Groundwater hydrochemistry of Rajnandgaon district, Chhattisgarh, Central India

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Abstract

The spreading of water-related diseases in Central India related to high concentrations of fluoride ion (F^-) is a cause of major concern. In this work, the hydrochemistry of the aquifers related to Seonath River, in Rajnandgaon district, Chhattisgarh state, has been studied, focusing on the presence and sources of F^-. Hydrochemical parameters were analyzed in the post-monsoon season in 160 wells located in nine tehsils, finding F^- concentrations ranging from 0.6 to 18.5 mg·L^{-1}. Seasonal variations were also studied in Chhuikhadan tehsil, in which the highest F^- values were registered, finding a noticeable enrichment in the pre-monsoon months. In many locations in the district, F^- concentrations exceeded the recommended value of 1.5 mg·L^{-1}, which have led to the appearance of several health issues. Multidimensional analysis statistical methods were adopted to investigate the sources of F^-, and the mineralization of bedrock elements into the groundwater was found be the primary source.

Keywords: APCS–MLR; aquifer; fluoride; PCA; Seonath River; source apportionment.

1. Introduction

Widespread fluoride contamination of aquifers is a major problem in India and in other regions of the World, resulting in a high incidence of fluorosis disorders (Amini et al., 2008; Handa, 1975; Panda & Kar, 2014; Raju et al., 2009; Roy & Dass, 2013; Saxena & Saxena, 2013; Saxena & Ahmed, 2001; Saxena & Ahmed, 2003; Shekhar et al., 2012; Suneetha et al., 2015; Suthar et al., 2007; Ugran et al., 2016; Yadav et al., 2019).

Fluoride-related diseases in both humans and animals have been reported in several districts of Madhya Pradesh, Maharashtra and Gujarat states (Beohar, 2013; Deshpande & Gupta, 2013; Jinwal & Dixit, 2009; Khare, 2017; Patel et al., 2012; Thakur et al., 2013).

In the neighboring Chhattisgarh state, fluoride contents in groundwater have been previously reported by our group (Dahariya et al., 2015; Patel et al., 2014; Patel et al., 2015a; Patel et al., 2015b; Sahu et al., 2016). In the present paper, a more detailed study is presented for Rajnandgaon district, covering all the nine tehsils (administrative divisions): Ambagarh Chowki, Chhuikhadan, Chhuriya, Dongargaon, Dongargarh, Khairagarh, Manpur, Mohla and Rajnandgaon. Hydrochemical data from 160 wells sampled in 2017 has been analyzed, studying the seasonal variability for 20 wells in one of the tehsils. Multidimensional analysis statistical techniques have been used to study the sources of fluoride and other elements.

2. Materials and methods

2.1. *Study area*

Rajnandgaon district (20°70'-22°29' N and 80°23'-81°29' E), in Chhattisgarh state, lies near the Satpura basin. This area of over 8,100 km^2, home to a population of 1,300,000 inhabitants, was selected for the study presented herein. The east flowing Seonath River (also called Shivnath River) and its tributaries (viz. Amner, Jonk, Ghumriya, Pairi Zura and Hanf) flow in this district. Several reservoirs (namely Chhindari dam, Pardan pat dam, Sankra dam, Sirpur dam, Matiyamoti dam, Kharkhara dam, Mongra dam, Navagarh lake and Kherkatta reservoir) were constructed in the district for irrigation and other purposes.

Physiographically, Rajnandgaon district is divided into three units: a hilly part in the west, a southern plateau and a plain region in the eastern part. The geology is complex, mainly consisting of phyllitic shales and hematitic quartzite, of the Lower Proterozoic age, basalts, granitoids with porphyritic and rapakivi textures, rhyolites, dolerites, pegmatitic rocks and volcanic related rocks (Shukla et al., 2010). Ten different aquifer systems, from hard rocks units to colluvial ones, have been recognized in the district. Their main hydrogeologic characteristics have been analyzed by Verma (2013).

The rainfall in the basin (≥ 1000 mm/year), coming from the southwest monsoon during summer season (from June to September), is the main source of water recharge (451.3 hm^3). Groundwater (GW) water level oscillates year round as a function of monsoon rains (5–15 meters below ground level, mbgl, in the pre-monsoon period). Total extraction is estimated at 231.05 hm^3, out of which 205.84 hm^3 would be used for irrigation water supply (Verma, 2013).

2.2. *Sample collection*

Groundwater samples from 160 tube wells were collected from during the post-monsoon period, in January 2017 (Figure 1). Samples from 20 tube wells of Chhuhikhhadan tehsil were also collected in the pre-monsoon (June 2017) and monsoon (September 2017) periods to study seasonal variations.

[FIGURE 1]

2.3. *Water analyses*

The physical parameters of the water samples were measured at the spot by using HANNA Instruments (Woonsocket, RI, USA) sensors. The alkalinity and total hardness values of the water were analyzed by titration methods (Nollet & De Gelder, 2013). The total F^- content in the water was determined using a Metrohm-781 ion meter (Metrohm AG, Herisau, Switzerland) equipped with a fluoride ion selective electrode. A fresh total ionic strength adjustment buffer (TISAB) solution (containing 300 g of sodium citrate, 22 g of trans-1,2-diaminocyclohexane-N,N,N′,N′-tetraacetic acid, and 60 g of sodium chloride in 1 L of de-ionized water, at a pH value of 5.2±0.2) in equal volume ratio was used for the potentiometric measurements. Anions and cations were analyzed with a Dionex ICS-1100 ion chromatography system (Sunnyvale, CA, USA). The iron content was obtained with an AA 8000 atomic absorption spectrophotometer (Labindia Instruments Pvt. Ltd., Thane, Maharashtra, India).

The sampling, transportation and analysis of the water samples were conducted according to standard procedures (APHA et al., 2012). The analytical precision was ensured through procedural blanks, spiked samples and duplicate analyses. The accuracy of the chemical analyses was confirmed by charge-balance errors (CBE) calculation in AquaChem software (Waterloo Hydrogeologic, Kitchener, Ontario, Canada), obtaining values below 5%. A 95% confidence interval was used.

2.4. *Statistical analyses*

Hierarchical cluster analysis (HCA), using Ward's method with squared Euclidean distance, was used as a measure of similarity. Principal component analysis (PCA), with the Varimax rotation method with Kaiser normalization, was used as an exploratory tool to recognize the main potential sources and to choose statistically-independent source tracers, as reported in the literature (Guo et al., 2004; Huang et al., 2010; Singh et al., 2005; Su et al., 2011; Zhou et al., 2007). Nonetheless, since PCA cannot afford quantitative insight into the contributions of the various pollution sources to the variables of interest related to water quality (Guo et al., 2004), it was complemented with absolute principal component score–multiple linear regression (APCS–MLR) methods (Singh et al., 2005; Su et al., 2011; Zhou et al., 2007). Statistical analyses were conducted in IBM SPSS software (IBM, Armonk, NY, USA).

3. Results and Discussion

3.1. *Physicochemical characteristics of the GW samples in the post-monsoon season*

The total set of results for the 160 wells is presented in Table S1. Table 1 presents the main statistical parameters (range of values, arithmetic mean, standard deviation and confidence limit (p=0.05)) of the main physicochemical parameters under study (viz., water temperature (T), pH, electrical conductivity (EC), total dissolved solids (TDS), dissolved oxygen (DO), oxidation-reduction potential (ORP), total alkalinity (TA) and total hardness (TH)) in each of the nine tehsils.

In the entire district, the pH of the GW samples varied from 4.8 to 8.2, with a mean value of 6.5±0.1 (Figure 2). In two of the tehsils (Mohala and Manpur), the pH value of the water was found to be below the recommended value of 6.5. The ionic ratio ($\Sigma_{anion}/\Sigma_{cation}$, where $\Sigma_{anion}=F^{-}+Cl^{-}+NO_3^{-}+SO_4^{2-}+HCO_3^{-}$ and $\Sigma_{cation}=NH_4^{+}+Na^{+}+K^{+}+Mg^{2+}+Ca^{2+}$) ranged from 0.45 to 2.73, with a mean value of 1.17±0.7, indicating the slightly acidic nature of the water. The mean water temperature was found to be 27.0±0.4 °C, with relatively higher water temperatures (30-31 °C) in two of the tehsils (Dongargaon and Ambagarh). In all tehsils, the EC, TA and TDS values were above the tolerated limits (Bureau of Indian Standards (BIS), 2012). Moreover, the TH value in the water of three tehsils (Chhuikhadan, Dongargarh and Rajnandgaon) was also found to be higher than the recommended limit (Bureau of Indian Standards (BIS), 2012). The ORP value of the water was at least 3-folds lower than the prescribed maximum value (650 mV) (Bureau of Indian Standards (BIS), 2012). Low DO values were observed, probably due to the greater depth of those wells.

[FIGURE 2]

The statistics for the ion (F^{-}, Cl^{-}, NO_3^{-}, SO_4^{2-}, PO_4^{3-}, Na^{+}, K^{+}, Mg^{2+}, Ca^{2+} and $Fe^{2+/3+}$) concentrations in the water of the nine tehsils investigated during the post-monsoon period is summarized in Table 2. Among them, F^{-} mean concentration in the water was found to be 3.7±0.4 $mg\cdot L^{-1}$, well above the recommended value of 1.5 $mg\cdot L^{-1}$ (Bureau of Indian Standards (BIS), 2012). In particular, remarkably high F^{-} concentrations (> 8.0 $mg\cdot L^{-1}$) were detected in the water samples from Chhuikhadan and Khairagarh tehsils. High concentrations of Cl^{-}, SO_4^{2-}, Na^{+}, Mg^{2+} and Ca^{2+} were also found in the water from Dongargaon, Dongargaon and Rajnandgaon, Dongargaon and Mohla, Chhuikhadan, and Khairagarh tehsils, respectively. The chemical species (mean values, Figure 2) in the water occurred in following increasing order: $PO_4^{3-} < Fe^{2+/3+} < F^{-} < K^{+} < NO_3^{-} \approx Mg^{2+} < NH_4^{+} \approx SO_4^{2-} < Na^{+} < Ca^{2+} < Cl^{-}$.

3.2. *Spatial variations*

Fluoride concentration results in the post-monsoon sampling are presented in Figure 3 in connection with the geology of the district, reported by Verma (2013). The highest F^{-} concentrations were found in areas of Bijli rhyolite, although high values were also detected in Gunderdehi Formation and Chandi limestones areas.

[FIGURE 3]

3.3. *Seasonal variation*

Seasonal variation studies were carried out with GW from locations in the Chhuikhadan tehsil, in which the highest F^- concentrations had been found in the district-wide post-monsoon study (Table S2). Two different behaviors were observed: on the one hand, the main natural ions, related to the bedrock geology, showed a general decrease by dilution by water recharge by the monsoon rainfall (Figure 4a). After the monsoon, there was a recovery of the pre-monsoon levels due to both chemical reaction between the recharged water and bedrock, and concentration by evaporation. On the other hand, ions related to anthropic activity, mainly NH_4^+ and NO_3^-, showed an increase during the monsoon, related to direct infiltration of pollutants from the surface (Figure 4b). Subsequently, the mixture of recently infiltrated water and the GW produced a dilution effect. However, it is worth noting that K^+ showed a distinctive pattern, tentatively ascribed to a double mechanism: part of the K^+ would come from human activities and the rest would come from chemical alteration of rock minerals, the increase in water temperature and the lowering of the water level.

[FIGURE 4]

3.4. *Statistical analyses*

3.4.1. *Hierarchical cluster analysis*

Large spatial variations in the values of the GW physicochemical parameters were identified among the water samples from the nine tehsils by HCA. The different locations were classified into two main clusters, using F^- as the discrimination factor (Figure S1). 114 and 46 locations were included in cluster-I and cluster-II, respectively. Fluoride concentration in the water from cluster-II locations was several folds higher than that from cluster-I locations. It has been suggested that the chemical dilution effect in the GW could be related to aquifer recharge induced by the use water reservoirs (Bhagavan & Raghu, 2005; Jacks, 2016). In the present study, the proximity of sampling points to a number of dams (Chhindari, Pardan pat, Sankra, Sirpur, Matiyamoti, Kharkhara, Mongra, Navagarh lake, Kherkatta reservoir and Shivnath river dams) could be a tentative explanation, although further studies would be needed to confirm this point.

3.4.2. *Principal Component Analysis*

PCA was first used to analyze the interrelationships among the ion concentrations in the post-monsoon water samples. The parameters of specific extracted initial communalities were checked by the Kaiser–Mayer–Olkin (KMO) test and the Bartlett test of sphericity to test data rationality and sampling adequacy of the analysis. The KMO value of 0.642 (>0.5) revealed sufficient sampling, and the significance level from the Bartlett test <0.0001 indicated that the data were appropriate and useful to substantially reduce the data dimension (Monteiro & Pinheiro, 2004). Then, four factors with eigenvalues >1 were extracted for the Varimax-rotated analysis (Table 3). 28.25%, 15.77%, 14.72% and 13.78% of the variance was explained by the first, second, third and fourth factor, respectively. The four common factors explained a total cumulative variance of 72.52%.

Component 1 (i.e., varifactor 1, VF1) was composed of Ca^{2+}, Mg^{2+}, F^- and NO_3^-. The former three ions are directly related to natural bedrock weathering, while nitrates would be related to agriculture, livestock and wastewater pollution. Component 2, associated with NH_4^+ and K^+, would be associated with surface pollution from anthropic activities. Component 3 consisted of SO_4^{2-} ion and TA. The former may arise from either natural sulphide mineral dissolution or atmospheric deposition (Sharma & Kumar, 2020), while the latter –normally associated with carbonates and hydrogencarbonates– would be related to weathering of limestones and silicates with the help of atmospheric dissolved CO_2

in the recharge water. As regards component 4, it consisted of Cl^- and Na^+. The former is considered to be a conservative element, whereas Na^+ is subjected to several hydrogeochemical processes. PCA thus served as a means to identify possible sets of sources.

The PCA analysis was also repeated considering all the measured physicochemical parameters (Table S3). In this case, 5 principal components (varifactors) were obtained, which explained 70.41% of the overall variance, with a KMO value of 0.746 and a Barlett's test significance level <0.001. The grouping of the parameters on the components was similar to that of previous analysis (Table 3), except for SO_4^{2-} and TA, which appeared in different components. New component 5 (VF5), apart from TA, also had moderate loadings with ORP and pH.

3.4.3. *Source apportionment using APCS-MLR*

After identifying possible pollution sources, the contributions of each source to water quality variables were then apportioned using APCS-MLR. Results of source apportionment are presented in Table 4. The estimated mean to measured mean (E/M) ratio varied between 0.62 (NO_3^-) and 1.23 (ORP), indicating the compatibility of the modeling approach with the source apportionment of groundwater quality, in agreement with Gulgundi and Shetty (2016). The R^2 values for the studied parameters obtained with the calculations using the receptor modeling were >0.5, indicating that there was a reasonable adequacy between the modeled and observed values, and that the source apportionment results were reliable. The accuracy of the model could be regarded as very high for Ca^{2+}, Mg^{2+}, NH_4^+ and TA (R^2 values between 0.8 and 1), moderate for ORP (R^2 between 0.4 and 0.6), and high for rest of the parameters (R^2 between 0.6 and 0.8). On the basis of the source contributions shown in Table 4, fluoride was primarily influenced by S1, which –as explained above for VF1– was related to natural sources (rock weathering). Hence, it appears that the sources of F^- pollution would be geogenic.

3.5. *Health hazards*

As discussed above, fluoride concentration, in both the ground and the surface water of the whole district, was found to be higher than the tolerance limit of 1.5 mg·L^{-1} (Bureau of Indian Standards (BIS), 2012). With regard to the risks of this fluoride exposure to humans, an up-to-date risk assessment may be found in the recent paper by Ali et al. (2019), which showed that the total hazard quotient (THQ) in both adults and children in the state of Chhattisgarh was higher than 1, so consumers would be at considerable risk. In relation to livestock, fluoride exposure also results in dental discoloration, non-skeletal and skeletal fluorosis in the cattle that drinks this water. In particular, skeletal fluorosis (Figure 5) prevalence rate varied from 20% to 30% in the nine tehsils.

4. Conclusions

Post-monsoon hydrochemical analyses showed F^- values ranging from 0.6 to 18.5 mg·L^{-1}, with the highest values in the northern tehsils of Chhuikhadan and Khairagarh. Several parameters (TDS, TA, TH and F^-) exceeded the recommended values (500, 120, 300 and 1.5 mg·L^{-1}, respectively). The study of season variations in the most polluted tehsil (Chhuikhadan) showed that the water recharge during the monsoon resulted in a temporary dilution for natural ions (F^-, Cl^-, SO_4^{2-}, Na^+, Ca^{2+}, Mg^{2+}, Fe^{3+}) and in an increase for anthropic pollution sources-related ions (NO_3^- and NH_4^+). PCA and APCS–MLR analyses identified that GW quality was affected by various sources, including the weathering of bedrock and agricultural practices. The mineralization of bedrock, mainly from rhyolites, into the GW appears to be the primary source of F^- concentrations. This fluoride-pollution derives in health hazards, such as skeletal fluorosis in cattle, with an average prevalence rate of 25% in Rajnandgaon district. The implementation of artificial recharge remediation strategies would be useful in this area.

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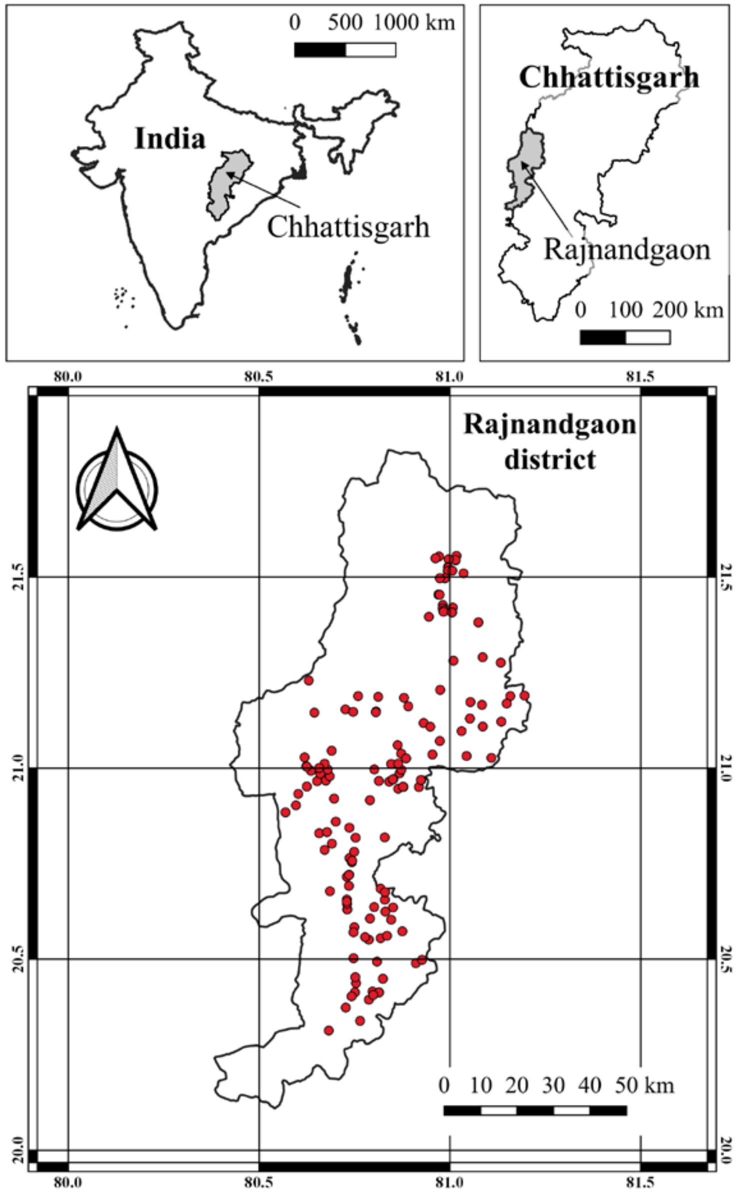
FIGURES



365 **Figure 1**. Location map of Rajnandgaon district, Chhattisgarh state, and locations of the wells sampled in this study.

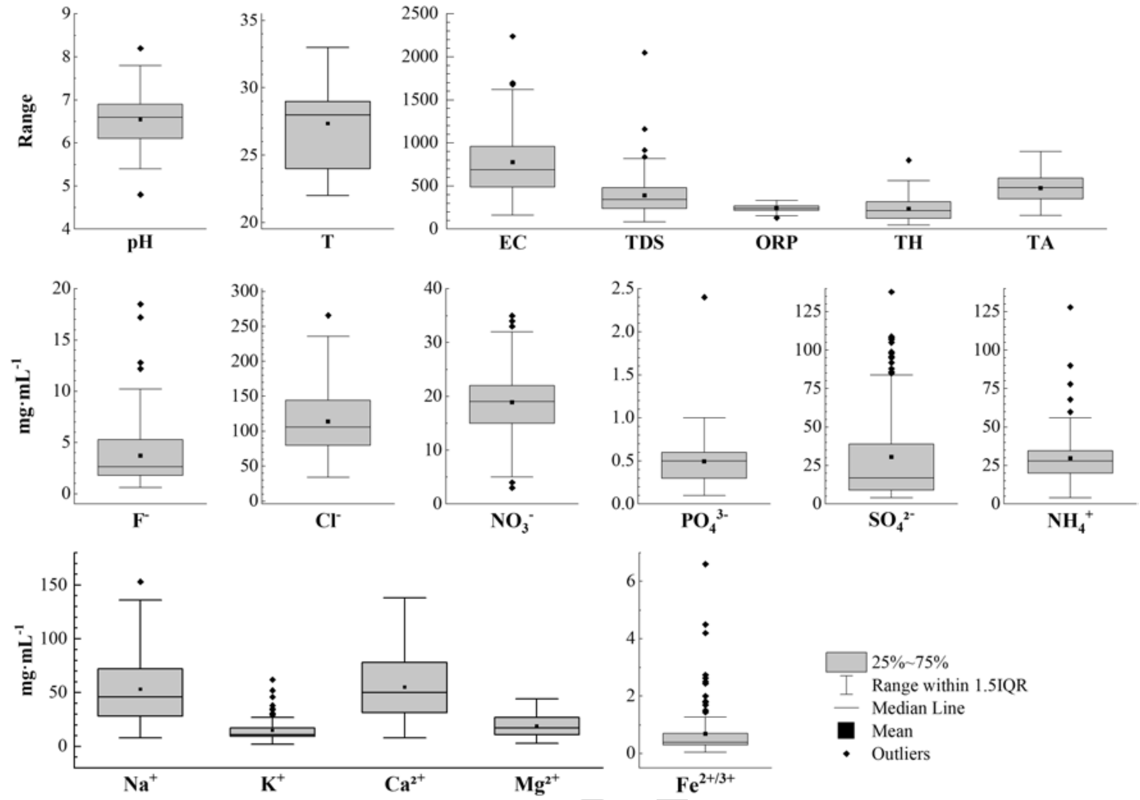


Figure 2. Box and whiskers plot of hydrochemical parameters of GW from Rajnandgaon district (2017 post-monsoon season). EC, TDS, DO, ORP, TA and TH stand for electrical conductivity, total dissolved solids, dissolved oxygen, oxidation-reduction potential, total alkalinity and total hardness.

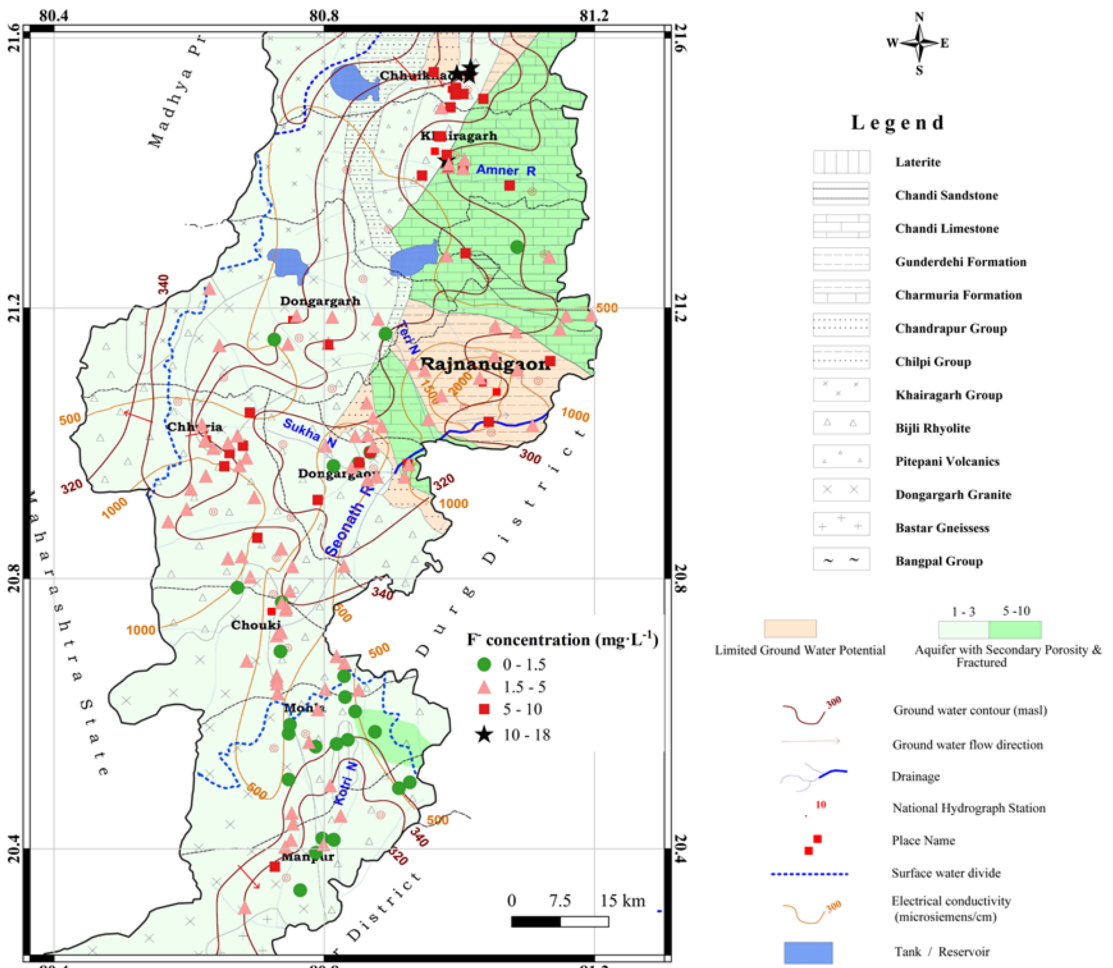
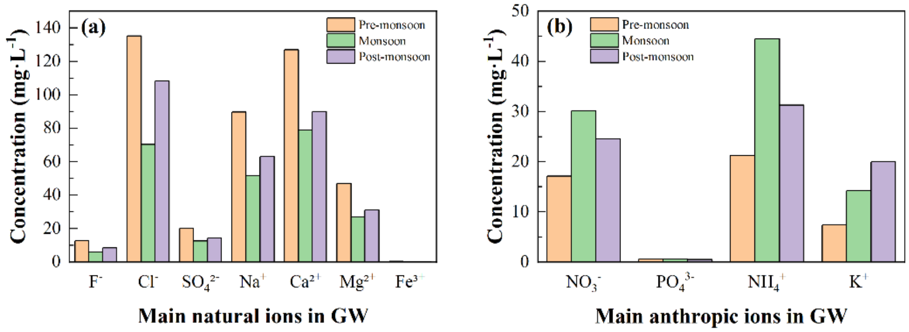


Figure 3. Spatial variations of F⁻ concentration in GW in the 2017 post-monsoon season in Rajnandgaon district.



380 **Figure 4**. Seasonal variation (monsoon, post-monsoon and pre-monsoon) of ion concentration in the GW of Chhuikhadan tehsil.

Figure 5. Examples of skeleton fluorosis in cattle in Rajnandgaon district.

TABLES

Table 1. Physico-chemical characteristics of GW in the nine tehsils in the post-monsoon season.

Block	Statistical parameter	pH	T (°C)	EC (μS·m^{-1})	TDS (mg·L^{-1})	DO (mg·L^{-1})	ORP (mV)	TH (mg·L^{-1})	TA (mg·L^{-1})
Chhuikhadan (n = 20)	Min	6.4	24	584	292	4.0	155	200	430
	Max	7.1	27	1389	695	6.8	242	495	775
	Mean	6.7	24	860	432	5.6	210	314	568
	STD	0.2	0.7	251	129	0.9	23	82	95
	CL	0.1	0.3	110	57	0.4	10	36	42
Khairagarh (n = 20)	Min	6.3	24	323	161	4	190	170	200
	Max	7.1	25	3840	2050	7	228	395	567
	Mean	6.6	24	1008	509	5.6	214	261	402
	STD	0.2	0.3	759	405	1.0	10	64	99
	CL	0.1	0.1	333	177	0.4	4	28	44
Dongargarh (n = 10)	Min	6.4	24	459	240	4.2	190	170	160
	Max	7.4	26	981	498	7.1	243	510	300
	Mean	7.0	25.2	690	360	5.9	225	349	212
	STD	0.4	1	200	99	1.0	17	101	47
	CL	0.2	0.4	121	60	0.6	11	61	28
Rajnandgaon (n = 10)	Min	7.2	28	738	367	4.2	167	187	179
	Max	8.2	29	1697	917	7.1	193	561	336
	Mean	7.6	28	1103	574	5.4	181	384	237
	STD	0.3	0.4	309	168	1.1	8	111	53
	CL	0.2	0.3	191	104	0.7	5	69	33
Dongargaon (n = 20)	Min	5.5	27	166	83	4.4	231	60	240
	Max	7.5	32	1320	659	7.4	333	800	900
	Mean	6.5	30	619	307	6.1	277	227	470
	STD	0.5	2	318	158	1.0	25	184	185
	CL	0.2	1	139	69	0.4	11	81	81
Chhuria (n = 20)	Min	6.4	27	463	242	4.4	213	120	240
	Max	7.1	29	2240	1162	7.5	280	502	870
	Mean	6.9	27.9	992	502	6.0	236	290	521
	STD	0.2	0.6	477	242	1.1	17	120	150
	CL	0.1	0.3	209	106	0.5	7	52	66
Ambagarh (n = 20)	Min	5.8	27	190	95	4.5	264	70	230
	Max	7.1	33	1475	739	7.6	316	360	760
	Mean	6.5	31	743	349	6.0	287	182	535
	STD	0.4	1	383	197	1	15	79	153
	CL	0.2	1	168	86	0.5	7	35	67
Mohla (n = 20)	Min	5.4	22	205	103	4.5	131	60	310
	Max	7.1	32	1189	594	7.6	297	270	690
	Mean	6.0	28	626	313	6.0	249	138	528
	STD	0.4	3	271	134	1	33	62	119
	CL	0.2	1	119	59	0.5	14	27	52
Manpur (n = 20)	Min	4.8	24	162	81	4.5	226	45	310
	Max	6.2	30	967	483	7.6	293	195	780
	Mean	5.8	27	469	237	6.0	255	100	552
	STD	0.3	2	191	95	1.0	17	37	138
	CL	0.1	0.7	84	42	0.5	7	16	60

Table 2. Ion concentrations (in mg·L^{-1}) in GW in the nine tehsils in the post-monsoon season.

Block	SP	F^-	Cl^-	NO_3^-	PO_4^{3-}	SO_4^{2-}	NH_4^+	Na^+	K^+	Ca^{2+}	Mg^{2+}	Fe^{3+}
	Min	5.3	43	10	0.3	7	17	25	2	58	17	0.3
	Max	18.5	230	35	0.8	31	45	125	12	136	44	0.5
Chhuikhadan	Mean	8.4	108	25	0.5	15	31	63	10	90	31	0.4
	STD	3.8	51	8.4	0.1	6	9	25	2.1	21	7	0.1
	CL	1.7	22	3.7	0.1	3	4	11	0.9	9	3	0.03
	Min	3.2	43	5	0.3	9	12	14	11	50	16	0.3
	Max	10.2	231	35	0.9	41	47	110	52	114	37	0.7
Khairagarh	Mean	5.6	106	23	0.5	19	29	64	17	82	26	0.4
	STD	2.0	67	10	0.2	9	11	32	10	16	6	0.1
	CL	0.9	29	4	0.1	4	5	14	4	7	3	0.06
	Min	1.3	39	12	0.4	53	4.6	18	4.0	32	11	0.4
	Max	3	110	28	0.7	138	60	35	13.0	78	27	0.8
Dongargarh	Mean	2.0	67	19	0.5	80.1	30	26	7.7	60	18.6	0.6
	STD	0.6	23	5	0.1	25	17	5	2.6	15	5.6	0.1
	CL	0.4	14	3	0.1	15	10	3	1.6	9	3.4	0.1
	Min	1.5	126	13	0.4	66	6	36	5	36	14	0.5
	Max	6.3	236	31	0.8	109	78	119	18	87	35	0.9
Rajnandgaon	Mean	3.0	178	21	0.6	90	39	75	10	67	24	0.7
	STD	1.8	32	6	0.1	16	22	30	4	16	7	0.1
	CL	1.1	20	3	0.1	10	14	18	2	10	5	0.1
	Min	1.5	67	8	0.3	7	28	8	11	16	7	0.05
	Max	6.6	186	23	2.4	151	128	45	46	51	41	4.2
Dongargaon	Mean	3.0	140	18	0.7	28	50	18	28	30	12	0.8
	STD	1.7	32	5	0.4	32	24	10	9	10	8	1.0
	CL	0.7	14	2	0.2	14	11	4	4	4	3	0.4
	Min	1.8	71	17	0.4	4	23	25	10	28	9	0.1
	Max	9.3	160	19	0.7	108	38	121	62	138	41	2.6
Chhuria	Mean	3.9	107	19	0.50	46	31	56	20	66	22	0.8
	STD	2.1	27	0.6	0.1	38	4	26	14	29	9	0.8
	CL	0.9	12	0.3	0.04	17	2	11	6	13	4	0.3
	Min	1.5	60	10	0.1	7	10	16	8	10	3	0.15
	Max	5.6	124	22	0.8	78	33	71	20	84	35	2.44
Ambagarh	Mean	2.5	89	17	1.0	30	22	34	12	43	15	0.90
	STD	1.0	21	5	0.1	19	7	16	4	19	9	0.66
	CL	0.4	9	2	0.1	8	3	7	2	8	4	0.29
	Min	0.6	34	11	0.2	5	13	17	8	8	6	0.12
	Max	3.3	164	20	0.8	29	33	153	31	104	33	6.6
Mohla	Mean	1.7	109	17	0.3	11	21	75	12	35	15	1.2
	STD	0.6	29	3	0.2	6	6	39	5	23	6	1.9
	CL	0.3	13	1	0.1	3	3	17	2	10	3	0.8
	Min	1	86	3	0.20	4	4	33	7	12	4	0.06
	Max	8.1	266	20	0.30	45	29	129	35	52	19	1.7
Manpur	Mean	2.2	129	14	0.22	10	19	62	11	30	10	0.3
	STD	1.7	43	6	0.04	10	8	21	6	12	4	0.4
	CL	0.7	19	3	0.02	4	3	9	3	5	2	0.2

SP = Statistical parameter

Table 3. Loadings of main ions on significant principal components (with Varimax rotation) for post-monsoon GW samples in Rajnandgaon district.

Parameters	Component			
	1	2	3	4
Ca^{2+}	0.947			
Mg^{2+}	0.921			
F^{-}	0.769			
NO_3^{-}	0.550			
NH_4^{+}		0.819		
K^{+}		0.752		
SO_4^{2-}			-0.815	
TA			0.805	
Cl^{-}				0.861
Na^{+}				0.733

Table 4. Source contributions (%) to variables according to APCS–MLR

Parameter	Source contribution (%)						Estimated mean concentration (E)	Observed mean concentration (O)	Ratio (E/O)	R^2
	S1	S2	S3	S4	S5	Unidentified sources				
Ca^{2+}	87.34	9.02	3.10				48.65	54.99	0.88	0.89
Mg^{2+}	85.11	14.96					14.24	19.03	0.74	0.84
F^{-}	79.81				19.95		4.21	3.71	1.13	0.71
Temp	63.98		12.88	16.34	6.80		33.23	27.33	1.21	0.65
TH	62.00	7.73	11.70	6.02		12.44	162.56	234.69	0.69	0.67
RP	47.86			5.05	47.09	0.00	297.56	241.28	1.23	0.57
Na^{+}	6.14	75.99				17.87	44.78	53.09	0.84	0.79
TDS	20.29	75.00	4.71				424.68	386.93	1.09	0.72
EC	13.55	75.00	8.13			3.32	610.24	771.46	0.79	0.76
Cl^{-}		69.00		13.18	17.83		78.54	113.93	0.68	0.69
PO_43			71.88	28.13			0.32	0.49	0.65	0.70
Fe^{3+}			69.39		14.29	14.29	0.49	0.68	0.72	0.69
SO_4^{2-}		31.03	68.97				19.56	30.47	0.64	0.68
NH_4^{+}	15.01			84.99			27.44	29.66	0.92	0.84
K^{+}				62.94	37.06		9.58	14.8	0.64	0.63
NO_3^{-}	46.00			37.12		16.95	11.8	18.84	0.62	0.60
TA	5.65	7.81			80.00	6.54	438.68	474.97	0.92	0.81
pH	29.86		39.93			30.22	5.56	6.54	0.85	0.76