Full Length Research Paper

Study of trace elements in groundwater of Western Uttar Pradesh, India

Mohammad Muqtada Ali Khan[1]*, Rashid Umar[2] and Habibah Lateh[1]

[1]School of Distance Education, University Sains Malaysia, 11800 Penang, Malaysia.
[2]Department of Geology, Aligarh Muslim University, Aligarh 202002, India.

The use of trace elements ions had witnessed a phenomenal rise in agriculture as well as in the industrial sectors in recent past. The study was conducted within parts of Central Ganga Plain with an objective to find out the concentration of fifteen trace elements (As, Pb, Sr, Ba, Mn, Co, Ni, Cu, Cd, Fe, Zn, Cr, B, Se, and Al) in the regional groundwater. These probe elements were further categorized as toxic metals (Pb, As), alkaline earth metals (Sr, Ba), transition metals (Mn, Co, Ni), metallic elements (Cu, Cd, Fe, Zn, Cr), and non-metallic elements (B, Se, Al). Inductive Coupled Plasma Mass Spectrophotometer (ICPMS) was employed to determine the concentration of these trace elements in collected water samples. The study reveals that some groundwater samples had marginally high concentration of Mn, Fe, Pb, and Cr, whereas, concentration of Al and Sr in water samples is very high as per W.H.O. standard for potable water. These high concentrations of metal ions in groundwater was probably due to unsafe discharge of effluent from sugar mill, pulp and paper, cooperative distilleries, municipal wastewater, fertilizers and other industries. The adverse effects of large-scale industrialization in these areas can now be distinctly observed in the form of deterioration of groundwater quality.

Key words: Trace element, groundwater, contamination, western Uttar Pradesh, India.

INTRODUCTION

Water is one of the vital natural resource without which life cannot flourish. Burgeoning industrialization and urbanization causes the release of waste material into the environment at higher rate than the rate of natural purification. In India, almost 80% of the rural population depends on untreated groundwater for potable water supplies (Reza et al., 2009).

Groundwater contamination and its management has become the need of time (hour) because of far reaching impact on human health. Contamination of groundwater mainly occurs through industrial effluent discharge and geochemical activities (Sudhakar and Mamatha, 2004).

Trace elements distribution in groundwater

Trace elements are distributed in groundwater from a variety of natural and anthropogenic sources (Mondal et al., 2010). Various anthropogenic activities under the shadow of urbanization and the industrial development results in effluent disposal, introduced the groundwater system to high concentration of trace metal. Trace metals like Fe, Mn, Cu, Zn, Co, and Ni are micronutrient for living system, their deficiency or excess can lead to a number of disorderness in human body (Jinwal et al., 2009). Some trace metals like Cd, Pb and Cr can be lethal to human being even at low concentration because of their tendency to accumulate in the body (Domenico and Schwartz, 1998).

A Characteristic feature of most of trace metals is their tendency to form hydrolyzed species in water, and few of them form complex species by combining with inorganic anions such as HCO_3^-, CO_3^{2-}, SO_4^{2-}, Cl^-, F^- and NO_3^-. The sole reason of groundwater contamination is not only the inorganic species, but dissolved organic compounds also plays important role in it (Freeze and Cherry, 1979). Trace elements in groundwater are generally dissolved in very minute quantities in most of the cases, its concentration is less than 1 mg/L (USGS, 1993). Some

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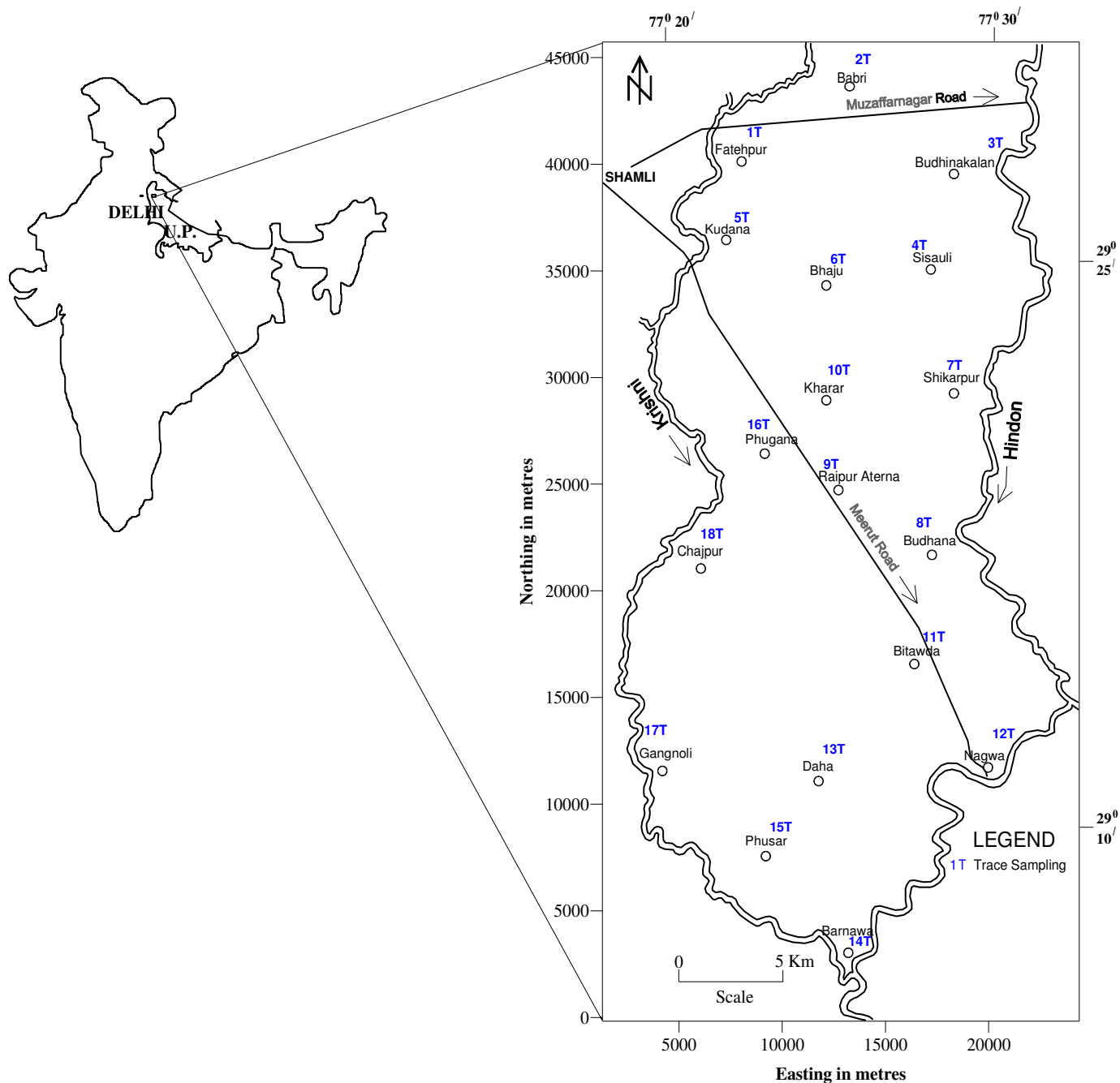*Corresponding author. E-mail:muqtadakhan@gmail.com. Tel: 006046535289.

Figure 1. Location of samples analysed for trace element.

trace elements come under micronutrient in living bodies, and it is required in the range of 50 to 18 mg/day. Acting as catalytic or structural components of larger molecules, they have specific functions and are indispensable for life.

A set of 15 trace elements comprising of As, Pb, Sr, Ba, Mn, Co, Ni, Cu, Cd, Fe, Zn, Cr, B, Se, and Al; which are categorized according to their place in periodic table and toxic nature as toxic element (Pb, As), alkaline earths (Sr, Ba), transition metals (Mn, Co, Ni), metallic elements (Cu, Cd, Fe, Zn, Cr), and non-metallic elements (B, Se, Al) were selected. For the present study samples were collected from 18 different locations and were analyzed for these trace elements.

Location

The selected study area is lying between rivers Hindon and Krishni, measuring 650 km^2 (29°05'N - 29°30'N:
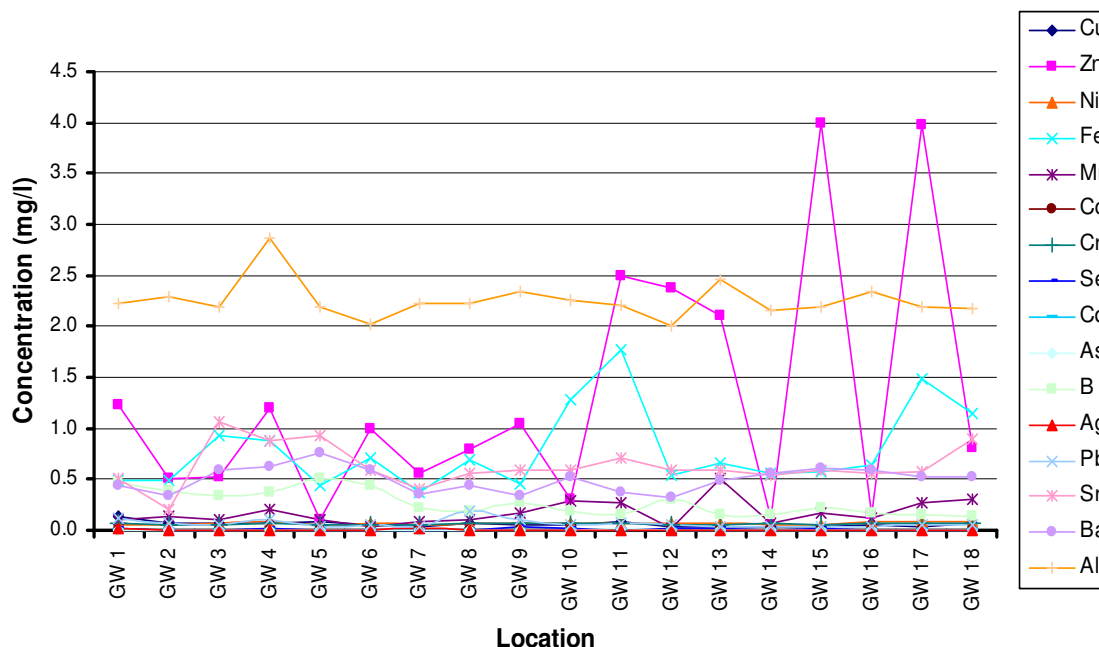
Figure 2. Distribution of various heavy metals at different locations.

77°20'E - 77°32'E) and is located in the western part of Muzaffarnagar district in the state of Uttar Pradesh, India (Figure 1). In this region, Fertilizers, pesticides, sugar factories, distilleries, pulp and paper factory and other minor manufacturing units or small scale industries are the most likely sources of groundwater contamination. Drainage is controlled by two rivers flowing from north to south and elevation varies between 224 and 256 m above sea level (Khan, 2009).

The area has >1000 m of Quaternary sediments over-lying a basement comprising quartzite of Proterozoic age belonging to Delhi Super Group (Kumar, 2005). The clay layer occurring above the granular zone is persistent throughout the area and the latter is intervened by several clay lenses. The aquifer tends to behave as a mono-stratum to a depth of about 121 m (Khan and Umar, 2010).

Depth of water table, as recorded in 2007, ranges between 9.67 and 29.44 m below ground level (m bgl), and no significant difference is noticed in pre- and post-monsoon measurements. The movement of groundwater is, in general, from north to south. Two significant and persistent groundwater troughs have been observed, which could have developed as a result of excessive and indiscriminate groundwater pumping. The transmissivity and hydraulic conductivity values for the aquifer in the area have been estimated between 720 to 1820 m²/day and 14.17 to 54 m/day, respectively (Bhatnagar et al., 1982).

Mostly, groundwater of this area recharges from precipitation; however, a canal is also available. The average annual rainfall is 588 to 697 mm as recorded at

two stations and the rains emanate from the southwest monsoon, usually in June–October. Sometimes rains also occur during the month of February.

MATERIALS AND METHODS

Eighteen groundwater samples from shallow and deep aquifer were collected in June 2007 in 1 L polyethylene bottles and acidified in the field by HNO_3 and uniformly distributed over the entire study area. Prior to collecting the samples, the wells were duly pumped so that the stagnant water, if any, is completely removed from storage in the well assembly. Values of pH were measured by a portable digital water analysis kit with electrodes. The instrument was calibrated with buffer solutions having pH values of 4 and 9. Total dissolved solids (TDS) were calculated by summing up the concentrations of all the major cations and anions. The values of electrical conductivity (EC) were also measured by portable kit with electrodes.

The trace elements like As, Pb, Sr, Ba, Mn, Co, Ni, Cu, Cd, Fe, Zn, Cr, B, Se, and Al were analysed at Geochemistry Laboratory, NGRI, Hyderabad, India by Inductive Coupled Plasma-Maas Spectrophotometer (ICPMS). The ICPMS is the most simple and direct method of chemical analysis. The sample to be analysed is introduced into argon-based high temperature plasma by a nebulizer spray chamber system. The sample stream causes desolvation, vaporization, atomisation and ionisation of target elements. Ions thus generated are extracted from the plasma into a low-pressure region through a sampler and skimmer cones and are allowed to pass through an electrostatic lens system, which extracts positively charged ions. These ions are separated on the basis of their mass–to-charge ratio by quadrupole mass analyzer. A detector counts the filtered ions and a computer processes the resulting information.

Distribution of various heavy metals at different locations (Figure 2); and the results of the trace element are presented in Table 1. Statistical measures of the trace elements in the samples are

Table 1a. Trace element compositions of groundwater samples (in mg/l).

S/No.	Location	Depth (m)	pH	EC	TDS	As	Pb	Sr	Ba	Mn	Co	Ni	Cu	Cd
1	Fatehpur	50	7.3	400	748	0.007	0.12	0.51	0.44	0.11	0.005	0.06	0.13	0.0045
2	Babri	50	8.2	400	1197	0.003	0.07	0.21	0.34	0.14	0.002	0.04	0.07	0.0009
3	Budhina kalan	50	8.1	400	788	0.002	0.05	1.07	0.59	0.10	0.002	0.06	0.06	0.0005
4	Sisauli	25	8.2	500	1127	0.004	0.10	0.87	0.63	0.20	0.003	0.09	0.06	0.0007
5	Kudana	69	8.4	400	879	0.003	0.03	0.92	0.75	0.10	0.002	0.06	0.09	0.0003
6	Bhaju	28	8.2	400	948	0.002	0.04	0.59	0.59	0.03	0.002	0.07	0.05	0.0003
7	Shikarpur	36	7.6	300	470	0.002	0.03	0.40	0.36	0.08	0.002	0.05	0.04	0.0000
8	Budhana	23	7.9	500	888	0.001	0.18	0.56	0.45	0.10	0.002	0.07	0.06	0.0018
9	Raipur Aterna	79	8.3	400	759	0.002	0.11	0.60	0.33	0.16	0.002	0.06	0.05	0.0003
10	Lank	30	8.4	400	830	0.002	0.04	0.59	0.53	0.28	0.003	0.07	0.05	BDL
11	Bitawda	28	8.5	400	1020	0.024	0.06	0.71	0.37	0.27	0.003	0.07	0.09	0.0006
12	Nagwa	15	7.7	800	1439	0.003	0.05	0.59	0.33	0.02	0.002	0.07	0.04	0.0004
13	Daha	69	8.4	500	948	0.002	0.03	0.59	0.48	0.51	0.003	0.07	0.03	0.0006
14	Barnawa	28	8.2	500	704	0.002	0.03	0.54	0.56	0.06	0.002	0.05	0.03	0.0002
15	Phusar	72	8.2	500	1233	0.001	0.04	0.60	0.60	0.16	0.002	0.05	0.03	BDL
16	Phugana	50	7.5	400	728	0.005	0.04	0.56	0.59	0.12	0.006	0.09	0.06	0.0036
17	Gangnoli	76	7.5	400	793	0.002	0.05	0.57	0.52	0.27	0.003	0.08	0.03	0.0009
18	Chajpur	26	8.1	500	913	0.002	0.05	0.89	0.53	0.31	0.003	0.09	0.07	0.0045

Table 1b. Trace element compositions of groundwater samples (in mg/l).

S/No.	Location	Depth (m)	Fe	Zn	Cr	B	Se	Al
1	Fatehpur	50	0.49	1.22	0.08	0.47	0.013	2.23
2	Babri	50	0.49	0.50	0.06	0.38	0.008	2.30
3	Budhina kalan	50	0.92	0.52	0.06	0.33	0.004	2.20
4	Sisauli	25	0.88	1.20	0.07	0.37	0.013	2.86
5	Kudana	69	0.43	0.11	0.06	0.51	0.003	2.19
6	Bhaju	28	0.71	1.00	0.05	0.44	0.008	2.03
7	Shikarpur	36	0.37	0.55	0.06	0.22	0.004	2.22
8	Budhana	23	0.69	0.80	0.06	0.19	0.004	2.23
9	Raipur Aterna	79	0.45	1.04	0.06	0.26	0.027	2.33
10	Lank	30	1.27	0.31	0.06	0.19	0.015	2.26
11	Bitawda	28	1.77	2.50	0.06	0.15	0.005	2.20
12	Nagwa	15	0.53	2.37	0.06	0.30	0.011	2.00
13	Daha	69	0.66	2.11	0.05	0.15	0.010	2.46
14	Barnawa	28	0.55	0.11	0.06	0.15	0.004	2.16
15	Phusar	72	0.57	4.00	0.06	0.21	0.013	2.19
16	Phugana	50	0.65	0.15	0.07	0.16	0.006	2.35
17	Gangnoli	76	1.47	3.98	0.06	0.15	0.005	2.19
18	Chajpur	26	1.14	0.81	0.06	0.13	0.006	2.18

pH -$\log_{10}$H$^+$, *EC* electrical conductivity (in μS/cm) at 25°C, *TDS* total dissolved solids (in mg/l),
all trace elements in mg/L, *BDL* below detection limit, all samples from hand pump.

presented in Table 2.

RESULTS AND DISCUSSION

Eighteen groundwater samples were collected from representative sampling stations established over entire study area and were analyzed for their trace elements content and physiochemical parameters mentioned in Table 1.

The results of the physiochemical parameters show that the TDS values range between 470 and 1439 mg/L

Table 2. Statistical measures of trace elements of Krishni- Hindon interstream, India.

Variables	Max	Min	Av.	SD	WHO (1994)		ISI (1991)	
					Highest desirable level	Max. permissible level	Highest desirable level	Max. permissible level
pH	8.5	7.3	8.04	0.36	7- 8.5	6.5-9.2	6.5-8.5	6.5-9.5
EC	800	300	450	104.32	-	1500	-	-
TDS	1439	470	911	227.93	100	500	300	600
As	0.024	0.001	0.004	0.005	-	0.01	0.05	0.05
Pb	0.18	0.03	0.06	0.041	-	0.1	0.1	-
Sr	1.07	0.21	0.63	0.2	-	0.07	-	-
Ba	0.75	0.33	0.5	0.122	-	0.7	-	-
Mn	0.51	0.02	0.17	0.122	0.05	0.5	0.1	0.5
Co	0.006	0.002	0.003	0.001	-	-	-	0.1
Ni	0.09	0.04	0.07	0.014	-	-	0.1	0.3
Cu	0.13	0.03	0.06	0.026	0.05	1.5	0.05	1.5
Cd	0.0045	0.0001	0.0012	0.002	-	0.01	0.01	0.01
Fe	1.77	0.37	0.78	0.39	0.1	1	0.3	1
Zn	4	0.1	1.29	1.22	5	15	-	-
Cr	0.08	0.05	0.06	0.005	-	-	0.05	0.05
B	0.51	0.13	0.27	0.124	-	0.3	-	5
Se	0.027	0.003	0.009	0.006	-	-	0.01	0.1
Al	2.86	2	2.25	0.185	-	0.2	-	0.2

All elements: in mg/l; EC: in µS/cm, TDS: in mg/l, pH: $-\log_{10}H^+$, Max: maximum; Min: minimum; Av: average, SD: standard deviation.

with an average value of 912 mg/L. Groundwater of the area, therefore, was 'fresh water' in general, with some of the samples being on the periphery of brackish water (Freeze and Cherry,1979).

The pH was measured at sample collection site, to avoid pH changes caused by escape of CO_2 and it had ranges between 7.3 and 8.5. Carbon dioxide in groundwater normally occurs at a much higher partial pressure than in the earth's atmosphere. When groundwater was exposed to the atmosphere, CO_2 will escape and the pH will rise. Groundwater was in general expected to be neutral to slightly alkaline in nature. For consumption point of view, all the samples may be considered fit, as they are neither acidic nor strongly alkaline. Electrical Conductivity values ranged between 300 to 800 µS/cm in the study area.

The results of chemical analysis of groundwater samples of June 2007 show that the concentrations of major anions SO_4, HCO_3, Cl, and NO_3 were in the ranges of 42 to 364, 177 to 845, 8 to 247 and 0 to16 mg/L, respectively. Major cations, Na, K, Ca and Mg had concentration levels in the range of 70 to 403, 6 to 116, 3 to 32 and 8 to 85 mg/L, respectively. Two major groups of groundwater, characterized by distinct chemical compositions, had been identified on L-L diagram, which were, Na-K-HCO_3 type and Mixed type (Khan, 2009).

The trace elements found in the groundwater of the study area had been classified and discussed in different groups like toxic elements (Pb and As), alkaline earths (Sr and Ba), transition metals (Mn, Co, and Ni), metallic elements (Cu, Cd, Fe, Zn, and Cr), and other non-metallic elements (B, Se, and Al).

Toxic element (Pb and As)

Lead (Pb) concentration in natural waters increases mainly through anthropogenic activities (Goel, 1997). The possible sources of lead in groundwater were diesel fuel consumed extensively in farm lands, discarded batteries, paint and leaded gasoline. Lead was also used in some pesticides such as lead arsenate. Lead was toxic to the central and peripheral nervous systems, including sub-encephalopathic neurological and behavioral effects. Its consumption in higher quantity may cause hearing loss, blood disorders, hypertension and eventually, it may prove to be fatal (WHO, 1993; and ISI, 1991).

Lead concentration in drinking water was permissible up to 0.05 mg/L according to ISI (1991). Concentration of Pb found in the study area ranged between 0.0283 and 0.1831 mg/L. Out of 18 samples analysed, 6 have concentration levels higher than the permissible limit of 0.05 mg/L, interestingly, high Pb concentrations were reported from those areas where Fe concentrations was also high.

Arsenic (As) was widely distributed throughout the earth's crust and it was toxic in nature. It was introduced into groundwater from industrial effluents, atmospheric deposition and also from pesticides, insecticides and herbicides, which were extensively used in the study

area. The permissible level of arsenic is 0.05 mg/L according to ISI 1991. The concentration of As in the study area ranged from 0.0013 to 0.024 mg/L, which was within the permissible limit.

Alkaline earths (Sr and Ba)

Strontium (Sr) minerals were widely distributed throughout the earth and are released to the groundwater by the natural re-crystallisation of rocks and weathering of rocks and soils (Greve et al., 2007). Water and soil, which contain much strontium, on consumption often leads to fractures and osteodystrophy. Strontium was also known to have a pronounced rachitic effect (Polyakova et al., 2010). The concentration of Sr was found more than permissible limit of 0.07 mg/L (WHO, 1984) throughout the area, it was observed in the range of 1.07 to 0.21 mg/L and the average calculated value was 0.63 mg/L, higher concentrations indicating that the source could be anthropogenic through agricultural activity causes an input of Sr, to some extent it depends on the content of fertilizers and carbonate additives and manure likes cattle, poultry etc (Negrel et al., 2004). Strontium concentrations in soil may also be attributed to dumping waste, and industrial wastes. Strontium in soil dissolves in water, so that it would be able to leach deeper into the ground and enter the groundwater.

Saxena et al. (2004) have established that Sr content could be linked to various water types. They suggested Sr values of < 1.6 mg/L for fresh groundwater, 1.6 – 5.0 mg/L for brackish water, and >5.0 mg/L for saline groundwater in the coastal aquifers. The Sr values obtained indicated that the all groundwaters samples fall with in fresh groundwater.

Barium (Ba) occurs as a number of compounds in the earth's crust and was used in a wide variety of industrial applications, but it passes into groundwater from natural sources mainly. Barium concentration in the groundwater of selected study site was found in the ranged of 0.75 to 0.33 mg/L, only few samples were found having higher concentration than the permissible limit of 0.7 mg/L (WHO, 1984).

Transition metals (Ni, Co, Mn)

Nickel (Ni) and Cobalt (Co) concentration in the study area ranged from 0.043 to 0.092 mg/L and 0.00172 to 0.00597 mg/L, respectively, which were within the permissible limit.

Manganese (Mn) was one of the most abundant metal in the earth's crust and usually occur together with iron. Manganese concentration in drinking water ranged between 0.05 to 0.5 mg/L (ISI, 1991). In collected water samples, Mn concentration was found in the range of 0.024 to 0.513 mg/L. only one out of 18 samples had

higher concentration of Mn, that is, 0.513 mg/L than the permissible limit, and that sample was collected from location Daha.

Metallic elements (Cu, Cd, Zn, Fe, Cr)

Copper (Cu) was an essential element in human metabolism and was considered to be non-toxic up to 0.05 mg/L concentration in drinking water (ISI, 1991; WHO, 1993). The concentrations of Cu was found in present study to ranged from 0.027 to 0.132 mg/L with mean value 0.06 mg/L and thus all samples lies within maximum permissible limit of 1.5 mg/L.

Zinc (Zn) was also an essential trace element found in virtually all kind of food and potable water in the form of either salt or organic complexes. Zinc concentration was found in range of 0.106 to 3.99 mg/L. Observed Zn concentration values were much lower than the permissible limit of 5 mg/L. The groundwaters, therefore, were clearly Zn-deficient. Zinc deficiency may leads to dwarfism, dermatitis and loss of taste. The concentration of Cadmium (Cd) in the study area ranged from 0.00004 to 0.004 mg/L, which properly lies within the permissible limit.

About 22% of the samples had Iron (Fe) concentration >1.0 mg/L (WHO, 1994). The higher concentrations of iron may cause toxic effect to human health. In this study, the Fe concentration was found between 0.365 and 1.765 mg/L, with A mean value 0.78 mg/L. High level of Fe concentrations were also reported in some parts of western Uttar Pradesh (Kalicharan, 2007). It was suggested that the studied wells were highly enriched with metal ions. It is possible that some Fe concentration could be attributed to the corrosion of pump parts as shown by Langaneger (1987). Higher Fe concentrations in the aquifers might have resulted from interaction of oxidized Fe minerals and organic matter and subsequent dissolution of Fe_2CO_3 at a comparatively lower pH (Mondal et al., 2010). This type of water was clear when drawn from the well, but shortly changes into cloudy and then turns brown due to precipitation of $Fe(OH)_3$. Another reason for high Fe concentration may be due to the removal of dissolved oxygen by organic matter, leading to reduced conditions. Under reducing conditions, the solubility of Fe-bearing minerals (siderite, marcasite, etc.) increases in water, leading to enrichment of dissolved iron in groundwater (Applin and Zhao, 1989; White et al., 1991).

The Chromium (Cr) concentration in selected study area was found between 0.053 and 0.076 mg/L, with an average value of 0.06 mg/L and thus, all the samples had concentration level approaching the highest desirable limit. High concentration of Cr in groundwater may cause ulceration of nasal septum and dermatitis (Singh and Bhayana, 1986). The cause of these relatively high Cr concentrations was not known. Normally, higher Cr

values may be expected in terrains characterized by the presence of basic rocks. In the area of study, confined to Gangetic plains, the only suggestion that may be offered was that Cr in groundwater is of anthropogenic origin probably from paper mills.

Non-metallic elements (B, Se, and Al)

Boron (B) usually occurs as a non-ionized form as H_3BO_3 in soils at pH < 8.5, but above this pH, it exists as an anion, $B(OH)_4$ (Miller and Donahue, 1995). Boron compounds were released into water from industrial and domestic effluents. It can also be dispersed in the environment through fertilizer application. Since the pH was less than 8.5 for all the samples, it was more likely that B would be in the non-ionized form. Long-term exposure of humans to boron compounds leads to mild gastrointestinal irritation. The maximum permissible limit of B was 0.3 mg/L (WHO, 1994). In this study, its concentration ranged from 0.13 to 0.51 mg/L. Six out of 18 samples showed concentration more than permissible limit of WHO (1994).

Selenium (Se) concentration in drinking water within the range of 0.01 to 0.1 mg/L according to ISI (1991) was safe. In this study, its concentration was found in the range of 0.0032 to 0.0271 mg/L and was, therefore, properly lies within the permissible limit. Only two samples had more than desirable level, that is, 0.01 mg/L. Small amount of selenium was beneficial, but excess amount was toxic. The potential health effects were on hair, finger nail loss and numbness in fingers or toes.

Aluminium (Al) concentrations in groundwater samples were found between 2.6 and 2.0 mg/L with an average value of 2.25 mg/L. The maximum permissible limit of Al in drinking water in the absence of Aluminum source is 0.2 mg/L (ISI, 1991). All samples had Al concentration higher than permissible limit. The source of Al in the groundwater samples may be through weathering of bedrock and soil or it may be related sources like industries, which introduced Al into groundwater. Health wise, there had been a considerable debate on the possible link between Al in drinking water with Alzheimer's disease in humans (Craun, 1990; Epstein, 1990; Flaten, 1990).

CONCLUSION AND RECOMMENDATIONS

The study reveals that Fe, Mn, Sr, Cr, Al and Pb are, in general, concentrated above the permissible limit in groundwater of the area of investigation. The increasing concentration of these elements in the groundwater of the study area is mainly originating from industrial effluents of sugar mills, pulp and paper factories, cooperative distilleries and municipal waste water.

Fe and Al in groundwater can be derived through the weathering followed by dissolution of Fe-bearing alumino-silicates that are abundant in the subsurface geology (quartzites underlain by granites) of the study area. Taking into consideration conventional immobility of Al and the fact that for such a water-rock interaction groundwater has to descend to the levels that is deeper than 1000 m, this postulation may be ruled out. The source for Fe and Al, therefore, is to be looked within the sphere of anthropogenic activities.

High concentration of Fe in most of the wells is attributed to the corrosion in casing pipes. However, this contribution appears to be relatively trivial.

As far as high values of Pb are concerned, a geogenic source may be ruled out straightaway. One possibility that has to be looked into is the use of lead arsenate as a pesticide. This speculation is also not tenable as in that case so therefore; Pb is being contributed to the groundwater from anthropogenic sources, such as, industrial effluents and diesel fuels. Interestingly, high Pb concentrations are reported where Fe concentrations are high too.

The area of investigation hosts several industries that are dealing with the treatment/manufacture of steel, aluminum, sugar and pulp and paper. The effluents of these industries are discharged to both the river through drains. These drains are mostly unlined, and consequently, sideways and downward seepage of part of the industrial wastes is facilitated. This, in turn, is reflected in anomalously high values of Al, Fe, Pb, Sr and Cr, in groundwater in the area.

The effects of large-scale industrialization in the area and laxity in proper treatment of effluents before discharging these into the river system are now showing up in the form of deterioration of groundwater quality.

On the basis of the present study, the following recommendations have been made for protection of groundwater of the study area:

1. Old casing pipes, which are still in use in wells and hand pumps should be replaced by new ones.
2. The shallow hand pumps should be replaced by deeper hand pumps to avoid water from shallow aquifers that are relatively more contaminated.
3. Groundwater quality investigations are required to be done periodically.
4. There is an immediate need to check the quality of effluent released from industries.

ACKNOWLEDGEMENTS

Division, National Geophysical Research Institute, Hyderabad, India for providing facility to carry out the trace element analysis of the water samples in ICPMS lab at NGRI.

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