Research Article

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Groundwater Quality Assessment: a Case Study in Manpur, India

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ABSTRACT

This research has been aimed at evaluating the groundwater quality in the Manpur block of Gaya District, Bihar, India, for drinking purposes. Collection, processing and analysis of different physico-chemical parameters such as pH, calcium, magnesium, conductivity, total hardness, total alkalinity, total dissolved solids, nitrate, chloride, fluoride, sulphate, iron and arsenic have been conducted for about 110 groundwater samples. The study revealed that in all the groundwater samples, pH, chloride, total arsenic, magnesium, nitrate, and sulphate were found under the acceptable limits of BIS. The pH was negative, and arsenic was not correlated significantly with most of the analyzed parameters. The positive correlations were seen among electrical conductivity, alkalinity, total dissolved solids and total hardness and also with calcium, magnesium, sulphate, nitrate and chloride; whereas, iron and fluoride were not significantly correlated to each other. The total dissolved solids, total alkalinity, total hardness, iron, fluoride, and calcium exceeded the BIS limits, which severely affected the groundwater quality in the study area.

Keywords: Correlation coefficients; Drinking water; Groundwater; Physico-chemical.

1. INTRODUCTION

Groundwater is the most significant source of drinking purpose throughout the world as well as in India. The majority of the people depend upon groundwater for drinking purposes, as it is a solitary source in India. It occurs almost everywhere below the earth's surface in thousands of local aquifers, and not in a single widespread aquifer (Vasanthavigar *et al.* 2010). Groundwater is not a rich water source present in aquifers, where it accumulates and moves steadily through the geologic formations of soil, sand and rock. About 90% of rural and 30% of urban households depend entirely on untreated groundwater or surface water (Palanisamy *et al.* 2007).

Approximately 80% of diseases are water-borne in human beings, as per World Health Organization (WHO). Due to waterborne diseases, mortality and morbidity rates are high in India. The deterioration of groundwater quality is the result of human activities and natural processes (Kouras *et al.* 2007; de Andrade *et al.* 2008; Gu *et al.* 2017). Anthropogenic practices such as industrialization, improper usage of inorganic fertilisers, poisons, herbicides, domestic wastewater and extreme use of groundwater have also contributed to the introduction of a vast amount of unwanted pollutants through land and surface water (Singh *et al.* 2004; Girija *et al.* 2007; Devic *et al.* 2014; Selvakumar *et al.* 2017). As a result, anthropogenic practices are to be blamed for both land and groundwater contamination (Niemi *et al.* 1990; Singh *et al.* 2018).

Groundwater contamination due to industrial pollutants is promising with both national and international issues. Development and management of groundwater resources play a very important role in agriculture, poverty, human health, environment and sustainable development. The deterioration of groundwater quality necessitates immediate attention. Previous studies have reported the groundwater quality in West Delhi (Adhikary *et al.* 2009), Garwa, Jharkhand (Avishek *et al.* 2010), Nainital, Uttarakhand (Jain *et al.* 2010), Jaipur, Rajasthan (Tank *et al.* 2010), Thirumanimuttar sub-basin, Tamilnadu (Vasanthavigar *et al.* 2010), Belgaum, Karnataka (Ravikumar *et al.* 2011), Krishna Delta, Andhra Pradesh (Mondal *et al.* 2010), Ghaziabad, Uttar Pradesh (Singh *et al.* 2012), Rural Bihar (Srikanth *et al.* 2013) and Samastipur, Bihar (Kumar *et al.* 2016).

Available groundwater quality studies for Manpur block in Gaya district, Bihar (India) are inadequate. A groundwater pollution database in this area is required. The objective of the study was to assess the groundwater quality for drinking purposes in the Manpur block situated about 8 km towards the east from district headquarters Gaya and 104 km from the state capital Patna towards the north.

2. MATERIALS AND METHODS

Manpur block is in the Gaya district of Bihar state, India, belonging to the Magadh division (Fig. 1), with Manpur town as headquarters. It is bounded by Gaya block towards the west, Atri block towards the east, Tankuppa block towards the south and Bodhgaya block towards the west is and situated on the banks of Phalgu river at an elevation of 113 m. The town is known for its handlooms and railroad tie factory. It is a country town where people from remote villages do their shopping. The main occupations of the people are business and handloom weaving and it is referred to as mini-Kanpur.

110 groundwater samples were collected from the study area from 110 different hand pumps, after flushing water for 10–15 minutes, to eliminate the stagnant water that was extensively used for drinking and other domestic purposes. Before groundwater sampling, the containers were washed, rinsed and dried. The groundwater samples were collected and analyzed according to standard methods and procedures, with suggested precautions being taken to avoid contamination. The various parameters such as pH, total dissolved solids and electrical conductivity were determined by pH meter, TDS meter and conductivity meter, respectively, during onsite sampling. The other parameters like total hardness and alkalinity were analyzed by titrating the sample with EDTA and sulphuric acid, respectively. The titrimetric analysis was also used to analyze chloride, calcium and magnesium concentrations. Total alkalinity was estimated by acid-base titration. Total arsenic and iron in the acid-digested samples were also measured. In addition to this, sulphate, nitrate, as well as fluoride, were determined by using a spectrophotometer.

To evaluate the potential relationship between various physico-chemical parameters, statistical analyses like mean, median, standard deviation and correlation coefficients were carried out using "IBM Statistical Package for the Social Sciences (SPSS) – 21".

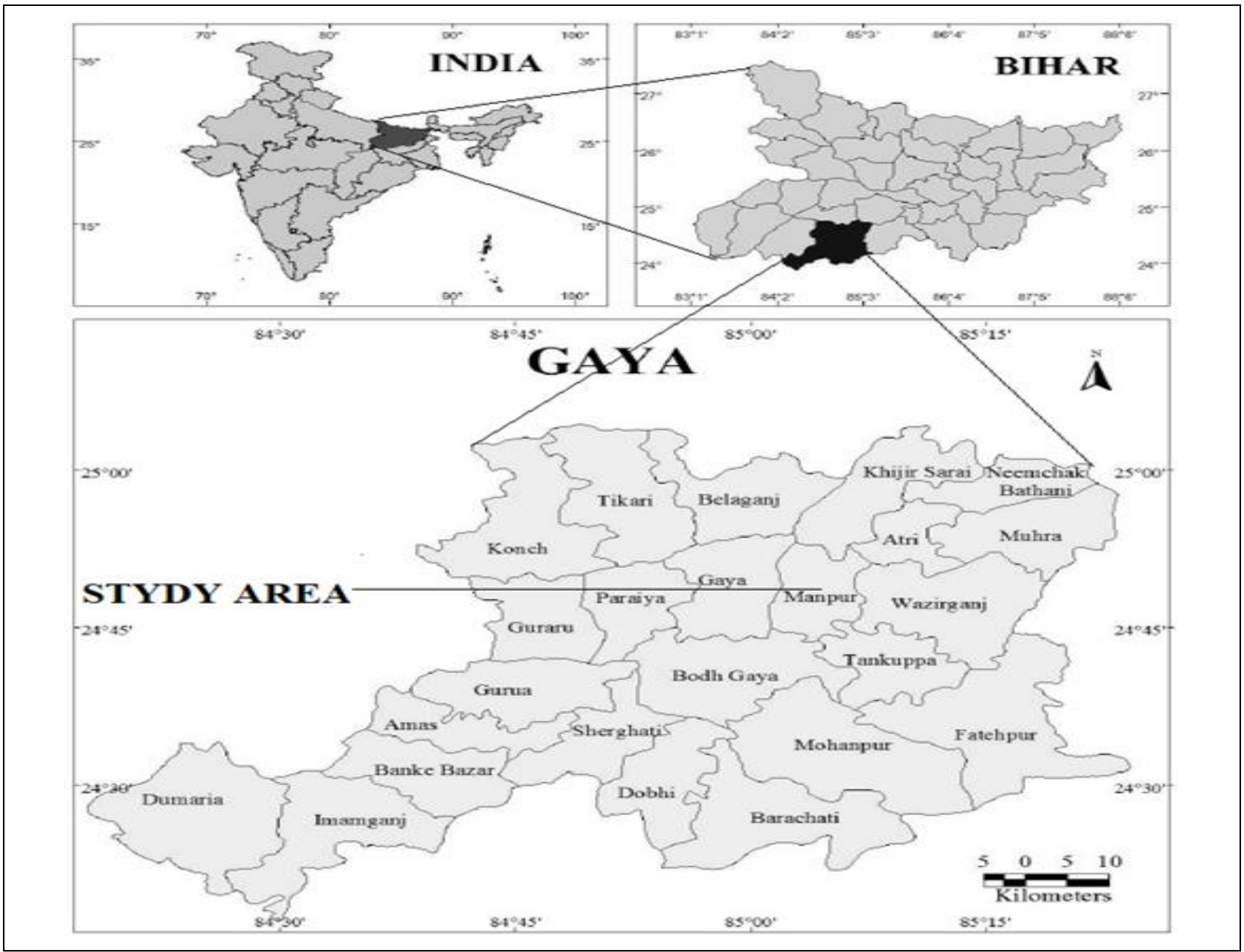

Fig. 1: Location map of the study area

3. RESULTS AND DISCUSSION

In groundwater quality assessment, the estimation of its physical and chemical characteristics is essential as it determines the suitability of this water for drinking purposes. As such, the appropriateness of groundwater for potable uses with regards to its physico-chemical characteristics have to be deciphered and defined on the basis of some essential characteristics of the water. Drinking water quality standards recommended by the Bureau of Indian Standards (BIS) have been used for finding the suitability of groundwater. The groundwater quality of the Manpur block is evaluated by comparing the range of values of different physico-chemical parameters of drinking water with the BIS. The summarized physico-chemical parameters and their comparison with BIS are presented in Table 1.

The groundwater properties in the study area, regarding central parameters, for example, pH, electrical conductivity, total dissolved solids and hardness, are discussed below. The pH varied from 6.5 to 7.5 with a mean value of 6.9 (Fig. 2). Hence the groundwater in the study area was mildly acidic to slightly alkaline, but for human use, all the samples were considered to be suitable, as they were found within the recommended limits for human consumption, which is 6.5-8.5, as per BIS. The electrical conductivity within 400 µmhos/cm at 250 C is considered fit for human use, whereas more than 1,500 µmhos/cm at 250 C may cause corrosion of iron structures (Umar *et al.* 2012). The electrical conductivity (EC) values were found to be within the range of 328 µmhos/cm to 3172 µmhos/cm with a mean value of 1057 µmhos/cm (Fig. 3).

Table 1. The summarized Physico-chemical parameters and their comparison with BIS, 2012

Parameter	Minimum	Maximum	Mean	Median	Standard Deviation	Indian Standard (BIS, 2012)	
						Requirement (Acceptable limit)	Permissible limit in the absence of alter source
pH value	6.5	7.5	6.9	6.9	0.21	6.5-8.5	No relaxation
Electrical conductivity (µs/cm)	328	3172	1057	921	554.27	--	--
Total dissolved solids (mg/l)	188	2007	641.4	570	346.26	500	1500
Calcium (as Ca) (mg/l)	33	248	100.5	92	42.85	75	200
Chloride (as Cl) (mg/l)	5	247	71.66	46	55.78	250	1000
Fluoride (as F) (mg/l)	0.30	4.88	1.72	1.07	1.35	1.0	1.5
Iron (as Fe) (mg/l)	0.06	2.24	0.61	0.54	0.43	0.3	No relaxation
Total arsenic (as As) (µg/l)	3	9	5	6	2	10	50
Magnesium (as Mg) (mg/l)	3	71	24.36	22	13.93	30	100
Nitrate (as NO_3) (mg/l)	0.21	30.77	7.44	6.70	5.21	45	No relaxation
Sulphate (as SO_4) (mg/l)	4	161	27.95	24	22.92	200	400
Total alkalinity (as $CaCO_3$) (mg/l)	112	821	377.5	351.5	156.45	200	600
Total hardness (as $CaCO_3$) (mg/l)	96	794	352.1	333	145.29	200	600

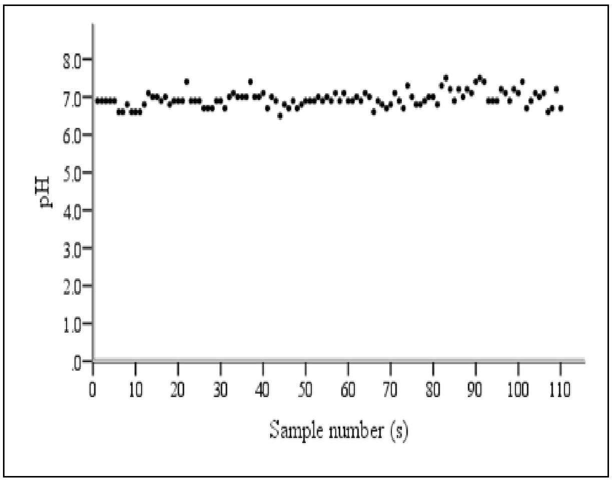

Fig. 2: Concentration of pH in groundwater samples

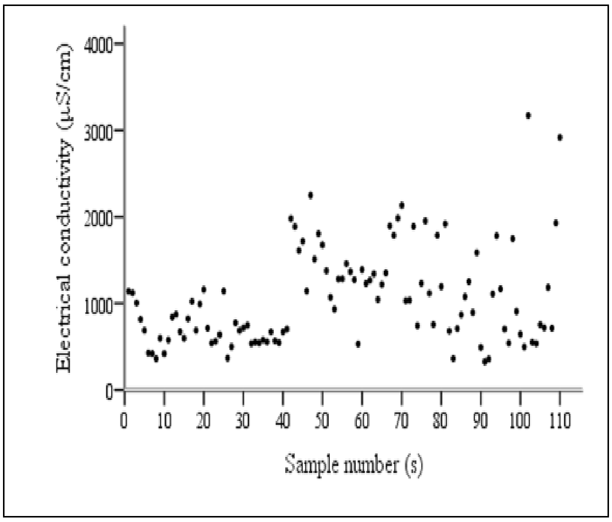

Fig. 3: Concentration of electrical conductivity in groundwater samples

In groundwater sources, total dissolved solids consist of a lot of minerals. Various dissolved gases and organic matter are also present in a trace amount (Jain *et al.* 2010). The Total Dissolved Solids (TDS) concentration varied from 188 mg/l to 2007 mg/l with a mean value of 641.4 mg/l and a standard deviation of 346.26 mg/l in groundwater samples. Only two groundwater samples exceeded the permissible limit of 1500 mg/l, but about 55% of samples exceeded the acceptable limit of 500 mg/l (BIS, 2012) (Fig. 4). TDS values of less than 500 mg/l are considered to be good and more than 1000 mg/l becomes significantly unpalatable for drinking purposes (Umar *et al.* 2012). Therefore, in the study area, groundwater was not truly ideal. A high concentration of TDS may incite a troublesome physiological response in the transient consumer and gastro-intestinal aggravation if utilized for drinking purposes (Shankar *et al.* 2008).

The alkalinity of drinking water has little public health significance. Dissolution of CO_2 in groundwater results in alkalinity in natural groundwater. Carbonates and bicarbonates thus formed are dissociated to yield hydroxyl ions. The total alkalinity was found in the range of 112 - 821 mg/l in groundwater samples with a mean value of 377.5 mg/l and a standard deviation of 156.45 mg/l. Approximately 92% of samples exceeded the acceptable limit of 200 mg/l, but only 13% of samples exceeded the BIS permissible limit of 600 mg/l (BIS, 2012) (Fig. 5).

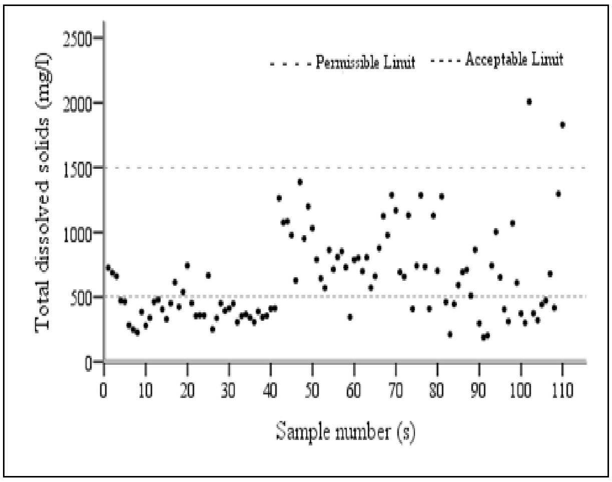

Fig. 4: Concentration of TDS in groundwater samples

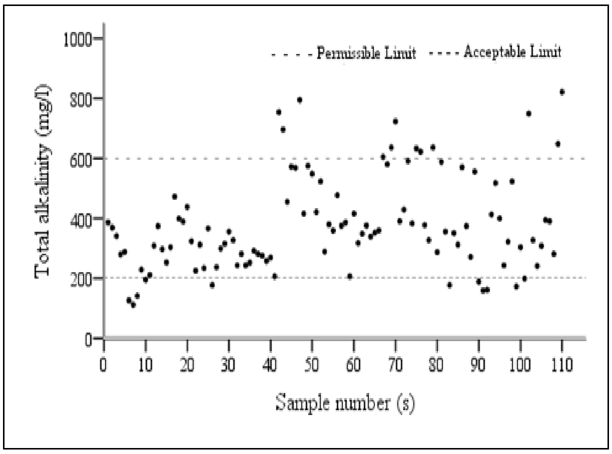

Fig. 5: Concentration of total alkalinity in groundwater samples

The total hardness values ranged from 96 mg/l - 794 mg/l in the study area with mean and median values of 352.1 mg/l and 333 mg/l, respectively, and a standard deviation of 145.29 mg/l. Only 9 % of the samples were under the BIS acceptable limit of 200 mg/l, and 6% of samples exceeded the BIS permissible limit (Fig. 6). Therefore, the groundwater can be categorized under hard to very hard category.

The concentrations of calcium ion (Ca++) in the sample area ranged from 33 to 248 mg/l, with a standard deviation of 42.85 mg/l. Just two groundwater samples surpassed the BIS allowable limit of 200 mg/l, notwithstanding the fact that 71% of samples exceeded the appropriate limit of 75 mg/l (BIS, 2012), as shown in Fig. 7. The magnesium (Mg) concentration varied from 3 mg/l to 71 mg/l with mean and median values of 24.36 mg/l and 22 mg/l, respectively. No samples exceeded the magnesium BIS permissible limit of 100 mg/l (Fig. 8). According to the relative abundance in rocks, generally, the calcium ion concentration in groundwater exceeded the magnesium ion concentration (Jain *et al.* 2010).

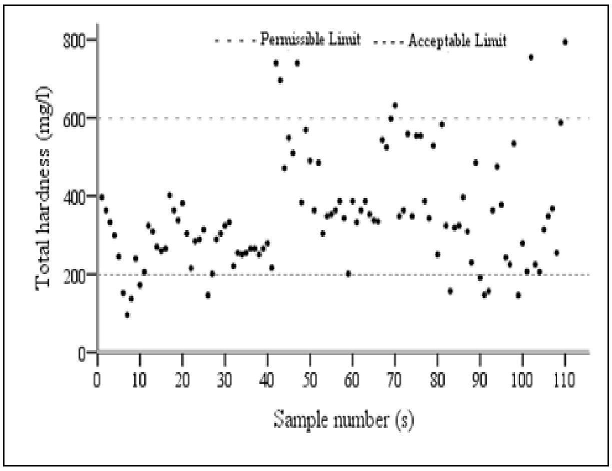

Fig. 6: Concentration of Total Hardness in groundwater samples

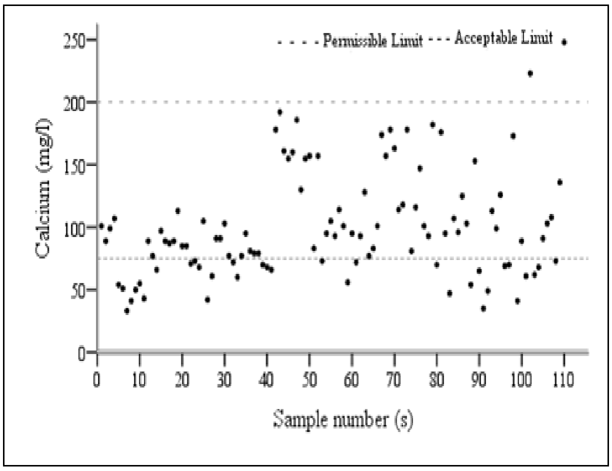

Fig. 7: Concentration of Calcium in groundwater samples

The chloride (Cl^-) concentration in groundwater samples have shown a wide variation from a minimum of 5 mg/l to a maximum of 247 mg/l with a standard deviation of 55.78 mg/l. All the groundwater samples in the study area are found within the BIS acceptable limit of chloride i.e., 250 mg/l (Fig. 9). High chloride concentrations in drinking water have no adverse health impacts on a human being (Jain *et al.* 2010).

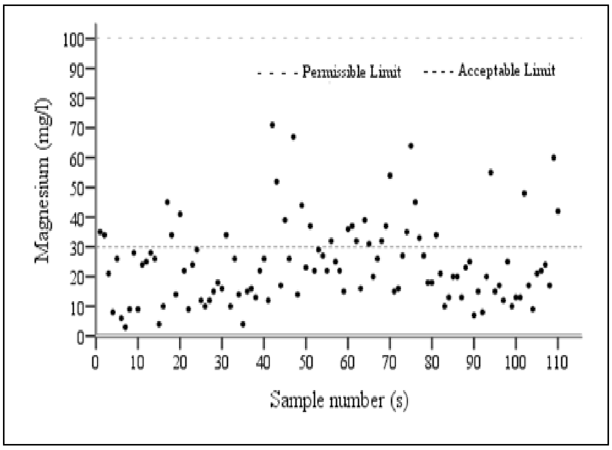

Fig. 8: Concentration of Magnesium in groundwater samples

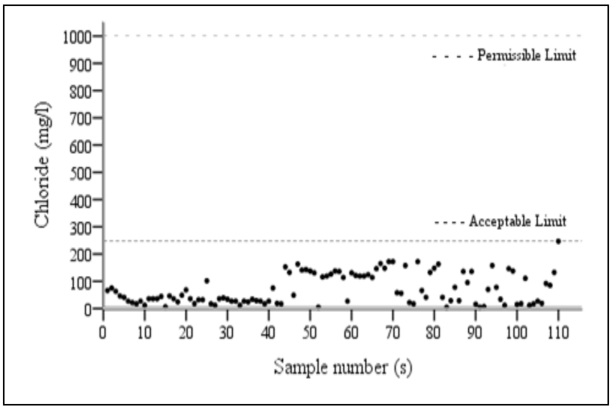

Fig. 9: Concentration of Chloride in groundwater samples

Major change takes place with time in sulphate ion concentration by groundwater recharge due to rainfall infiltration. In the groundwater samples, the sulphate concentration varied from 4 mg/l to 161 mg/l with a mean value of 27.95 mg/l. All the groundwater samples were found within the BIS acceptable limit of 200 mg/l in the study area (Fig. 10). Sulphate alone has no adverse impact on health, but it may cause gastro-intestinal irritations when it is more than 400 mg/l with sodium or magnesium (Shankar *et al.* 2008).

In many parts of India, high nitrate concentrations are reported in groundwater due to excessive use of nitrogen fertilizers in agriculture. More than 45 mg/l nitrate (NO_3) in drinking water causes Methemoglobinemia or Blue baby syndrome and Gastric Carcinoma (Tank *et al.* 2010). The concentration of nitrate ranged from 0.21 mg/l to 30.77 mg/l with a mean value of 7.44 mg/l. All groundwater samples were found within the acceptable limit of 45 mg/l (Fig. 11).

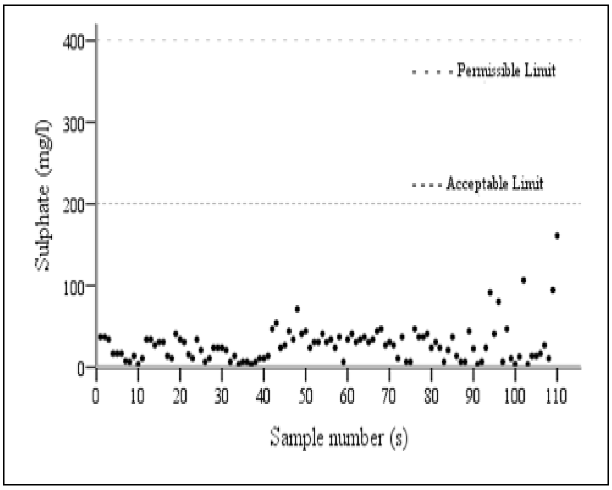

Fig. 10: Concentration of Sulphate in groundwater samples

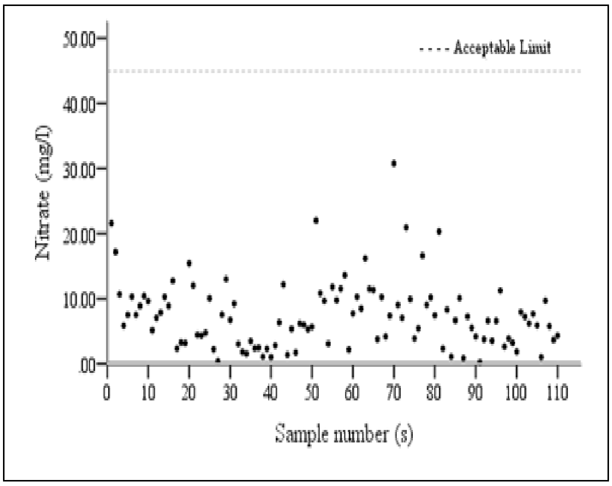

Fig. 11: Concentration of Nitrate in groundwater samples

Worldwide, the range of fluoride concentration in groundwater is 0.01 to 48 mg/l, which causes fluorosis and has an adverse impact on teeth and bones. Fluoride-contaminated drinking water is imposing a serious threat to human health. Fluoride generally occurs as a natural constituent in the groundwater. With a mean value of 1.72 mg/l, fluoride (F-) concentration varied from 0.30 mg/l to 4.88 mg/l in the study area. About 54% of samples were found within the acceptable limit of 1 mg/l as per BIS, whereas about 43% of samples exceeded the permissible limit of 1.5 mg/l (Fig. 12).

High concentrations of iron in groundwater result in turbidity, inky flavor and bitter and astringent taste. Groundwater, while pumping out, remains clear having soluble iron, but when it exposed to air, causes turbidity and rusty colour due to the precipitation of iron (Jain *et al.* 2010). In aquifers, high iron concentration occurs due to the interaction of oxidized Fe-bearing minerals and organic matter and subsequent dissolution of Fe_2CO_3 at lower pH. Another possibility is that reduced conditions due to dissolved oxygen removal by organic matter results in increasing the solubility of Fe-bearing minerals (Mondal *et al.* 2010). In groundwater samples, iron concentration varied from 0.06 mg/l to 2.24 mg/l with a standard deviation of 0.43 mg/l. Only 28% of samples were found within the acceptable limit of 0.3 mg/l as per BIS (Fig. 13).

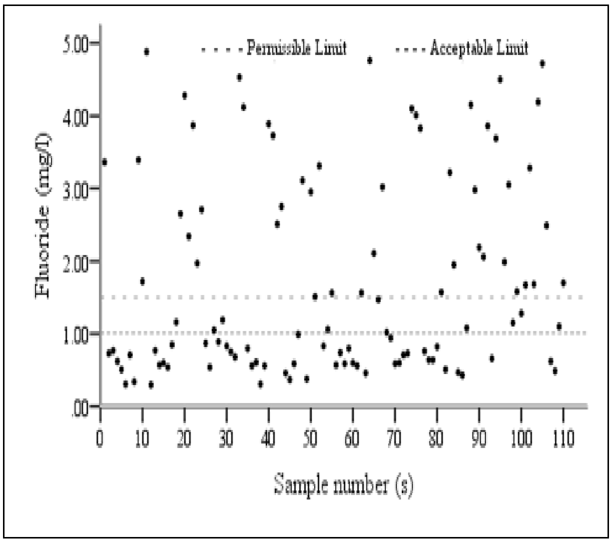

Fig. 12. Concentration of Fluoride in groundwater samples

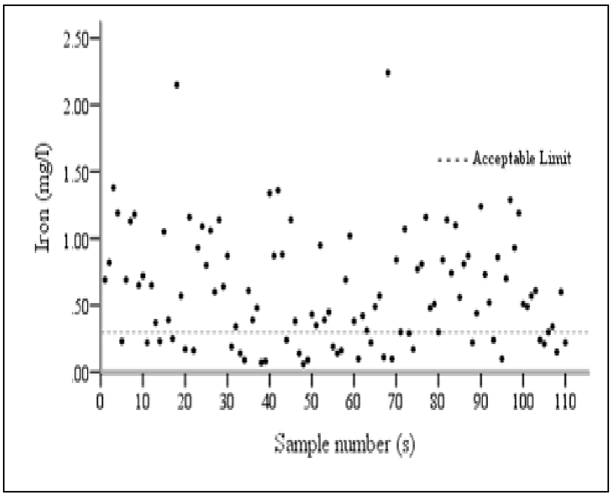

Fig. 13: Concentration of Iron in groundwater samples

Arsenic (As) contamination of groundwater is one of the most significant environmental evils. Melting operation, fossil fuel combustion, fertilizers, agrochemical and disposal of municipal and industrial wastes are the geologic and anthropogenic actions due to which it is prevalent (Requejo *et al.* 2006). Cancers, lung diseases, heart diseases and hyperkeratosis occurs in humans due to drinking water arsenic contamination (Mandal *et al.* 2002). The arsenic concentration in groundwater samples of the study area ranged from 3 µg/l to 9 µg/l with a mean value of 5 µg/l, and all groundwater samples were found to be within the acceptable limit of 10 µg/l (Fig. 14).

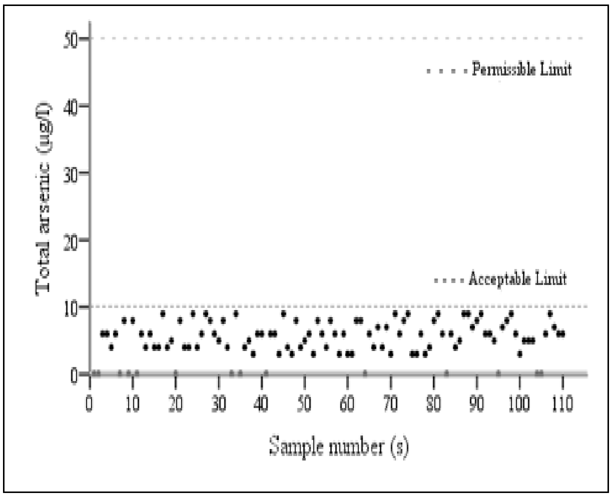

Fig. 14: Concentration of Total Arsenic in groundwater samples

A statistical measure of interrelationship and coherence pattern of two or more random variables is the Pearson's correlation coefficient which measures the degree of linear association and the closeness between independent and dependent variables. The correlation matrix presents the correlation coefficient value of the analyzed parameters in groundwater quality data (Table 2). Except for iron, magnesium and arsenic, most of the physico-chemical parameters were negatively correlated with the pH. Arsenic was not significantly correlated with any of the analyzed physico-chemical parameters. The significantly positive correlations were seen among alkalinity, electrical conductivity, total hardness and TDS and also with calcium, magnesium, sulphate, nitrate and chloride. The dependency of conductivity on TDS results in a high correlation between electrical conductivity and TDS (Singh *et al.* 2012).

Table 2. Correlation matrix for different water quality parameters

	pH	EC	TDS	TH	Ca	Mg	F	Fe	As	Cl	SO_4	NO_3	AKL
pH	1												
EC	-0.31	1											
TDS	-0.31	0.99	1										
TH	-0.26	0.92	0.91	1									
Ca	-0.28	0.89	0.88	0.94	1								
Mg	-0.14	0.67	0.66	0.77	0.51	1							
F	0.22	-0.03	-0.03	0.00	-0.07	0.13	1						
Fe	-0.01	-0.10	-0.11	-0.04	-0.03	-0.04	-0.11	1					
As	0.06	0.08	0.08	0.05	0.08	-0.03	-0.29	0.08	1				
Cl	-0.31	0.81	0.80	0.61	0.60	0.41	-0.13	-0.21	0.12	1			
SO_4	-0.21	0.74	0.73	-0.07	0.64	0.48	0.04	-0.07	0.04	0.57	1		
NO_3	-0.19	0.27	0.24	0.23	0.18	0.24	-0.09	0.09	-0.08	0.27	0.16	1	
ALK	-0.22	0.91	0.89	0.98	0.92	0.75	-0.01	-0.21	0.05	0.60	0.61	0.22	1

Iron and fluoride were not significantly correlated and also not significantly correlated with electrical conductivity, TDS, total hardness, magnesium, calcium, sulphate, nitrate, arsenic, alkalinity, as well as calcium and magnesium, were significantly correlated and also significantly correlated with chloride and sulphate. Nitrate was positively and significantly correlated with chloride and magnesium but not significantly correlated with sulphate and calcium. Chloride was positively correlated with sulphate and no significant relationships were found with fluoride.

4. CONCLUSION

The study revealed that in all the groundwater samples, pH, chloride, total arsenic, magnesium, nitrate and sulphate were under the BIS acceptable limit. TDS in 55%, total alkalinity in 92%, total hardness in 91%, calcium in 71%, fluoride in 46% and iron in 72% of the samples exceeded the BIS acceptable limit. Thus, for consumption in domestic purposes, the water should be treated first.

For thirteen variables, the correlation matrix was formed. The pH was negative and arsenic was not significantly correlated with most of the analyzed physico-chemical parameters. Electrical conductivity, alkalinity, total dissolved solids and total hardness were seen significantly positively correlated and furthermore with calcium, magnesium, sulphate, nitrate and chloride. Iron and fluoride were not significantly correlated and furthermore not significantly correlated with electrical conductivity, total hardness, total dissolved solids, calcium, magnesium, sulphate, nitrate, arsenic and alkalinity.

It was evident that the groundwater was severely affected by total alkalinity, total hardness, total dissolved solids, iron, calcium and fluoride in the study area.

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CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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