.069	0.019	ND	39.7	24.1	18.3	1.3
15	Barha	6.8	421	263	328	12.0	0.98	30.5	4.80	103	0.049	2.10	0.182	0.079	0.013	0.0027	104.8	16.5	22.3	0.63
16	Chitahra	7.5	557	348	540	27.2	1.06	34.5	7.18	109	0.034	1.35	0.079	0.042	0.017	0.0029	147.3	42..8	18.5	1.2
17	Majhagawan	7.7	657	410	703	33.4	1.52	41.1	8.26	54	0.036	1.42	0.143	0.048	0.019	0.0031	179.2	64.0	35.3	7.0
18	Karigohi	7.4	360	225	255	24.3	0.69	27.7	7.34	79	0.032	1.32	0.050	0.134	0.014	0.0030	48.6	32.9	22.0	3.5
19	Gujhewa	7.0	340	212	195	15.8	0.89	26.4	3.65	89	0.025	1.56	0.078	0.044	0.015	0.0026	65.0	8.4	32.3	5.8
20	Jariha	6.8	416	260	341	25.7	0.75	13.8	4.45	94	0.020	2.72	0.246	0.070	0.011	0.0029	60.5	47.6	42.2	3.5
21	Bijhari	6.9	490	306	395	19.5	0.37	17.9	1.98	202	0.052	2.47	0.230	0.054	0.018	ND	64.2	58.7	14.8	3.5
22	Pratappur	7.0	736	460	502	29.7	0.87	28.9	7.10	305	0.013	1.53	0.185	0.087	0.018	0.0027	139.8	38.1	22.3	4.5
23	Sukwah	6.8	816	510	693	33.4	0.86	31.7	4.92	109	0.011	0.89	0.208	0.082	0.016	0.0048	165.4	70.2	30.1	8.1
24	Hariharpur	7.5	456	285	514	27.1	1.30	30.0	7.05	185	0.010	0.27	0.042	0.046	0.015	0.0020	140.0	41.2	18.3	2.1
25	Bahera	7.2	536	335	202	30.2	0.62	24.6	5.30	106	0.017	0.79	0.034	ND	0.013	0.0019	55.2	16.4	15.3	3.1
26	Domhai	7.3	423	264	260	25.2	0.79	38.4	5.18	107	0.009	0.30	0.020	ND	0.010	0.0040	69.0	21.8	22.3	2.3
27	Rimari	7.9	496	310	403	20.3	0.82	45.2	7.58	103	0.024	0.78	0.021	0.035	0.015	ND	110.4	32.2	27.0	2.5
28	Andharwar	7.8	430	268	376	18.7	0.94	35.4	5.86	109	0.018	0.76	0.031	0.040	0.016	ND	98.5	32.4	32.00	2.4
29	Tihai	6.7	600	375	490	22.4	1.17	39.2	5.05	203	0.012	1.28	0.084	0.072	0.019	0.0023	127.3	43.5	12.3	1.2
30	Mohania	6.8	488	305	621	25.5	0.96	47.2	4.47	53	0.021	1.53	0.089	0.067	0.017	0.0028	118.1	55.2	18.0	1.3
31	TIkuri	7.5	548	342	764	37.4	1.53	37.8	2.40	55	0.017	1.26	0.070	0.092	0.014	ND	149.3	62.6	15.3	1.5
32	Bihara	7.3	666	416	652	33.1	0.80	39.8	8.59	62	0.021	1.38	0.089	0.048	0.017	0.0021	210.0	59.5	14.2	4.1
33	Lakhanwah	6.9	676	422	710	29.3	0.91	49.5	6.10	164	0.016	2.98	0.148	0.075	0.015	0.0026	162.8	61.4	15.2	1.6
34	Bamhauri	7.0	648	405	822	25.4	0.97	45.2	6.90	159	0.013	2.35	0.282	0.046	0.023	0.0018	190.5	58.1	10.3	1.2
35	Kotar	7.4	772	482	885	32.7	1.20	50.8	9.80	110	0.025	1.78	0.102	0.102	0.022	0.0028	215.8	70.4	15.4	5.3

Unit: EC μsS/cm, pH unitless, other are in ppm.

Table 3. Comparison of the quality parameters of groundwater of the study area with WHO and ISI for drinking purpose.

S. No.	Water quality parameter	WHO (1993)		BIS (1991)		Concentration in study area
		Max. desirable	Max. permissible	Max. desirable	Max. permissible	
1.	pH	7.0	8.5	6.5	8.5	6.8-8.5
2.	TH	300	500	300	600	166-885
3.	TDS	500	1500	500	1000	152-510
4.	Ca	75	200	75	200	39.7-215
5.	Mg	30	150	30	100	8.4-70.4
6.	Na	-	200	-	200	4.8-42.2
7.	K	-	12	-	-	0.8-12.2
8.	Cl	200	600	250	1000	12-37.4
9.	SO_4	200	400	150	400	60-305
10.	HCO_3	-	-	200	600	53-305
11.	F	1	1.5	1	1.5	0.37-1.53
12.	Lead	-	0.05	0.05	No relaxation	0.007-0.06
13.	Iron	0.3	1.0	0.3	1.0	0.28-2.48
14.	Manganese	0.1	--	0.1	0.3	0.20-0.282
15.	Copper	0.05	1.0	0.05	1.5	Nil-0.134
16.	Nickel	--	0.02	..	0.02	Nil-0.025
17.	Cadmium	...	0.005	0.01	No relaxation	Nil – 0.005

Except pH all values are in ppm.

Manganese is regarded as one of the least toxic elements but its excess amount in the human body may cause growth retardation, fever; fatigue and eye blindness, and may affect reproduction.

Cadmium

Cadmium is a cumulative environmental pollutant and its exposure to the body results damage of the kidney, and causes renal dysfunction, arteriosclerosis, cancer etc. (Goel, 1997; Robards and Worsfold, 1991). In the present study, the concentration of cadmium ranged from nil to 0.005 mg/L which is well within the permissible limit as recommended by BIS (1991) and WHO (1993) respectively. The concentration of cadmium in water samples of the study area may be attributed to the runoff from the agricultural sector where pesticides as well as cadmium phosphatic fertilizer are being used.

Conclusions

The analysed groundwater samples of the study area indicate a slightly alkaline nature of groundwater. The water is hard to very hard (the categorization as hard to very hard is possibly based on incorrect analytical data) due to the presence of calcium and magnesium in the aquifers. The hard water may require chemical treatment before use for drinking. The calcium is high in few localities due to the calcareous nature of the sandstone. The other cations are generally within the permissible limit and their sources are the shale and sandstone aquifers. The concentration of sulphate is elevated due to the presence of gypsum bands associated with shale formations. The gypsum easily dissolves into the groundwater, attributing to the permanent hardness. The associated intake of sulphate in higher concentrations may cause laxative effect. Chloride and nitrate concentrations are within the permissible limits. The fluoride concentration exceeds the maximum desirable limit in a few localities (BIS > 1 mg/L) due to the fluorine rich mica and phosphate fertilizers.

The iron is generally elevated in most localities, originating from laterite bearing geologic formation. The continuous higher intake of iron may cause toxic effects to the human health. At greater depth, with reducing conditions, the solubility of Fe-bearing minerals in water increases leading to an enrichment of dissolved iron in groundwater (Applin and Zhao, 1989; White et al., 1991). The concentrations of copper and nickel are within the permissible limit and their sources are geologic as reported by Tiwari and Dubey (2012). The concentration of manganese is elevated in a few localities due to its affinity with iron. Higher concentrations of manganese may cause metabolic disorder. The study reveals that iron and manganese are exceeding permissible limits and their main sources are combined effects of geogenic and anthropogenic sources. Proper monitoring is needed to avoid anthropogenic contamination.

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