Uranium Contamination in Shallow Aquifers of Haryana State, India

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Abstract - *Haryana, the state in the northern region of India is having an area of 44,212 sq. km and home to 2.54 crore people. The state is flourishing in the economic sectors like Agriculture, Industry and Services sector. In most of rural and semi-urban areas of Haryana State, ground water is a major source for drinking and irrigation purposes. During the present study, 451 number of ground water samples were collected from dug wells and/or hand pumps of shallow depths spread uniformly over 22 districts of Haryana. Monitoring of the ground water quality through these structures has been carried out for its various parameters including uranium. The ground water in the state is in general suitable for drinking purposes except at few places where it is not suitable due to high salinity or high fluoride or nitrate or combination of these parameters. As a part of special study, Uranium concentrations in shallow aquifers are studied with an objective to know the distribution in space and its health impacts in the state. Uranium is naturally occurring actinide series element, having three major isotopes: Uranium-238 (99.28% natural abundance), Uranium-235 (0.71% natural abundance), Uranium-234(0.0054% natural abundance). All these isotopes are radioactive emitting alpha particles. There are other five trace isotopes. Uranium-238 is the most stable isotope of uranium, with a half-life of about 4.468×10^9 years. Uranium-238 is usually α emitter (occasionally, it undergoes spontaneous fission), decaying through the uranium series which has 18 members, into Lead-206, by a variety of different decay paths. A person can be exposed to uranium (or its radioactive daughters, such as radon) by inhaling dust in air or by ingesting contaminated water and food. In Haryana, except for the districts like Mewat, Panchkula and Rewari, all other districts are having pockets where uranium concentration is above WHO limits of 30 µg/L. High Uranium content up to 300.8 µg/L in ground water is one of the most serious concerns as it is being released from large unconsolidated aquifers in to ground water and the problem is compounded because the drinking water supply in the thickly populated parts is dependent on shallow aquifers which are found to be contaminated. The study also reveals correlation between the Uranium concentration and the parameters like Electrical conductivity, Fluoride, Chloride and Nitrate. The correlation reveals some positive correlation between these parameters. It is observed that there is strong correlation between uranium and fluoride which can be interpreted as geogenic source of contamination for uranium.*

***Key Words*: Ground Water Quality, Uranium, Water pollution, Haryana.**

1. INTRODUCTION

Uranium is a radioactive element occurring naturally in groundwater, soil and sediments [1][2]. Uranium is having three major isotopes: Uranium-238 (99.28% natural abundance), Uranium-235 (0.71% natural abundance), Uranium-234 (0.0054% natural abundance). All these isotopes are radioactive emitting alpha particles. Uranium-238 is the most stable isotope of uranium, with a half-life of about 4.468×10^9 years. Uranium-238 is usually α(alpha) emitter (occasionally, it undergoes spontaneous fission), decaying through the uranium series which has 18 members, into lead-206, by a variety of different decay paths.

Normal functioning of the kidney, brain, liver, heart, and other systems can be affected by uranium exposure, because, besides being weakly radioactive, uranium is a toxic metal. Uranium is also a reproductive toxicant. Radiological effects are generally local because alpha radiation, the primary form of uranium-238 decay, has a very short range, and will not penetrate skin. A more comprehensive systematic studies is required to establish the chronic health effects of uranium exposure [3]. Uranium contaminated water, if consumed has the potential of causing chronic lung diseases and nephrotoxic damage [4][5][6][7]. The occurrence of uranium in groundwater especially in Haryana state, is very poorly understood and documented. Reports of widespread uranium contamination [8][9] in groundwater across India demand an urgent response. Hence it is very much required to quantify the amount of naturally/otherwise occurring uranium in ground water which is being used for various purposes.

2. METHODOLOGY

The total 451 ground water samples were collected during monitoring of national hydrograph network stations established by Central Ground Water Board. All the samples were collected in 100 mL HDPE bottles, filtered with special filter and acidified with 0.50mL supra-pure nitric acid (67%). The analysis of Uranium has been carried out by Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) technique installed in Chemical laboratory of CGWB at Chandigarh. The location map of samples collection for uranium study depicted in Figure-1.

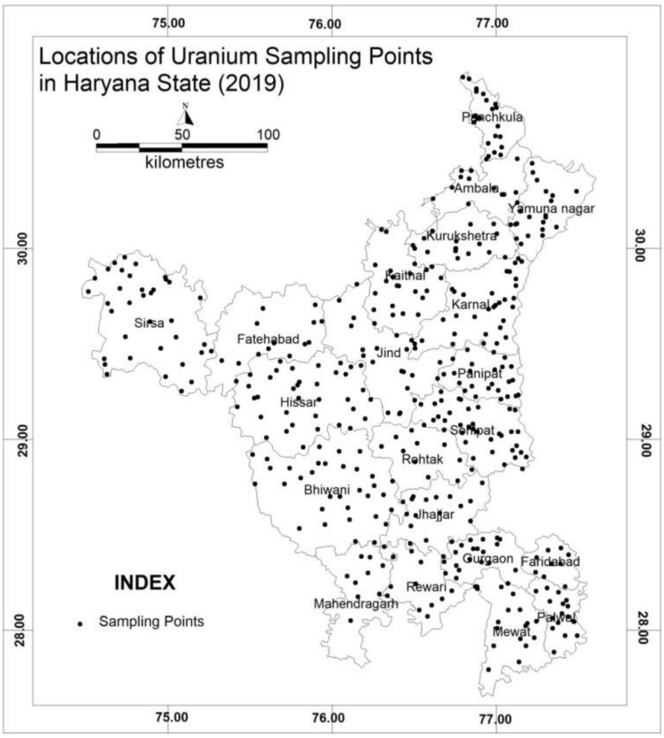

Fig -1: Sample Locations

3. HYDROGEOLOGICAL SETUP

Three geological groups are present in Haryana state viz. Pre-Cambrian, Tertiary and Quaternary. The Quaternary group comprises of Alluvium which occupies 98% of the area of the state. The Tertiary group is represented by the outermost zone of the Siwalik system composed mainly of sandstones, clay and boulders. The rocks of Pre-Cambrian age which form part of the Aravalli hill ranges are exposed in Gurgaon, Mewat and Faridabad districts and as small outcrops in other southern districts. The area in Panchkula, Ambala amd Yamunanagar is underlain by the 'Kandi, Sirowal and the Alluvium. The sediments comprise boulders, pebbles, gravel and sand with clays mixed in varying proportions. The area in Gurgaon district is underlain by the rocks of Delhi system and by Quaternary alluvium. In Hisar and Bhiwani districts area is underlain by unconsolidated sediments of Quaternary age. The sediments comprise sand, silt, clay and kankar. In Sonipat, Jind, Karnal and Kurukshetra districts the area is underlain by alluvium deposits of Quaternary age. Alluvium comprises clay, silt, and sands of various grades, kankar, gravel and pebbles. In Mahendragarh and parts of Bhiwani districts, alluvium and windblown sands are underlain by Post Delhi intrusive- Pegmatite, quartz veins, granites etc. Prolific aquifers are present in the alluvial zones in the state with yield potentials ranging between 300 to about 1500 LPM discharges. The depth to water level during May 2018 varies from 0.74 m bgl at Bhalaut in Rohtak district to 100m bgl at Kultajpur in Mahendragarh district.

4. SOURCE OF WATER POLLUTION

The quality of groundwater may be impacted by naturally occurring processes as well as by actions directly attributable to human activities. Four general ways in which the chemical composition of groundwater may be changed include natural processes, nonpoint agricultural and urban runoff, waste disposal practices, spills, leaks and other unintentional/intentional releases. The magnitude of environmental impact associated with each of these processes may be far different. The nature of contamination impacts may be assessed in terms of the characteristics of the chemicals that are released and in terms of their distribution and difficulty of restoration or containment. In addition, impacts are directly related to potential human and ecological exposures and risk. Groundwater moves slowly, so it takes time for contamination to appear at potential receptor locations. It follows that it will take a correspondingly long time to remediate the initial release of contaminants. Broadly, two types of contaminants exist and these are as follows:

4.1 Geogenic Contaminants

Deterioration of quality of ground water due to natural contamination from aquifers and overlaying soils is called geogenic contamination. This type of contamination occurs due to entrapped water reaction with the strata. Presence of high Fluoride, Selenium and Arsenic are usually a result of geogenic contamination as there are only a very few other sources of these ions. The Contaminants and their Possible Sources are presented in Table 1.

Table 1: Geogenic Contaminants

Contaminant	Possible source
Salinity	Long residence time and geological formations
Fluoride	Lime Stone, sandstone, granite as Fluorspar (CaF_2), Cryolite (Na_3AlF_6), Fluorite (CaF_2), Fluorapatite {$Ca_5F(PO_4)_3$}, Insecticides, Disinfectants Preservatives, Phosphatic fertilizers
Arsenic	1.Geothermal/Volcanic activities 2.Weathering of rocks & minerals- Arsenopyrite (FeAsS) Lollingite(FeAs2), Orpiment, Realger, Native Arsenic 3.Herbicides 4. Pesticides
Uranium	Geothermal/Volcanic activities Nitrate pollution may further enhance uranium mobilization.

4.2 Anthropogenic Contaminants

4.2.1 Due to Agricultural Activities

Agrochemicals comprising of fertilizers, pesticides, insecticides, fungicides, weedicides, plant growth regulator, ripening agents and some preservatives, are widely used in agricultural activities. Some of them been used in agriculture since the advent of green revolution as agrochemicals are important input and one of the main features of the green revolution. Being major benefiter of green revolution, application of these agrochemicals increased in Haryana over the years which is directly or indirectly contributing to the contamination of valuable ground water resources. The initial increase in agricultural production in the state was mainly due to increase in net sown area, however stunning rise of food grain production can be largely attributed to intensive use of agrochemicals. The indiscriminate use of fertilizers, pesticides, insecticides, herbicides etc. is causing soil and ground water pollution. Application of excess agrochemicals which are mostly water soluble flows to the nearby water bodies and then reaching to the ground water. The main fertilizers used in the State are nitrogen based. The exorbitant increase in use of farm chemicals through the years[10] is depicted in table2.

Table -2: Chemical Fertilizer Consumption (Nutrients) in Haryana (In Ton)

Year	Consumption			
	N	P	K	Total
1	2	3	4	5
1966-67	12,626	574	147	13,347
1970-71	60,972	6,860	2,228	70,060
1980-81	1,87,385	31,340	12,098	2,30,823
1990-91	4,43,245	1,38,005	5,042	5,86,292
2000-01	7,14,308	2,06,319	9,668	9,30,295
2010-11	9,74,045	3,35,950	47,627	13,57,622
2011-12	10,20,892	3,69,624	37,531	14,28,048
2012-13	10,23,999	3,11,755	17,307	13,53,061
2013-14	9,50,563	1,98,457	15,651	11,64,671
2014-15	10,13,267	2,54,437	36,199	13,03,903
2015-16	10,37,101	2,90,591	19,699	13,47,391
2016-17	10,07,232	2,90,555	41,522	13,39,279
2017-18	10,49,270	2,80,270	46,211	13,75,751
2018-19 (Projected)	11,07,798	3,11,608	57,273	14,76,679

Nitrogenous based fertilizer releases large amounts of NO_3^- which accumulate in the soil profile and is susceptible to leaching. High rates of leaching and nitrification in permeable or porous soils and relatively high use of fertilizer combine to make nitrate-leaching a serious problem in many irrigated soils [11]. Animal wastes also appear to be the major contributors to high NO_3^--N in groundwater in villages where livestock rearing is an additional source of income for the farmers apart from the agricultural activity.

4.1.2 Industrial Wastewater Pollution

Number of Industrial units are rapidly increasing in the State and the organic and toxic wastes generated cause water pollution. Categorization of Water Polluting Industries in Haryana identified by Haryana State Pollution Control Board [12] is given in the table 3. Non treatment of industrial waste water is major issue as far as pollution of water bodies and ground water is concerned. These untreated waters are contaminating the vital water resources of country. Industrial chemicals, heavy metals, pharmaceuticals and antibiotic residues are creating large scale environmental problems.

Table -3: Categorization of Water Polluting Industries in Haryana

Region	Red	Orange	Green	White	Total
Bahadurgarh	251	961	51	4	1267
Ballabgarh	488	504	28	8	1028
Dharuhera	157	511	40	5	713
Faridabad	156	267	36	0	459
Gurugram (N)	257	615	44	11	927
Gurugram (S)	327	375	148	85	935
Hisar	64	760	23	00	847
Jind	78	1347	24	0	1449
Panchkula	146	902	143	49	1240
Panipat	385	223	22	06	636
Sonepat	264	718	164	33	1179
Yamuna Nagar	301	1132	50	1	1484
Total	**2874**	**8315**	**773**	**202**	**12164**

4.1.3 Due to Municipal Waste

Application of sewage sludge to agricultural fields and untreated industrial effluents alone, or in combination with ground/canal water, is a common practice in Haryana state, especially in the vicinity of large cities and industrial clusters as these are considered reusable sources of essential plant nutrients and organic Carbon are causing pollution to the ground water. Discharge of partially/untreated water contributes to biological contamination of surface and groundwater. The rapid increase in population due to urbanization in the state after country's independence has lead to proportionate increase in generation of municipal, bio-medical and hazardous waste. The physical composition of municipal solid waste generated in the state indicates that on an average, it contains some recyclables, compostable matter and inert material.

5. GROUND WATER QUALITY SCENARIO

Evaluation of ground water quality through analysis of its physical, chemical and biological parameters is essential to determine its suitability for the intended use [13][14][15]. It helps not only in finding its suitability; it also helps in taking effective remedial measures for its improvement on scientific lines. 451 nos. of ground water samples were collected from these structures spread uniformly over 22 districts of Haryana and no specific treatment such as acidification or filtration was given at the time of sampling. The water samples were analyzed for major cations (Ca, Mg, Na, K) and anions (CO_3, HCO_3, Cl, NO_3, SO_4) in addition to pH, EC, F, SiO_2, PO_4 and TH as $CaCO_3$ in the Regional Chemical Laboratory by following 'Standard analytical procedures' as given in American Public Health Agency Handbook. The district-wise concentration range of some chemical components in ground water is depicted in Table 4.

Table -4: Range of Chemical Constituents in Groundwater of Haryana State, India

Sr. No.	District	Number of samples analysed	Range	pH	EC (µS/Cm At 25^{0}C)	Cl (mg/L)	F (mg/L)	NO_3 (mg/L)
1	Ambala	12	Min.	8.37	303	21	0.11	BDL
			Max.	8.87	2750	432	0.76	9.98
2	Bhiwani and CharkhiDadri	34	Min.	7.81	295	21	0.14	BDL
			Max.	8.93	8498	1880	5.71	470
3	Faridabad	8	Min.	7.55	739	106	0.05	7.39
			Max.	8.60	3860	1099	0.92	35
4	Fatehabad	12	Min.	8.01	358	28	0.31	BDL
			Max.	8.87	7390	1163	2.23	260
5	Gurgaon	24	Min.	7.51	192	42	0.34	BDL
			Max.	9.06	13960	4126	0.95	35
6	Hisar	38	Min.	7.74	325	14	0.19	BDL
			Max.	8.92	12630	1751	3.80	577
7	Jhajjar	15	Min.	7.59	274	14	0.14	BDL
			Max.	8.75	11000	1595	9.90	28
8	Jind	21	Min.	7.62	318	14	0.08	2.54
			Max.	8.91	13060	1227	12.0	29
9	Kaithal	24	Min.	7.75	517	7.29	0.30	BDL
			Max.	9.08	5900	1021	0.92	53
10	Karnal	32	Min.	7.09	340	14	0.46	BDL
			Max.	9.01	2120	397	0.66	135
11	Kurukshetra	20	Min.	6.95	335	21	0.07	BDL
			Max.	8.94	1816	255	0.75	28
12	Mahendragarh	9	Min.	7.77	580	56	0.25	BDL
			Max.	8.89	5160	1163	1.96	74
13	Mewat	11	Min.	7.46	214	42	0.05	0.79
			Max.	8.55	13920	3424	0.69	31
14	Palwal	23	Min.	7.75	1074	78	0.08	1.19
			Max.	8.90	7430	1978	0.99	28
15	Panchkula	23	Min.	8.15	264	14	0.08	BDL
			Max.	8.76	1826	277	0.88	120
16	Panipat	20	Min.	8.36	387	14	0.20	BDL
			Max.	9.07	3059	574	6.50	15
17	Rewari	12	Min.	7.74	816	156	0.19	BDL
			Max.	8.91	6630	1404	0.72	85
18	Rohtak	12	Min.	8.37	960	28	0.19	BDL
			Max.	9.10	10240	1808	10	25
19	Sirsa	37	Min.	7.91	261	14	0.19	BDL
			Max.	8.92	10711	2425	6.50	290
20	Sonepat	39	Min.	7.98	338	14	0.09	BDL
			Max.	8.71	7267	1801	2.90	292
21	Yamunanagar	21	Min.	8.06	235	14	0.07	BDL
			Max.	8.67	1558	177	0.60	21

6. SPATIAL DISTRIBUTION OF URANIUM IN HARYANA STATE

Table -5: District Wise Range of Uranium Concentration in µg/L

S.No.	District	Number of Samples Analyzed	Min	Max	Average
			Uranium Concentration in µg/L		
1	Ambala	13	0.655	32.712	8.404
2	Bhiwani and Charkhi Dadri	34	0.504	78.101	15.722
3	Faridabad	9	1.711	37.697	14.042
4	Fatehabad	12	4.839	45.904	25.918
5	Gurugram	24	1.396	45.943	8.594
6	Hisar	38	0.741	131.445	26.228
7	Jhajjar	15	0.842	44.545	14.561
8	Jind	21	3.727	136.668	30.935
9	Kaithal	24	0.014	56.900	20.678
10	Karnal	32	0.011	40.775	10.320
11	Kurukshetra	19	0.014	33.575	8.461
12	Mahendragarh	9	4.378	56.062	14.002
13	Mewat	11	2.486	27.422	11.218
14	Palwal	23	3.047	58.722	24.451
15	Panchkula	23	0.625	7.491	3.885
16	Panipat	22	5.245	82.643	26.110
17	Rewari	12	3.391	25.436	9.770
18	Rohtak	12	1.726	72.424	21.193
19	Sirsa	37	3.384	300.796	50.433
20	Sonipat	40	0.615	34.172	17.225
21	Yamunanagar	21	2.042	39.747	9.435

6.1 District Ambala

The minimum concentration of uranium has been found at Dhanaura (0.65 µg/L), Barara block and maximum concentration of uranium has been found at Jandheri (32.71µg/L) Ambala I block of the district and the average concentration of uranium is 8.40 µg/L. Only one sample among total collected samples is having concentration greater than WHO limits of 30 µg/L.

6.2 District Bhiwani

The minimum concentration of uranium has been found at Lachhmanpur (0.50 µg/L) Tosham block and maximum concentration of uranium has been found at Badala (78.10µg/L) Bhiwani block of the district and the average concentration of uranium is 15.72 µg/L. Two samples among total collected samples are having concentration greater than AERB value of 60 µg/L.

6.3 District Faridabad

The minimum concentration of uranium has been found at Faridabad city (1.71µg/L) and maximum concentration of uranium has been found at Ballabhgarh (37.70µg/L). The average concentration of uranium is 14.04µg/L. Only one sample among total collected samples is having concentration greater than 30 µg/L.

6.4 District Fatehabad

The minimum concentration of uranium has been found at Nahla (4.84 µg/L) Bhuna block and maximum concentration of uranium has been found at Nangla (45.90µg/L) Tohana block of the district and the average concentration of uranium is 25.92µg/L. Four samples among total collected samples are having concentration greater than 30 µg/L.

6.5 District Gurugram

The minimum concentration of uranium has been found at Kherla (1.40 µg/L) Sohana block and maximum concentration of uranium has been found at Kasan (45.94 µg/L) Gurugram block of the district and the average concentration of uranium is 8.59 µg/L. One sample which is having concentration more than 30 µg/L.

6.6 District Hisar

The minimum concentration of uranium has been found at Mirka (0.74 µg/L) Hisar-I block and maximum concentration of uranium has been found at Sohu (131.44µg/L) Uklana block of the district and the average concentration of uranium is 26.23 µg/L. It reveals that the 12 samples of ground water having uranium concentration more than30µg/L and 2 samples having uranium concentration more than 60µg/L.

6.7 District Jhajjar

The minimum concentration of uranium has been found at Chamanpura (0.84 µg/L) Beri block and maximum concentration of uranium has been found at Bagoa(44.55µg/L) Beriblockof the district and the average concentration of uranium is 14.56µg/L. In all only two samples are having uranium concentration more than30µg/L.

6.8 District Jind

The minimum concentration of uranium has been found at Karsola (3.73 µg/L) Safidon block and maximum concentration of uranium has been found at Uchana (136.67µg/L) Uchanablock. Average concentration of uranium in the district is 30.94 µg/L, though only 10 samples out of 21 samples are having uranium concentration either more than 30 µg/L

6.9 District Kaithal

The minimum concentration of uranium has been found at Mundri (0.01 µg/L) Kaithal block and maximum concentration of uranium has been found at Mataur (56.90µg/L) Kalayat block of the district and the average concentration of uranium is 20.68 µg/L. 9 out of 24 ground water samples having uranium concentration more than30µg/L.

6.10 District Karnal

The minimum concentration of uranium has been found at Garhi Khajur (0.01 µg/L) Gharaunda block and maximum concentration of uranium has been found at Mound (40.78 µg/L) Assandh block of the district and the average concentration of uranium is 10.32µg/L. Only 2 out of 32 ground water samples are having uranium concentration more than30µg/L.

6.11 District Kurukshetra

The minimum concentration of uranium has been found at Mathana (0.01 µg/L) Thanesar block and maximum concentration of uranium has been found at Thana (33.57 µg/L) Pehowa block of the district and the average concentration of uranium is 8.46µg/L. Only 2 out of 19 ground water samples having uranium concentration more than30µg/L.

6.12 District Mahendragarh

The minimum concentration of uranium has been found at Ratta Kalan (4.38 µg/L) Kanina block and maximum concentration of uranium has been found at Narnaul (56.06µg/L) Narnaul block of the district and the average concentration of uranium is 14.00µg/L. Only 1 out of 9 ground water samples having uranium concentration more than30µg/L.

6.13 District Mewat

The minimum concentration of uranium has been found at Rangola Dhani (2.49 µg/L) Taoru block and maximum concentration of uranium has been found at Nuh (27.42µg/L) Nuh block of the district and the average concentration of uranium is 11.22 µg/L. All samples collected from the district are below the WHO limits of 30 µg/L.

6.14 District Palwal

The minimum concentration of uranium has been found at Badram (3.05 µg/L) Palwal block and maximum concentration of uranium has been found at Rasulpur (58.72 µg/L) Palwal block of the district and the average concentration of uranium is 24.45µg/L. 7out of 23 ground water samples having uranium concentration more than 30 µg/L.

6.15 District Panchkula

The minimum concentration of uranium has been found at Dharampur (0.63 µg/L) Pinjore block and maximum concentration of uranium has been found at Patwi (41.543 µg/L) Barwala block of the district and the average concentration of uranium is 3.89µg/L. All 23 ground water samples collected from the district are well below the 30µg/L.

6.16 District Panipat

The minimum concentration of uranium has been found at Tajpur (5.25 µg/L) Bapoli block and maximum concentration of uranium has been found at Lohari (82.64 µg/L) Madlauda block of the district and the average concentration of uranium is 26.11µg/L. There are 6 samples out of 22 which are having uranium concentration more than the 30µg/L.

6.17 District Rewari

The minimum concentration of uranium has been found at Bawal (3.39 µg/L) Bawal block and maximum concentration of uranium has been found at Sangwari (25.44 µg/L) Rewari block of the district and the average concentration of uranium is 9.77µg/L. All 12 ground water samples collected from the district have uranium concentration well below the 30µg/L.

6.18 District Rohtak

The minimum concentration of uranium has been found at Sampla (1.73µg/L) Sampla block and maximum concentration of uranium has been found at Maham(72.42µg/L) Maham block of the district and the average concentration of uranium is 21.19µg/L. 2 of 12 samples are having uranium concentration more than 60 µg/L.

6.19 District Sirsa

The minimum concentration of uranium has been found at Gigorani (3.38 µg/L) Nathusari Chopta block and maximum concentration of uranium has been found at Kalanwali Mandi(300.80µg/L) Odhan block of the district and the average concentration of uranium is 50.43µg/L. 9 out of 37 samples are having uranium concentration more than the WHO limits of 30 µg/L and 9 samples are having more than 60 µg/L.

6. 20 District Sonipat

The minimum concentration of uranium has been found at Bhunderi (0.62 µg/L) Kathura block maximum concentration of uranium has been found at Khanpur Kalan (34.17µg/L) Gohana block of the district and the average concentration of uranium is 17.23 µg/L. Only 2 out of 40 samples are not suitable for drinking purpose as per WHO limits 30 µg/L.

6.21 District Yamunanagar

The minimum concentration of uranium has been found at Bilaspur (2.04µg/L) Bilaspur block and maximum concentration of uranium has been found at Umari (39.75µg/L) Jagadhri block of the district and the average concentration of uranium is 9.43 µg/L. Only 1 out of 21 samples is not suitable for drinking purpose as per WHO limits 30 µg/L.

7. INTER SPECIATION CORRELATION

Only in eight locations among all the locations where ground water is polluted with uranium have other heavy/trace elements beyond the prescribed limits as per BIS 10500:2012 drinking water standard. Figure 2 depicts the locations where ground water contains the uranium more than 30 µg/L. Overall in Haryana State only 16% of samples are having uranium concentration more than 30µg/L, only 4% samples are having uranium concentration more than 60µg/L.

The correlation coefficient for parameters was calculated using Pearson correlation. Correlation coefficient measures the strength and direction of correlation between parameters. It ranges from '-1' through '0' to '+1'. '-1' indicates negative correlation, '+1' indicates positive correlation while '0' indicates absence of correlation. It is also called the linear correlation coefficient because 'r' measures linear correlation between two variables.
Correlation analyses of uranium concentration with other quality parameters like Specific Conductance (EC), Chloride (Cl), Fluoride (F) and Nitrate (NO_3) revealed some positive correlation between these parameters. It is observed that there is a strong correlation between uranium and fluoride which can be attributed to geogenic source of contamination for both the elements.

Table-6: Correlation analysis between uranium concentration and EC, Cl, F, NO_3

	U	EC	F	Cl	NO3
U	1.000	0.147	0.351	0.043	0.125
EC	0.141	1.000	0.051	0.919	0.304
F	0.048	0.051	1.000	-0.034	0.051
Cl	0.043	0.919	-0.034	1.000	0.217
NO3	0.125	0.304	0.051	0.217	1.000

Table -7: depicting overall suitability of GW with respect to Uranium for drinking purpose as per WHO and AERB norms

District	Number of Samples Analyzed	% of samples above WHO Limits (30 µgL^{-1})	% of samples above AERB limits (60 µgL^{-1})
Ambala	13	7.69	Nil
Bhiwani	34	5.88	5.88
Faridabad	9	11.11	Nil
Fatehabad	12	33.33	Nil
Gurugram	24	4.17	Nil
Hisar	38	31.58	5.26
Jhajjar	15	13.33	Nil
Jind	21	38.10	9.52
Kaithal	24	37.50	Nil
Karnal	32	6.25	Nil
Kurukshetra	19	10.53	Nil
Mahendragarh	9	11.11	Nil
Mewat	11	Nil	Nil
Palwal	23	30.43	Nil
Panchkula	23	Nil	Nil
Panipat	22	27.27	9.09
Rewari	12	Nil	Nil
Rohtak	12	16.67	16.67
Sirsa	37	24.32	24.32
Sonipat	40	5.00	Nil
Yamunanagar	21	4.76	Nil

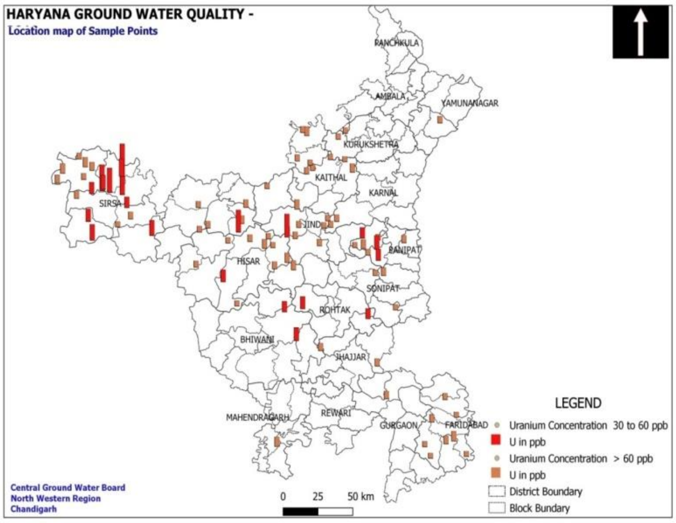

Fig -2: Locations where ground water contains the uranium more than 30 μg/L

7. CONCLUSIONS

In Haryana State ground water is generally suitable for drinking uses except at few places in the western part and central and eastern parts as far as the uranium contamination is concerned. Sirsa district in the western part of the state is worst affected district having considerable locations where uranium concentration is detected either above WHO limits (30μg/L) or AERB limits (60 μg/L). Except in three districts, Mewat, Panchkula and Rewari, all other districts are having locations where uranium concentration is either above WHO limits (30μg/L) or AERB limits (60 μg/L), though the number of samples exceeding these limits are not much as compared to Sirsa district. Elevated Uranium content in ground water is one of the most serious concerns as it affects large unconsolidated aquifers and the problem is compounded because the drinking water supply in the thickly populated parts is dependent on shallow aquifers which are found to be contaminated.

The remedial measures include variety of options, ranging from removing uranium from ground water after it is extracted, tapping of alternate uranium safe aquifers, reducing the level within the aquifer itself, blending with potable water etc. The options of first choice should be mitigation or to provide alternative sources of safe water. It is suggested that each individual technique should be applied in each of the pockets on pilot basis. Site or location specific techniques shall be developed as per the requirement. Dedicated monitoring mechanism should be established to know the effectiveness of the technique so as to arrive at the best method suitable for the entire area.

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