Analytical study of water quality parameters with special focus to uranium and fluoride concentration in groundwater of Bhagalpur district, Bihar, India

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Abstract - **The present status of groundwater in the study area was determined by studying spatial distribution of physical, chemical and radiological parameters of groundwater. Geographic Information System (GIS) technique was used to learn spatial variations in water quality parameters. Water samples were collected from 72 sites (bore wells) at varying depth during pre- and post- monsoon periods. In-situ water quality parameters were analyzed with the help of portable multi-parameter water analysis instrument and ex-situ parameters were analyzed in the laboratory as prescribed by APHA. Uranium was analyzed using LED Flourimeter as per BARC Standard Protocol for National Uranium Project (NUP). Special focus has been drawn to fluoride and uranium concentration in groundwater of Bhagalpur district because of having no previous study on uranium concentration in groundwater in the region and not having systematic study on fluoride mapping in groundwater of Bhagalpur district. Uranium concentrations in groundwater samples analyzed vary in a wide range from**

keywords - **Radiological parameters, Geographic Information System, spatial variations, water quality parameters**

1.1 Introduction

Water belongs to the world, not to an individual. It constantly moves and changes its form, but the total amount of water on the earth is constant. It plays a vital role in our existence. Therefore, we need to use water judiciously. People in general are using groundwater as potable water due to non-availability of surface water as safe drinking water. Anthropogenic activities lead to contamination of surface and subsurface water (Thilagavathi *et* al. 2012). Availability of potable water in terms of quality and quantity is threatened in many parts of the world (Redwan et al. 2016; Aghazadeh *et* al. 2010; Sridharan *et* al. 2017; Beyene *et* al. 2019) due to anthropogenic activities. Over-extraction of water from aquifer is one of the major causes that lead to increase in ionic concentration of groundwater (Kadam *et* al. 2020).

The physico-chemical and radiological parameters like pH, total dissolved solids (TDS), electrical conductance (EC), dissolved oxygen (DO), oxidation reduction potential (ORP), salinity, alkalinity, hardness, calcium, magnesium, iron, carbonate, bicarbonate, fluoride, chloride, sulphate, nitrate, phosphate, uranium, etc. are assessed to define the quality of groundwater. The availability of these parameters in groundwater beyond the permissible limit is considered as water quality hot-spots (CWC report, 2011). Special focus has been drawn to fluoride and uranium concentration in groundwater of Bhagalpur district mainly because of the following reasons;

(a) There are no previous geospatial studies reported on uranium concentration in groundwater in the region.
(b) Earlier studies (Kumari & Choudhary, 2017; Jha and Kumar, 2014; Verma *et al.* 2017)) report high fluoride concentration in groundwater in the district but lack systematic study on its mapping.

A radioactive ubiquitous element Uranium (Nolan *et* al. 2015; Nagaiah et al. 2013; Singh *et* al. 2018) is available naturally in all matrices of environment such as rocks, soil, food, water and air. Uranium in water gets derived mostly from host rocks and soil that the water runs over. The mechanism of leaching of uranium depends on factors like rock characteristic, contact time, temperature, and

elemental geochemistry. Geo-scientific research and Health physics are understood much better way by learning the radiation sources which may be caused by the naturally occurring radio-nuclides present in the local soils / sand originated from rocks. Other physico-chemical parameters (Yingzhi *et* al., 2020) like pH, ORP, EC, TDS, DO, salinity, total hardness, total alkalinity, major anionic ligands (Cl^-, NO_3^-, SO_4^{2-}, PO_4^{3-}, F^-), etc. also affect the concentration of uranium in groundwater (Shukla *et* al., 2018). The study of uranium toxicity (Selden *et* al., 2009; Shrivastava *et* al., 2015; Sharma *et* al., 2017) reported by some of the scientists across the globe drew attention of the Govt. of India to have in-depth study with a sense of urgency. It was why; a hydro chemical study was undertaken by the author under National Uranium Project (NUP, 2016) undertaken by Board of Research for Nuclear Studies (BRNS) under Bhabha Atomic Research Centre (BARC).

1.2 Material and Methods

1.2.1 Study Area

The study area covers the whole district of Bhagalpur (fig.1) that is located in the south-eastern part of Bihar spreading between the north latitudes of 25^0-03'-40" and 25^0-30'-00" and east longitudes of $86^0$30'00" and $87^0$29'45". It is a part of the mid- Gangetic alluvium plain covering an area of 2570km^2. Flat Indo-Gangetic alluvium tract and marginal alluvium tract are the major physiographic units whereas Ganga, Kosi, Bhadua, Koa, Garha, Chandan, Kadwa are the major drainages in the district. Kahalgaon Super Thermal Power, a coal based power plant in Kahalgaon Block is situated at 34km from Bhagalpur city. Figure-1 highlights the study area in Bihar, India (mapsofindia.com).

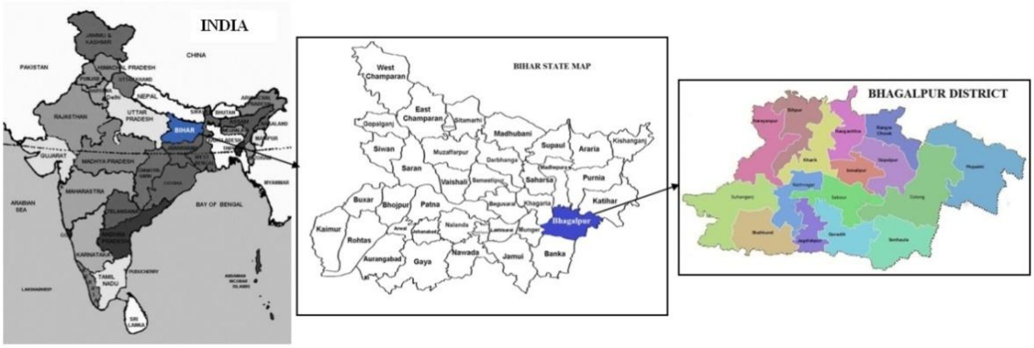

Fig. 1: Map of Bhagalpur district

1.2.2 Geology

Quaternary Formations and Basement Precambrian Granitic Gneiss with a few exposures as Inliers are the dominating geological formation in the district as per the report of Mines & Geology Department, Government of Bihar (2018)). Geologically, it represents generally granites, quartzites, phyllites, schists, amphibolites and intrusive all metamorphosed sedimentary and igneous rocks. The older and newer alluviums are contributory factors for the soils that are mainly loamy in character with moderate to heavy texture in the district. The pH of the soil gradually decreases from north to south. Soils of the study area comprise of vertisols, entisols, alfisols, andultisols. Highly fertile calcareous soils along the river Ganga comprise of inceptisols and entisols. Hydrogeologically, the newer and older quaternary alluvium sandy layers constitute the source of underground water as per the CGWB Ground Water Information Booklet, Bhagalpur District (2013). Fine to medium sand with clay, silt and kankars comprise of the shallow aquifers whereas sand, gravel and calcareous nodules with alternating layers of clay form the deeper aquifers (Srivastava *et* al., 2010).

1.2.3 Methodology

The study area was divided into optimized grid size of 6km x 6km using latitude-longitudes reference coordinates. One water sample from each grid was collected for analysis in pre-acid cleaned polythene bottle in both pre-monsoon and post-monsoon. Garmin GPS e-Trax was used to locate the sampling site (Phillips *et* al., 2001). A descriptive record of the sampling site was captured using camera. Radiation meter (Polimaster, PM 1405) was used to measure Gamma radiations at sampling site. Extensive sampling from 72 sites was carried out to analyze physical, chemical and radiological parameters during pre- and post-monsoon. The in-situ parameters as per the guidelines for water quality monitoring, Central Pollution Control Board (2007) were analyzed using electrode based sensor (SYSTRONICS Water Analyser-371). The ex-situ parameters were analyzed as per the Standard Protocol of American Public Health Association, 22nd Edition (2012). Quantitative measurement of uranium was carried out using LED Fluorimeter LF-2a (Quantalase, Indore) as per BARC Standard Protocol for National Uranium Project (NUP). Ion Selective method was used to measure fluoride concentration. SO_4^{2-} and PO_4^{3-} were measured by VIS Spectrophotometer whereas NO_3^- was measured using UV Spectrophotometer. Total hardness, total alkalinity, carbonate, bicarbonate and Cl^- were analysed as titrametric method as per standard protocol for NUP (2016) and APHA (2012).

1.3 Results and Discussion

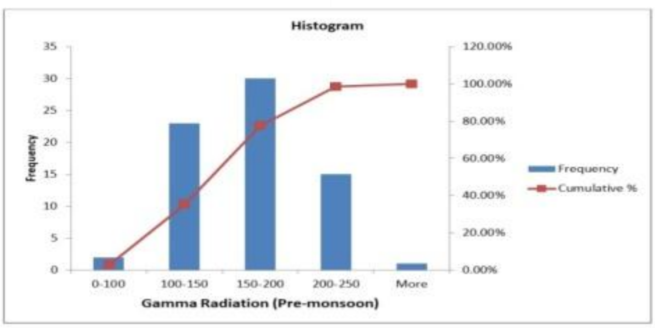

Fig.2

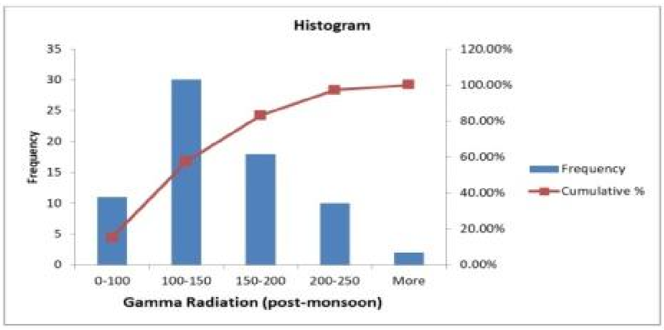

Fig.3

The frequency histogram of gamma radiation in the study area during pre- and post- monsoon is exhibited through fig. 2 and fig. 3. They show the level of terrestrial gamma radiation dose rate (TGRD) and the associated dose rates from the naturally occurring radio-nuclides (UNSCEAR, 1988; Rahman et al. 2005) in soil / rocks samples. The highest gamma radiation levels were measured at the depth of 150-200 feet followed by 100-150 feet in the region of Pirpainti and Kahalgaon in the range of 234-267nSv/h. It is in the range of Bhadeshwar Hill near Kahalgaon Super Thermal Power Station (KhSTPP) located in Kahalgaon Block and adjoining Salempur Hill of Pirpainti Block where metamorphosed sedimentary and igneous rocks

predominate. Rajmahal Coal Fields of Eastern Coalfields Limited (Lalmatiya) serves as the coal source and the river Ganges serves as a water source needed for electricity production in Kahalgaon Super thermal Power established in 1985. Large amounts of data were simplified quantitatively using Descriptive Statistics (Trochim et al., 2006) in our research study.
Descriptive statistical analysis of Uranium and associated water quality parameter of groundwater of Bhagalpur district during Pre- and Post-monsoon is shown in table-1.

Parameters	Pre-monsoon				Post-monsoon				BIS (2012) / WHO (2011) limits
	Min	Max	Average	Median	Min	Max	Average	Median	
pH	6.66	7.64	7.18	7.19	6.8	7.9	7.33	7.3	**6.5 – 8.5**
TDS (ppm)	267	1780	604.99	519.5	221	3839	614.18	421	**500**
EC (µS/cm)	534	3390	1129.14	974	445	7629	1227.96	840.5	**-**
Salinity (ppm)	250	1690	573.33	490	220	3760	605.28	415	
ORP (mV)	-24	26	1.78	1.5	-144	346	37.56	28	**-**
Temp. (°C)	27.3	33.8	29.57	29.25	26	34	29.53	29.5	**-**
DO (ppm)	6.5	9.5	7.55	7.4	1.2	2.8	1.96	2	**-**
F^- (ppm)	0.05	2.5	0.64	0.53	0.23	2.63	1.28	1.05	**1**
Cl^- (ppm)	7.09	287.14	51.69	33.68	7.09	903.98	158.15	76.22	**250**
NO_3^- (ppm)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	**45**
SO_4^{2-} (ppm)	1	148.36	25.92	17.76	1.0	125.75	20.51	13.94	**200**
PO_4^{3-} (ppm)	0.25	0.90	0.38	0.32	0.1	3.94	0.27	0.11	**-**
U (ppb)	0.25	29.28	8.03	5.94	0.21	29.32	9.50	7.81	**60 (AERB, 2004)**
Total Hardness (ppm)	90	925	275.35	240	85	475	211.18	185	**200**
Ca Hardness (ppm)	20	365	133.47	125	30	355	120.94	105	**-**
Mg Hardness (ppm)	10	775	141.87	107.5	10	270	90.24	80	**-**
Total Alkalinity (ppm)	35	135	75.28	72.50	85	370	173.82	165	**200**

Table-1: Comparison of water quality parameter of groundwater in Bhagalpur district (pre-monsoon & Post-monsoon

pH, EC, TDS, Salinity and ORP in the water samples were found to vary in the range of 6.7-7.6, 6.8-7.9; 534-3390µS/cm, 445-7629µS/cm; 267-1780 ppm, 221-3839 ppm; 250-1690 ppm, 220-3760 ppm and -24mV to 26mV, -144mV to 346mV during pre- & post- monsoon respectively. The TDS level was found to be higher than the BIS (2012) acceptable limit of 500 ppm-2000ppm for 1.38% water samples in post-monsoon. The TDS concentration, (sum of the cations and anions) in the water provides simply a qualitative measure of the amount of dissolved ions. Increased TDS beyond acceptable limits can have a significant impact on municipal, industrial, and agricultural use of water (Joseph, 1987).
Chloride level was found well within the acceptable limit of BIS 250ppm-1000ppm during pre- & post-monsoon. Nitrate and sulphate level in water sample during pre- & post- monsoon were found to be lesser than BIS acceptable limit of 45ppm-100ppm and 200 ppm-400 ppm respectively. The fluoride concentration varies in the range of 0.05ppm-2.5ppm with the average value of 0.64ppm and the median value of 0.53ppm in pre-monsoon and 0.23ppm-2.63ppm with the average value of 1.28ppm and median value of 1.05ppm in post monsoon. Fluoride (Mondal *et* al. 2014; Reddy *et* al. 2010; Ahda *et* al. 2017) level in 6.94% water samples during pre-monsoon and in 31.94% water samples during post-monsoon was found to be greater than BIS acceptable limit of 1ppm-1.5ppm. No dependence of higher fluoride concentration (>1.5ppm) is observed with depth of the bore well as (Table-2). The host rock may be responsible for fluoride contamination.

Table-2: Higher fluoride concentration with GPS coordinates

Tehsil	GPS Coordinate (WGS 84, decimal)		Depth of water level (feet)	Fluoride (ppm)
	Latitude	Longitude		
Pirpainti	25.263	87.41358	90	1.96
Pirpainti	25.2218	87.46936	85	1.96
Kahalgaon	25.3231	87.284705	120	2.23
Kahalgaon	25.254	87.26929	120	1.56
Kharik	25.3883	86.9825	120	1.97
Kharik	25.4264	86.9971	120	2.1
Bihpur	25.3923	86.93377	80	2.03
Narayanpur	25.4137	86.87782	120	1.97
Nathnagar	25.1635	86.93344	150	2.04
Shahkund	25.1354	86.11893	120	2.27
Shahkund	25.1216	86.88739	120	2.35
Shahkund	25.1212	86.81207	85	2.36
Sultanganj	25.1183	86.70686	120	2.18
Sultanganj	25.1344	86.69729	120	2.42

Sultanganj	25.1808	86.75024	150	2.37
Sultanganj	25.2099	86.70904	120	1.9
Sultanganj	25.2358	86.82294	150	2.21
Sanhaula	25.1538	87.16376	70	2.04
Goradih	25.1426	87.05714	70	1.95
Goradih	25.1923	87.04573	110	2.16
Jagdishpur	25.1446	86.9829	110	2.21
Jagdishpur	25.1109	87.04897	120	2.22
Jagdishpur	25.1137	86.96561	90	2.63

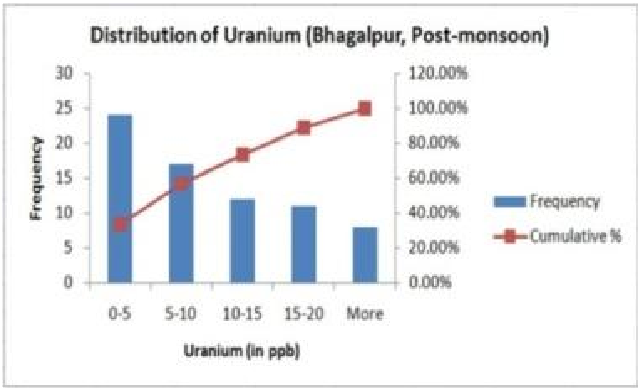

Fig 4

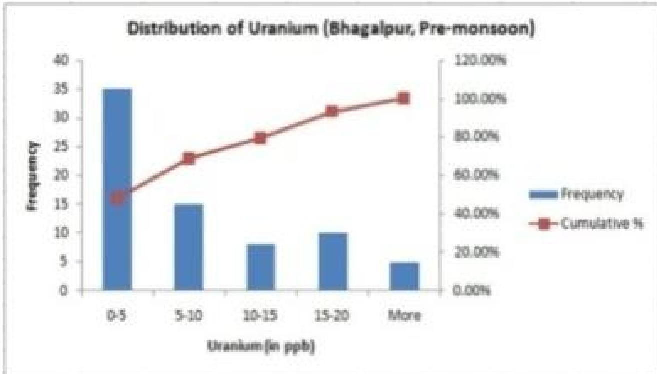

Fig 5

The uranium concentration in analyzed drinking water samples was found well within the safe standard limit of WHO (2011), US EPA (2011) and AERB (2004) varying from <0.5ppb to 29.28 ppb and from <0.5ppb to 29.32ppb with a median value of 5.88ppb and 7.82ppb in pre- & post-monsoon respectively.

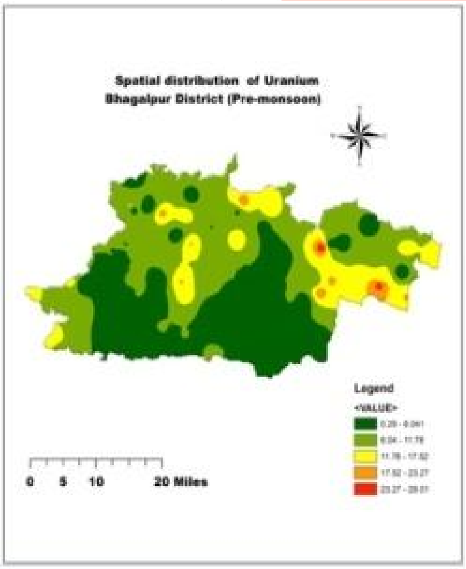

Fig.6 Uranium distribution (Pre-monsoon)

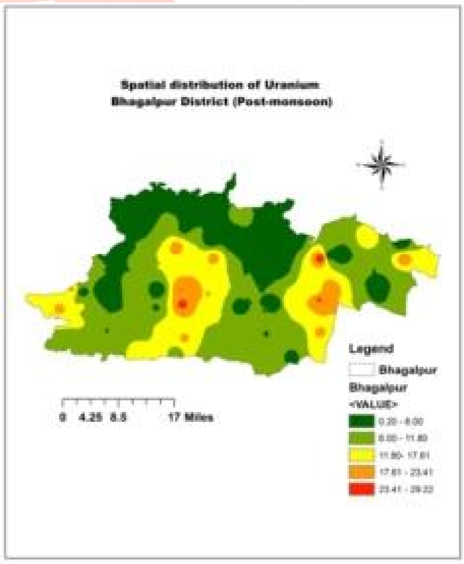

Fig.7 Uranium distribution (Post-monsoon)

Figure 4 and 5 highlight the distribution of uranium during pre- and post- monsoon respectively. The spatial hot spots of Uranium in Bhagalpur district during pre- & post-monsoon are shown in fig. 6 and fig. 7 respectively.

The linear relationship between two variables is established using correlations. Accordingly, Pearson correlation of different water quality parameters during pre- and post-monsoon are presented through table-3 and table-4. Positive correlation shown between the variables indicates that both the variables increase or decrease together, whereas negative correlation between them indicates that as one variable increases, so the other decreases, and vice versa.

Table-3: Pearson correlation of water quality parameters during pre-monsoon

	pH	TDS	EC	ORP	Temp.	Salinity	DO	Fluoride	Chloride	Nitrate	Sulphate	Phosphate	Uranium	Total hardness	Calcium hardness	Magnesium hardness	Total Alkalinity
pH	1																
TDS	-0.43332	1															
EC	-0.43468	0.99996	1														
ORP	-0.20239	0.42814	0.42706	1													
Temp.	-0.08198	-0.0666	-0.06598	-0.34093	1												
Salinity	-0.43483	0.99994	0.99999	0.42833	-0.06713	1											
DO	0.14952	-0.09437	-0.0959	-0.09713	0.01055	-0.09653	1										
Fluoride	0.10693	0.07422	0.07406	0.13179	-0.20991	0.07428	0.14927	1									
Chloride	-0.44518	0.86828	0.86857	0.37197	-0.06526	0.86812	-0.03234	0.11208	1								
Nitrate	-0.12586	0.23744	0.23791	0.20156	-0.16507	0.23858	0.01789	-0.14338	0.07656	1							
Sulphate	-0.45481	0.89124	0.89239	0.49065	-0.0982	0.89271	-0.08122	0.00705	0.83532	0.23872	1						
Phosphate	0.05343	0.17518	0.17589	0.05067	0.12923	0.17627	-0.12228	-0.03397	0.12111	0.0875	0.20118	1					
Uranium	-0.30786	0.50811	0.50889	0.46861	-0.17069	0.50981	0.10689	0.04028	0.43969	0.13504	0.58939	0.00092554	1				
Total hardness	-0.44823	0.71471	0.71601	0.34248	-0.02361	0.71628	-0.1569	-0.16217	0.78912	0.12029	0.78008	0.136673745	0.4768135	1			
Calcium hardness	-0.56884	0.73285	0.73255	0.34088	0.00124	0.73189	-0.23605	-0.26186	0.78396	0.12123	0.71562	0.13864746	0.2946008	0.788050359	1		
Magnesium hardness	0.00632	0.21478	0.21729	0.11622	-0.03996	0.21859	0.04989	0.07465	0.26968	0.03888	0.34322	0.0430048	0.3941584	0.606925344	-0.01097438	1	
Total Alkalinity	-0.10072	0.44568	0.44695	0.1102	-0.13652	0.44756	0.12233	0.41719	0.35919	0.08577	0.45023	0.168692728	0.367158	0.253796761	0.049771595	0.347987836	1

Table-4: Pearson correlation of water quality parameters during post-monsoon

	pH	TDS	EC	ORP	Temp.	Salinity	DO	Fluoride	Chloride	Nitrate	Sulphate	Phosphate	Uranium	Total hardness	Calcium hardness	Magnesium hardness	Total Alkalinity
pH	1																
TDS	-0.44528	1															
EC	-0.43976	0.99799	1														
ORP	-0.90015	0.38245	0.37706	1													
Temp.	0.01667	0.03951	0.07252	0.09037	1												
Salinity	-0.45397	0.99888	0.99849	0.38671	0.04412	1											
DO	0.01684	0.02086	0.00233	-0.04688	0.00857	0.013104	1										
Fluoride	0.10549	0.28595	0.30438	-0.1449	0.23084	0.283684	-0.19466	1									
Chloride	-0.4615	0.9215	0.92313	0.45511	0.15515	0.918673	0.03837	0.211303	1								
Nitrate	-0.02281	0.05738	0.05326	0.03072	-0.15736	0.055173	-0.01717	-0.0695344	-0.026307	1							
Sulphate	-0.36972	0.72018	0.7108	0.33613	-0.00264	0.710638	0.21159	0.2183726	0.6711016	0.18872	1						
Phosphate	0.22825	-0.29334	-0.30183	-0.26495	-0.20062	-0.296957	0.01133	-0.3107347	-0.283031	-0.11793	-0.2469711	1					
Uranium	0.04061	0.10931	0.09538	-0.10655	-0.42786	0.106555	-0.01434	0.0765345	0.0087944	0.19384	0.21376539	-0.069013605	1				
Total hardness	-0.47027	0.83208	0.81594	0.46742	-0.05807	0.826852	0.04	-0.0472201	0.8402623	-0.06981	0.55163936	-0.185826441	0.038583	1			
Calcium hardness	-0.36272	0.27159	0.23752	0.36786	-0.15641	0.257416	0.22905	-0.2891743	0.3663691	0.03243	0.42111264	0.132483052	0.0625803	0.50008094	1		
Magnesium hardness	-0.37721	0.83214	0.82881	0.37166	0.00308	0.832457	-0.0561	0.0745772	0.7993413	-0.09438	0.44442802	-0.271768875	0.0163458	0.92279696	0.1278232	1	
Total Alkalinity	-0.16575	0.65255	0.65327	0.02116	-0.12152	0.658849	0.14024	0.4153127	0.4033196	0.15766	0.43615951	-0.093143298	0.1682978	0.3385349	-0.082404	0.424383672	1

Other associated water quality parameters including uranium were found well within the recommended limit of BIS. However, concentration of uranium is found quite close to danger limit of 30 µg L^{-1} (WHO, 2011) at some places. Uranium concentrations are elevated mostly in Kahalgaon followed by Jagdishpur and Pirpainti block of the district. Thermal Power Station in Kahalgaon may be one of the factors causing enhanced uranium concentration. Therefore, constant monitoring of all those places is a must. A good correlation of Uranium concentration with TDS, EC, Salinity, Chloride, and total hardness are observed during pre- & post- monsoon.

1.4 Conclusion

The study brings out the fact that groundwater in the study area was found suitable as potable water in general with exceptions of increased fluoride concentration at some places. In board spectrum, test results were found to be compatible in pre- & post-monsoon. The appearance, taste, colour and odour were acceptable to the consumers. It was F^- (fluoride ion) concentrations available in varying aquifers of different depth that pose threat to human and animals being a prominent contaminant in the study area. 6.94% water samples during pre-monsoon and 31.94% water samples during post-monsoon contain higher concentration of fluoride than BIS acceptable limit of 1ppm-1.5ppm. Therefore, measures must be adopted to mitigate the fluoride contamination in the area specified before use. The geochemical conditions especially water-rock interaction may be responsible for increased concentration of fluoride. The elevated concentration of uranium is observed near Kahalgaon thermal power station. However, it is well within the safe standard limit of WHO, US EPA and AERB. There seems to have correlation between the composition of each lithological area and gamma radiation dose rate. Times to time qualitative and quantitative measurements are needed to constantly monitor the water quality parameters from the various groundwater sources to adopt appropriate remediation strategies.

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