ISSN: 0973-4929, Vol. 15, No. (3) 2020, Pg. 653-662

Current World Environment

www.cwejournal.org

Geospatial Groundwater Quality Assessment and Identification of Polluted Risky Regions in Jamui District of Bihar With Special Reference to Uranium and Fluoride Concentration

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Abstract

Groundwater is an important source for community water needs. Geographical Information System (GIS) mapping the spatial pollution characteristics helped identifying the potential polluted risky regions in Jamui district that is covering an area of 3098 km^2. It is situated between 24^{0}23'15" and 25^{0}08'30" North Latitude and 85^{0}49'30" and 86^{0}38'00" East Longitude forming a part of Phalgu-Kiul sub-basin of Ganga Basin. Water quality parameters such as pH, TDS, conductance, DO, ORP, salinity, alkalinity, hardness, calcium, magnesium, iron, uranium, carbonate, bicarbonate, fluoride, chloride, sulphate, nitrate, phosphate, etc of 91 samples were assessed as per standard protocol during pre- and post-monsoon. The results indicated that the water quality at several places in the study zone has been found contaminated with higher fluoride concentration that exceeded the permissible limit of BIS and WHO. Statistically16.48% water samples during pre-monsoon and 20.87% during post-monsoon were found seriously contaminated with fluoride concentration. However, the Uranium concentration during pre- and post-monsoon were found well within the prescribed national and international limits but at places it is in borderline and need constant monitoring. A positive correlation of fluoride with pH, total dissolved solid, electrical conductance, salinity, uranium and total alkalinity has been observed during pre-and post- monsoon. These results may provide useful information for control of groundwater pollution and its management in the area.

Article History

Received: 17 June 2020
Accepted: 18 November 2020

Keywords

Groundwater Quality,
Radiological Parameter,
Spatial Pollution,
Risky Regions.

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Doi: http://dx.doi.org/10.12944/CWE.15.3.30

Introduction

Groundwater is the water present beneath Earth's surface in pore spaces of the sediments and in the fracture of rock formation. Precipitation infiltrates below the ground surface into the aquifers causing groundwater. Water percolates downward after having saturated soil zone. Rain can cause the water table to rise whereas continuous extraction of ground water can cause the level to fall. Since groundwater is part of the hydrologic cycle, contaminants in other parts of the cycle, such as the atmosphere or bodies of surface water, can eventually be transferred into our groundwater supplies. Pollutants released to the ground due to surface activities such as ill agricultural practices, domestic / industrial waste disposal, mining, etc. and making their way down into underground water specially in shallow aquifers particularly in the permeable unconsolidated deposits cause groundwater contamination.[1]

Drinking contaminated groundwater can have serious health effects. Approximately one third of the world's population use groundwater for drinking.[2] More than 80% of India's population depends on groundwater for drinking and irrigation purposes. About 22% groundwater in India is either dried up or in the overexploited or critical categories as per the report of 'Dynamic Ground Water Resources of India.[3] A decrease in availability and quality of fresh water and a significant increase in demand for groundwater cause problems related to environmental sustainability.[4,5] The impacts of anthropogenic activities, the interaction of surface water and groundwater, rock water interaction and over-extraction of groundwater lead to deterioration of water quality[6] for drinking purposes in term of physical, chemical and radiological characteristics. A lot of attention has been drawn in the past in Jamui district due to fluoride contamination in ground water and its toxicity in human body.[7] There are various pathways of fluoride to enter in the groundwater[8] out of which interaction of fluoride containing mineral with aquifer water is the prominent one. The fluoride hazard mainly includes dental fluorosis or skeletal or non-skeletal fluorosis resulted from excess exposure.[9] A naturally occurring radionuclide Uranium is increasingly becoming a concern for people on the globe these days for its radioactivity, toxicity and its carcinogenic potency.[10-15] It is found in all matrices of environment such as rocks, soil, air, surface / underground water, in fauna and flora in varying amounts. Uranium contaminant in water is either geogenic or man-made.[16] It can find its way into drinking water when groundwater or rainwater dissolves mineral that contains uranium.[17,18] Access to safe drinking water has become a challenge in developing countries in the context of growing population and increasing water contamination.[18-25]

Groundwater pollution potential in the study zone has been assessed by means of proper data analysis of water quality parameters such as pH, TDS, conductance, DO, ORP, salinity, alkalinity, hardness, calcium, magnesium, iron, uranium, carbonate, bicarbonate, fluoride, chloride, sulphate, nitrate, phosphate, etc as per standard protocol. Recorded data from ongoing monitoring program, hydro geological and geographical information, published studies, and environmental impact assessments are the important factors for evaluation of water quality. The Fig.1 shows location of Jamui district[26] in Bihar (India).

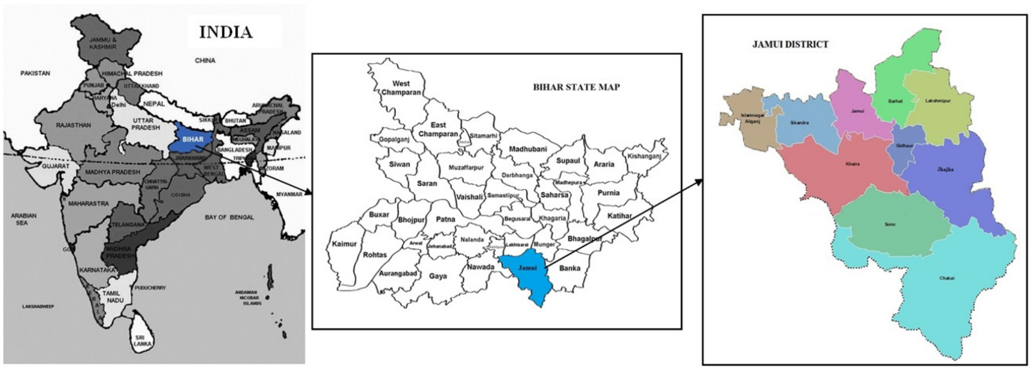

Fig.1: Location of Jamui district

The objective of the present study is to analyze the quality of groundwater of the Jamui district, Bihar (India) with emphasis on uranium and fluoride distribution and concentration because of having very limited information on groundwater quality of the district.

Study Area[27]

Jamui district, a part of Phalgu-Kiul sub-basin of Ganga Basin is situated between 24^{0}23'15" and 25^{0}08'30" North Latitude and 85^{0}49'30" and 86^{0}38'00" East Longitude covering an area of 3098 km^2. The catchments of Kiul and Barnar rivers form a major part of the district. It has a diverse geomorphology ranging from hills to flood plains comprising of alluvial plain, rocky upland, and plateau /pediplain. Jamui terrace represents alluvial plain. Denudation of Chakai plateau and Kharagpur hill results in the formation of sediments causing alluvial plain consisting of ultisols and alfisols group of soils. They are formed under different lithological and pedogenic conditions. Hard rock/ fissured formation and unconsolidated / porous formation are the two main parts prevailing in the district hydro geologically. Granite gneisses[28] (Chotanagpur gneissic complex), quartzite and phyllites (Kharagpur gneissic formation) contribute the fissured formation. Fracturing / weathering of rocks develop the secondary porosities leading to the formation of poor aquifer being main repository of ground water in the rock. The quaternary alluvium creates the main hydro geological unit.

Material and Method

Sampling and Measurement of In-Situ Parameters

A grid map of Jamui district was prepared at the optimized grid size of 6km x 6km using latitude-longitudes as reference coordinates. GPS Coordinates of the sampling sites in all the grids were noted using Garmin GPS e-Trax. Radiation meter (Polimaster, PM 1405) was used to measure gamma radiation and Polaroid camera was used to make descriptive record of the sampling site. The sampling of groundwater from 91 locations in the study area was done at different depths i.e., shallow (<30 m), medium (30-60 m) and deep aquifer (>60 m)) during pre-and post-monsoon in 2016-2018 (fig.2). Water samples were collected in a cleaned (with 15% (v/v) HNO_3 acid followed by double distilled water) flexible double capped, unbreakable polypropylene bottle.

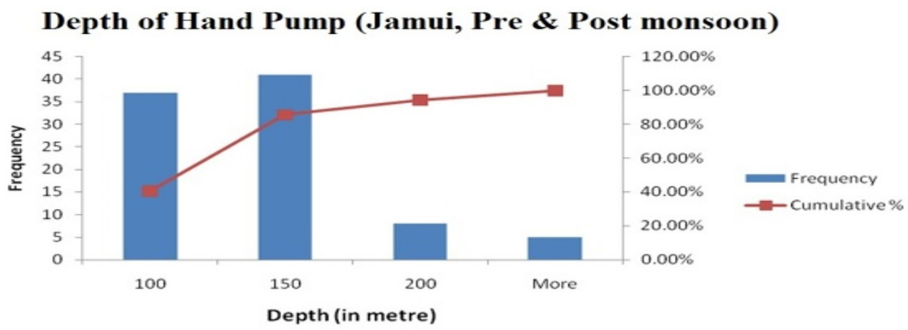

Fig.2: Depth of Aquifer

pH, temperature, total dissolved solids (TDS), electrical conductivity (EC), dissolved oxygen (DO), salinity, oxidation reduction potential (ORP) etc. were measured using field instruments immediately after the sample was collected. One litre water sample was collected in a neck to neck filled bottle for analysis of U, F^-, Cl^-. NO_3^-, SO_4^{2-} and PO_4^{3-}. Duplicate acidified sample (1ml of Conc. HNO_3 for 500 ml of water) was also collected from each sampling site.

Sample Analysis in the laboratory

Major cations and anions were analyzed in the collected water samples at the chemistry lab of A N College, Patna. LED Fluorimeter LF-2a (Quantalase, Indore) was used to measure uranium concentration as per BARC Standard Protocol for National Uranium Project (NUP).[29] Fluoride concentration was measured using Ion Selective method. SO_4^{2-}, PO_4^{3-} and NO_3^-, total hardness, total alkalinity and

Cl- were analysed as per standard protocol for NUP[29] and APHA[30].

Result

The descriptive statistical analysis of uranium and associated water quality parameter of groundwater in the study area during pre-monsoon and post-monsoon is shown in table-1.

pH, EC, TDS, Salinity and ORP in the water samples were found to vary in the range of 6.5-8.86, 6.36-8.01; 134-1985µS/cm, 162-2310µS/cm; 72ppm-1134ppm, 91ppm-1240ppm; 30ppm-1130 ppm, 100ppm-1390ppm and -253mV to 44mV, -44mV to 40mV respectively during pre- and post- monsoon. The stated values fall almost within the permissible limit of BIS.

Table-1: Descriptive statistical analysis of Uranium and associated water quality parameter

Parameters	Pre-monsoon				Post-monsoon				BIS[31] limits (Desirable – Permissible)
	Min	Max	Average	Median	Min	Max	Average	Median	
pH	6.5	8.86	7.55	7.4	6.36	8.01	7.04	6.99	6.5 – 8.5
TDS (ppm)	72	1134	393.67	324	91	1240	355.33	237	500ppm – 2000ppm
EC (µS/cm)	134	1985	724.29	603	162	2310	646.35	422	-
Salinity (ppm)	30	1130	391.813	320	100	1390	367.826	210	
ORP (mV)	-253	44	-32.11	-19	-44	40	5.52	7.0	-
Temp. (°C)	23.6	33	28.75	29	24.6	29.1	26.66	26.5	-
DO (ppm)	2.9	14.9	6.22	6.3	3.5	5.7	4.58	4.6	-
F^- (ppm)	0.1	5.14	1.053	0.79	0.13	3.6	0.97	0.72	1ppm - 1.5ppm
Cl^- (ppm)	7.09	255.24	46.01	28.36	10.64	287.15	65.81	39.0	250ppm – 1000ppm
NO_3^- (ppm)	0.5	12.3	4.53	4.2	0.5	8.90	3.68	3.90	45ppm – 100ppm
SO_4^{2-} (ppm)	1.0	115.47	17.77	8.14	2.06	165.08	27.70	12.98	200ppm – 400ppm
PO_4^{3-} (ppm)	0.1	2.01	0.15	0.1	0.33	0.74	0.41	0.37	-
U (ppb)	0.50	20.07	4.89	1.60	0.50	29.45	8.02	3.90	60 (AERB32)
Total Hardness (ppm)	30	615	221.32	185	45	695	204.56	140	300ppm-600ppm
Ca Hardness (ppm)	15	430	102.86	80	35	550	156.30	105	-
Mg Hardness (ppm)	10	480	118.46	95	10	145	48.26	40	-
Total Alkalinity (ppm)	5	110	41.26	35	10	105	46.74	40	200ppm – 600ppm
Bicarbonate (mg of $CaCO_3$)	5	110	41.26	35	10	105	46.74	40	

Distribution of fluoride concentration in water samples during pre- & post- monsoon is addressed by fig. 3 & fig 4

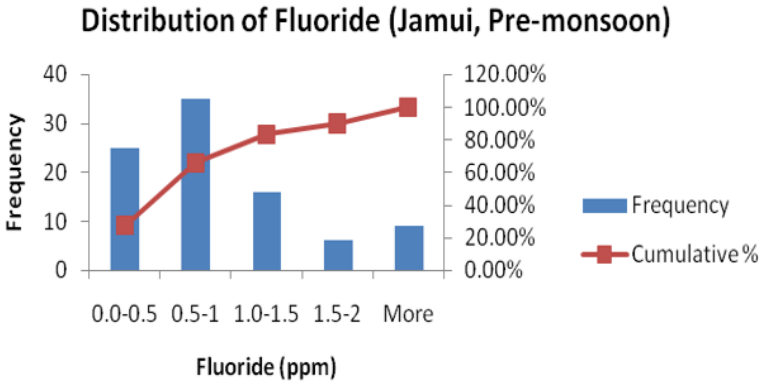

Fig. 3: Fluoride distribution (Pre-monsoon)

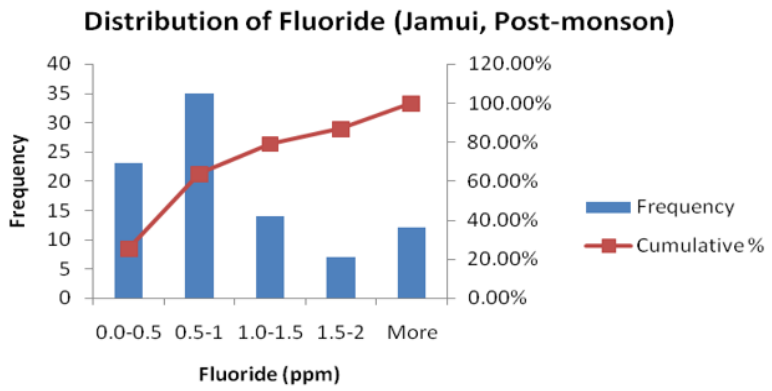

Fig. 4: Fluoride distribution (Post-monsoon)

Fluoride concentration varies in the range of 0.1ppm-5.14ppm with the median value of 0.79ppm and 0.13ppm-3.6ppm with the median value of 0.72ppm during pre- & post-monsoon respectively. The values of fluoride concentration exceed the permissible limit of BIS and WHO[33] in some of the analyzed samples.

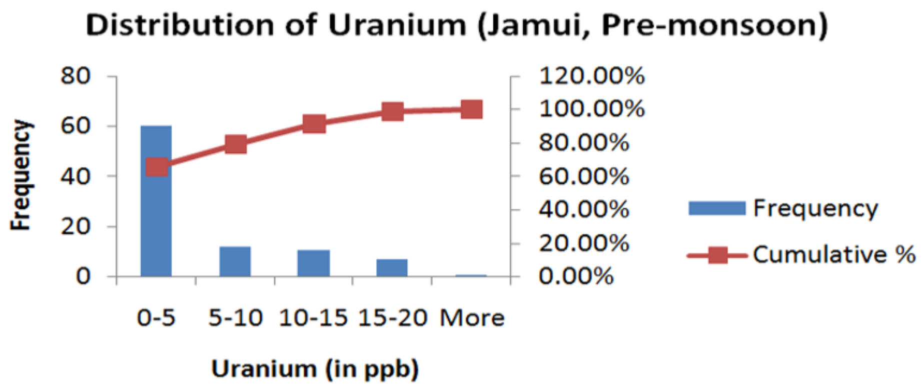

Fig. 5: Distribution of Uranium (Pre-monsoon)

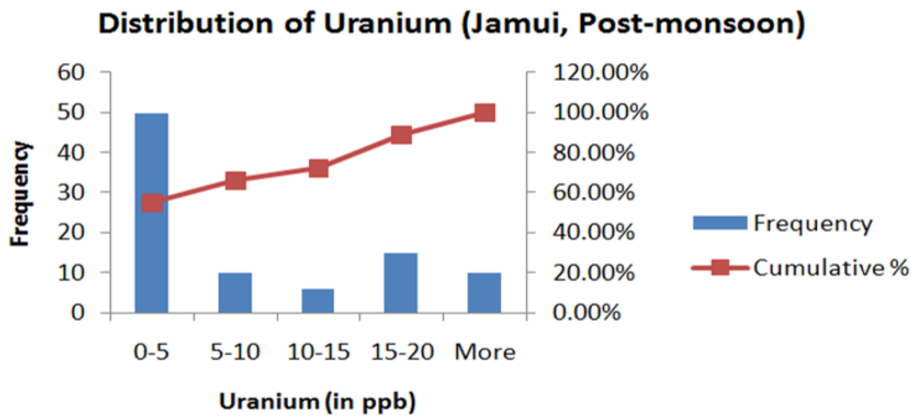

Fig. 6: Distribution of Uranium (Post-monsoon)

The distribution of Uranium during pre- & post monsoon is shown by fig.5 & fig.6. Uranium level in analyzed water samples varies in the range of <0.5-20.07ppb and <0.5-29.45ppb with a median value of 1.6ppb and 3.9ppb respectively in pre- & post-monsoon. Rest of the chemical parameters is found to be well within the permissible limit of BIS.

Discussion

Alkaline nature of groundwater was recorded irrespective of the aquifer sampled. The cations and anions dissolved are well within ±5% of normalized inorganic charge balance. Elevation of fluoride concentration in 16.48% water samples during pre-monsoon and in 20.87% water samples during post-monsoon from aquifers of varying depth has been observed higher than WHO and BIS limits. It is indicative of water rock interaction. The sources of human exposure to the increased concentration of fluoride[34-36] in drinking water have drastically increased. In view of the cases of fluoride toxicity[37], it is urgently needed to be addressed in the study area. Spatial statistics was used to identify the uranium hotspot[38] in groundwater in the study area during pre- & post-monsoon as represented through fig.7 & fig.8. At some places as is evident from the figure, it is in borderline and need constant monitoring. Fluctuation of uranium concentration has been found in water samples from aquifers of different depth.

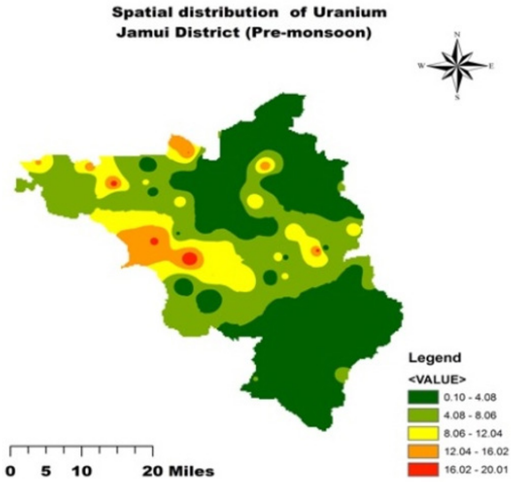

Fig. 7. Hot spot of uranium (pre- monsoon)

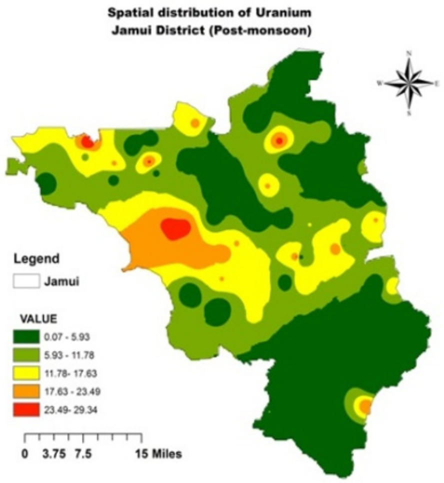

Fig. 8. Hot spot of uranium (post-monsoon)

Pearson correlation has been established among analyzed parameters during pre- and post-monsoon (table-2 & table-3).

A positive correlation of fluoride with pH, total dissolved solid, electrical conductance, salinity, uranium and total alkalinity was observed[39] during pre-and post- monsoon. Strong correlation of uranium has been observed with TDS, EC, salinity, total hardness, total alkalinity, fluoride, chloride and sulphate. However, there is negligible correlation between uranium with phosphate. Likely, no correlation has been observed between fluoride and chloride.

Table-2: Pearson correlation (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	0.19326821	1															
EC	0.15686216	0.995148572	1														
ORP	-0.6678187	-0.173670273	-0.15083	1													
Temp.	-0.168402	-0.010942393	-0.02304	0.19291	1												
Salinity	0.17519434	0.99750929	0.994701	-0.15081	-0.02172	1											
DO	-0.080714	0.048093343	0.035979	-0.13781	0.003731	0.048934	1										
Fluoride	0.3714962	0.020447543	0.015176	-0.27935	-0.04377	0.020359	-0.23881	1									
Chloride	-0.0787475	0.834375792	0.851084	0.017607	-0.05926	0.83236	-0.07017	-0.14855	1								
Nitrate	0.11510361	0.323555736	0.316562	-0.12004	-0.09588	0.321824	-0.02252	0.031691	0.242265	1							
Sulphate	-0.0117973	0.780722897	0.782984	-0.05045	0.007816	0.779893	-0.0756	-0.12914	0.815945	0.201343	1						
Phosphate	0.16306185	0.111670934	0.102328	-0.01053	-0.11473	0.115016	0.081878	-0.06948	0.14495	-0.04151	-0.01087	1					
Uranium	0.17510183	0.717781019	0.720498	-0.17315	-0.07505	0.724417	-0.03487	0.302897	0.522959	0.214598	0.517806	0.05173796	1				
Total hardness	0.00353316	0.847522654	0.864168	-0.02679	-0.04459	0.850298	-0.04492	-0.15207	0.869769	0.244416	0.752328	0.10570751	0.5976668	1			
Calcium hardness	-0.1898818	0.510589515	0.554072	0.05858	-0.02331	0.506955	-0.07889	-0.1572	0.691563	0.136891	0.567776	-0.12761808	0.4116573	0.73257	1		
Magnesium hardness	0.16683903	0.784432791	0.771341	-0.08845	-0.04429	0.791522	0.002575	-0.08488	0.662273	0.235046	0.598754	0.26080365	0.5092252	0.814713	0.202126	1	
Total Alkalinity	0.1579631	0.762985135	0.748547	-0.11683	-0.00452	0.773638	0.18666	0.101863	0.377953	0.260024	0.436574	-0.12942778	0.6388782	0.522819	0.218948	0.565701374	1

Table-3: Pearson correlation (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	0.18339	1															
EC	0.182228	0.997862	1														
ORP	-0.86694	-0.21522	-0.22177	1													
Temp.	0.399537	0.301076	0.327007	-0.38639	1												
Salinity	0.207452	0.993551	0.992974	-0.23832	0.31641	1											
DO	-0.08948	-0.30026	-0.30143	0.040075	-0.1824	-0.30627	1										
Fluoride	0.404902	0.176276	0.176797	-0.29128	0.049329	0.196367	-0.214	1									
Chloride	0.039206	0.866015	0.864121	-0.18384	0.222608	0.84798	-0.11535	-0.00268	1								
Nitrate	0.082656	0.277314	0.264897	-0.0979	0.099843	0.259188	0.072189	-0.02169	0.28355	1							
Sulphate	-0.01988	0.81864	0.814509	-0.00034	0.220087	0.805605	-0.20098	0.035337	0.807327	0.12628	1						
Phosphate	-0.06303	-0.11723	-0.11332	0.052495	0.062192	-0.11323	0.039119	0.106755	-0.08143	-0.06051	-0.03306	1					
Uranium	0.355552	0.734328	0.721149	-0.3005	0.186725	0.735888	-0.12405	0.445474	0.597779	0.225191	0.542122	-0.0895368	1				
Total hardness	0.073699	0.916097	0.908668	-0.0844	0.222046	0.908606	-0.18364	0.034276	0.786969	0.266829	0.756143	-0.1225531	0.692378	1			
Calcium hardness	0.037934	0.866875	0.861673	-0.04786	0.198737	0.855546	-0.17093	0.029278	0.748915	0.249566	0.729752	-0.1248353	0.660514	0.9630101	1		
Magnesium hardness	0.131454	0.776678	0.766416	-0.14096	0.212927	0.779522	-0.16183	0.035904	0.658031	0.232565	0.610194	-0.0846738	0.575432	0.8115105	0.624034	1	
Total Alkalinity	0.33693	0.828166	0.832124	-0.3709	0.302321	0.836647	-0.37957	0.280542	0.595862	0.188032	0.490199	-0.1706644	0.598354	0.7105231	0.683182	0.578893031	1

Conclusion

Current finding involves the area where general water quality is found to be suitable but some important parameters such as pH and fluoride concentration exceeded the permissible limit of BIS and WHO at several places. Fluoride concentration in 16.48% water samples during pre-monsoon and in 20.87% water samples during post-monsoon were found higher than BIS and WHO acceptable limit of 1ppm-1.5ppm. Elevated fluoride level has been observed in varying aquifers of different depth which may be caused to water-rock interactions. It draws the attention of the authorities to supply de-fluoridated water to the residents for drinking purposes. However, uranium level in analyzed water samples were well within the safe standard limit of WHO, US EPA[40] and AERB along with other associated water quality parameters during pre- and post-.monsoon but at some places it is in borderline and need constant monitoring. These results may provide useful information for control of groundwater pollution and its management in the study area with the time. The continuous assessment of such parameters is important for future perspective and awareness[41,42]. Educating the users and defluorinating the groundwater before consumption are essentially important for the resident.[43,44] Implementation of rainwater harvesting schemes in the affected area may be a resilient and sustainable solution for dilution of elevated ionic concentration in water for drinking and irrigation purposes. Use of rainwater capture by check dams and other small system following simple treatment of coagulation, flocculation, filtration and chemical treatment may prove the ultimate economical solution for the fluoride menace in the study area based on the principal of "Prevention is better than cure" because of having good quality of surface water in the study zone.

Acknowlegdement

The authors are thankful to the residents of the study area for providing assistance in collecting the samples. The present work is a part of the research project funded by BRNS, DAE, Government of India, (GoI) vide NRFCC Letter no 36(4)/14/37/2015-BRNS/10046 dated 2nd May 2016. Hence, the financial support from the BRNS is acknowledged. Special thanks goes to Dr Ajay Kumar, Health Physics Division, BARC, Mumbai along with the member of TSC-4, NRFCC, BRNS, HPD, HS & E Group, BARC and NUP team members for their continual support.

Funding Sources

The author got no financial assistance from any government or non- government organization.

Conflict of Interest

Author has no conflict of interest in this article.

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