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Human Health Risk Assessment through Depiction of Major Ion Chemistry of Groundwater from Part of Balaghat District (MP), Central India

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ABSTRACT

The key interpretations on the study concerning the human health risk appraisal and hydrogeochemical environment of major ions (cations and anions) of the groundwater samples from the part of Balaghat District (MP) latitude 21°31'42": 2143'11" N and longitude 79°50' 30": 80°11'30"E., Central India are presented here. The pH and EC values were found to grade between 7.3 to 8.6 and 50 to 5080 µS/cm, unraveling the alkaline nature of groundwater and numerous phases of processes in groundwater characterization. The ion exchange along with the solubilization processes during the rock-water interaction undoubtedly represents the geogenic as well as non-geogenic sources for the salinity in the groundwater of the study area. The Ca^{2+} is predominant over the other cations, wherein the abundance succession of cations is $Ca^{2+} > Na^{+} > Mg^{2+} > K^{+}$. The HCO_3^- predominates over the other anions with the abundance succession as - $HCO_3^- > Cl^- > NO_3^- > SO_4^{2-} > F^-$. The concentrations of the cations and the anions have been subjected to Aquachem-4 software to get the Piper trillinear diagram for the groundwater samples of the study area and it has been found that the alkaline earths (Ca + Mg) exceed the alkalis (Na + K). The three major facies evaluated after the analysis from the study area are Mg-HCO_3 (75%), Na-HCO_3 (16%) and Ca-HCO_3 (9%). The total health hazard quotient (THI) values due to NO_3^- content range from 0.026 to 6972 mg/kg/day for the adult and from 0.034 to 1002.7 mg/kg/day for children. Similarly, the health hazard quotient (THI) values due to F^- concentration ranges from 0.01 to 0.19 mg/kg/day and from 0.02 to 0.52 mg/kg/day for adult and children respectively. Thus, the study points out that the children are more susceptible to the non-carcinogenic risk than to adults and may pose undesirable health effects.

***Key words**: Human Health Risk, Major ions, Chemistry, Groundwater, Balaghat, Madhya Pradesh, Central India*

Introduction

The chemical properties of major ions present in groundwater govern the long-lasting hydrogeochemical behaviour, taken place at the interface of aquifer-rocks and groundwater therein. Thus, the cation-anion combinations at this interface have the frequent, important and influential hydrogeochemical changes, commonly expressed as geogenic transformations in the groundwater system. If certain ion or group of ions exceeds the certain prescribed levels of combinations then they pose threat to human health and hence, referred to as geogenic contamination (Sreedevi, 2004; Nagaraju *et al.*, 2011; Wen *et al.*, 2008; Si *et al.*, 2009; Deshpande and Murkute, 2023). Equally, the human interventions, which are also referred to as anthropogenic activities add non-natural contents, which again deteriorate the groundwater quality and certainly cause the threat to human health (Si *et al.*, 2009; Li *et al.*, 2011; Ravikumar and Somashekhar, 2011; Agoubi *et al.*, 2011; Rajesh *et al.*, 2012; Omran *et al.*, 2012; Bauder *et al.*, 2014; Amiri *et al.*, 2014; Xu *et al.*, 2018; Ahada and Suthar, 2018; Wagh *et al.*, 2018; Zhang *et al.*, 2018; Eyankware *et al.*, 2020; Murkute, 2023).

Since the ever increasing groundwater contamination poses immense threat to the human health, the unfailing examinations have been expanding the apprehension of hydrogeochemical, environment through statistical investigations and other related issues (Li *et al.*, 2012; Brindha and Elango, 2013; Wu *et al.*, 2015; Hirojeet *et al.*, 2015; Thilagavathi *et al.* 2015; Duraisamy *et al.*, 2018; Sreedevi *et al.*, 2018; Li *et al.*, 2018; Xu *et al.*, 2018; Adimalla and Qian 2019; Wang *et al.*, 2019; Singh *et al.*, 2019; Eyankware *et al.*, 2020; Gogulothu *et al.*, 2022). In this scenario, the interrelated studies give a hand in devising the policies for planning, remedial measures, regulations to cope up with groundwater contamination.

The study area signifies the western-south part of Balaghat district latitude 21°31′42′: 2143°11″ N and longitude 79°50′ 30″: 80°11′30″E, Madhya Pradesh, Central India. The study area also covers to five watersheds, wherein all these watersheds cover-up the rural part of the district, in which groundwater is the sole source of water for drinking and irrigation purpose. Seldom, public water supply scheme provides the tap-water, but again the source of water is groundwater from shallow as well as deep aquifers. There is very little information available on hydrogeochemical characters of groundwater from this area. It is, therefore, an endeavor has been made to examine the hydrogeochemical behavior of groundwater by emphasizing on the statisctical methods, which would provide significant on groundwater quality. Hence, the statistical tool of cluster analyses have been commenced to understand the various leading processes of groundwater chemistry (Hegeu and Kshetrimayum, 2019; Ravish *et al.*, 2020; Naidu *et al.*, 2021; Natesan *et al.*, 2022; Nayak and Hota, 2023).

Study Area

The Balaghat district is located in the southeastern part of Madhya Pradesh, Central India and is bounded by Mandla, Rajnandgaon and Seoni districts in the north, east and west respectively. The study area covers the western-south part of Balaghat district. It falls in degree sheet numbers 64B, 64C, 55O and 55N between latitude 21° 15 and 22° 30 N and longitude 79° 30 and 81° 00 E. It represents the undulating area, where the semi-arid climatic condition prevails. In summer seasons the utmost temperature blazes up to 45°C and drops down up in winter to 8°C. The average annual rainfall is 1167 mm in the monsoon season and humidity varies from 11 to 78%. The small streams of various orders delineate the dendritic-drainage pattern and drain out towards northern part of study area.

Geology and Hydrogeology

The Precambrain gneisses and meta-quartzites represent the fundamental geological set-up of the study area. These gneisses are coarse- to medium grained and are composed mainly of plagioclase, quartz, microcline with seldom biotite and hornblende mineral suites. The meta-quartzites are composed of coarse- to medium grained quartz and plagioclase feldspars.

The borewells located in these lithological units have normal depth and diameters up to 60 meters below ground level (mbgl) and from 4 to 8 inches respectively; however private borewells are drilled deeper than the normal depth. The groundwater discharge from these borewells have discharge of 90 to 150 m^3/ day.

Materials and Methods

77 groundwater samples were collected from preferred borewells and the procedures precisely suggested by APHA 2012 were used for analytical measures. Respective field-meters were utilized to measure the temperature, pH and electrical conductivity (EC) at the borewells locations. The Ca^{2+}, Mg^{2+}, Cl^-, and HCO_3^- were estimated by the titration method; the Na^+ K^+ concentrations were noted from flame photometer. SO_4^{2-}, F^- and NO_3^- were determined by the UV-visible spectrophotometer. Total dissolved solids (TDS) as well as total hardness (TH) were worked out from mathematical expressions, and the concentrations of various ions have been presented in Table 1. Cluster analysis ramifies the variables into the sets of comparatively homogeneous and distinct groups. Cluster analysis is carried out from correlation coefficient and Euclidean distances.

Health risk assessment initiated by the United States Environmental Protection Agency (USEPA, 2014) has been followed in the present study to evaluate the possible harmful impacts of the groundwater on the health of children and adults (Subba Rao *et al.,* 2019, 2020 and 2021). Drinking and the bathing are the two main ways by which the human-body absorbs the harmful material from the groundwater; however, the impact on human-health hazard through bathing is relatively uncommon. Therefore, the effects of drinking water on human health have been unraveled in the present study. The NO_3^- contaminated groundwater is possibly consumed by the cooking and drinking. To measure the probable non-carcinogenic risk of health hazard quotient, the following formulae suggested by USEPA (2014) were used.

$$\text{Mean daily dose (DD)} = \frac{Cp \times Ir \times Ed \times Ef}{Bw \times Et} \qquad \text{Equation 1}$$

$$\text{Health hazard quotient (HHQ)} = \frac{DD}{Rd} \qquad \text{Equation 2}$$

In the above expression, Cp represents the concentration of pollutants in mg/l. The values for intake rate (Ir) for infant, children as well as male and female adults are 0.31, 0.78, 2.5 and 2.0 l/day respectively (USEPA, 2014). The values for exposure duration (ED) for children and , adults are 12and 64 years respectively (WHO, 2017); while the exposure frequency for all is 365 days (USEPA, 2014). The values for average body weight (Bw) and the average exposure time (Et) for children and adults are 15 and 65 as well as 365 and 23360 days respectively (ICMR, 2009; USEPA, 2014). The reference dose (Rd) for all is considered as 1.6 mg/Kg/ day (USEPA, 2014). The allowable limit of health hazard quotient (HHQ) is 1.0 (USEPA, 2014). HHQ value less than 1.0 suggests that the non-carcinogenic risk is within the range of acceptable limit, while HHQ value more than 1.0 suggests the non-carcinogenic risk of the contaminant. The various groundwater fitness parameters, evolved through the mathematical calculations have been checked for drinking and irrigation suitability of groundwater from the study area.

Major Ion Chemistry

The pH and EC values were found to vary from 7.3 to 8.6 and 50 to 5080 µS/cm (Table 1) depicting alkaline nature and series of processes in groundwater characterization (Subba Rao, 2017). This high conductivity in groundwater is due to the ion exchange along with the solubilization processes during the rock-water interaction and may represents anthropogenic activity also (Sanchez-Perez and Tremolieres, 2003; Choi *et al.,* 2005); while the high TDS (average value - 847.5 mg/l) undoubtedly represents the geogenic as well as non-geogenic sources for the salinity in the groundwater of the study area (Subba Rao *et al.,* 2017).

The Ca^{2+} is the dominant constituent of the abundance succession of cations ($Ca^{2+} > Na^+ > Mg^{2+} > K^+$); wherein the concentration of Ca^{2+} varies from 8.0 - 493.0 mg/l whereas the Na^+ content ranges from 4.2 - 540.0 mg/l (Table 1). The plagioclases present in host rocks are the chief sources of Ca^{2+} and the dissolution of calcium-bearing mineral suites is the significant geogenic process responsible for the derivation of Ca^{2+} content in groundwater (Subba Rao and Chaudhary, 2019; Murkute, 2023). Moreover, the reverse ion exchange as well as change in precipitation cause the behavioral alteration in Ca^{2+} content in groundwater (Ahada and Suthar, 2018; Nayak and Hota, 2023). The preponderance of Na^+ in groundwater points to the weathering as well as dissolution of the host rocks as well as involvement of anthropogenic inputs. The intake of such excessive concentration of Na^+ than the permissible limit always pose a threat in human body causing the intaker prone to cardiac, renal and circulatory diseases (Mor *et al.,* 2006). The concentration of Mg^{2+} (4.9 - 332.9 mg/l) and the K^+ (0.3 - 5.8 mg/l) are expected to be released from the mineral-suites resulting through the ion exchange processes of geogenic origin (Thivya *et al.,* 2018; Gogulothu *et al.,* 2022); contrary the surplus use of fertilizers, pesticides, domestic wastes, septic tank spillages contribute the anthropogenic inputs of Mg^{2+} in groundwater regime (Roy *et al.,* 2018; Mgbenu and Egbueri., 2019; Subba Rao., 2021). The sodics plagioclases, potash feld-

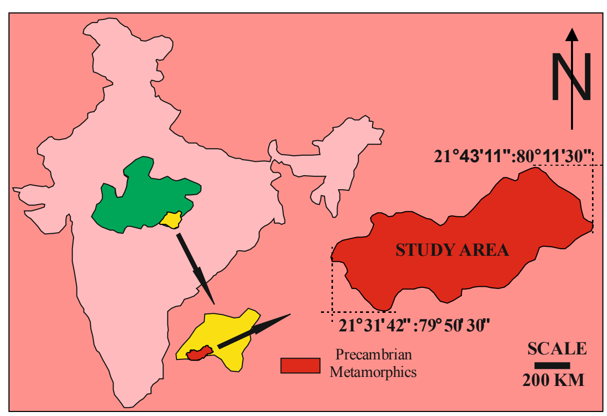

Fig. 1. Location map and geological map of study area with

Table 1. Range of cations and anions with desirable and permissible limits (n = 77)

Parameter	Min	Max	Avg	WHO (2017)		BIS (2020) IS: 10500		SD	CV
				DL	PL	DL	PL		
pH	7.3	8.6	8.0	7.0-8.5	6.5-9.2	6.5-8.5	8.5-9.2	0.3	3.8
EC	50.0	5080.0	1408.7	750	1500	-	-	1113.6	79.0
TDS	34.0	3098.0	847.5	500	1500	500	2000	659.4	77.8
TA	20.0	516.0	288.1	100	500	200	600	92.0	31.9
TH	40.0	2597.3	579.8	100	500	300	600	490.8	84.6
Ca^{++}	8.0	493.0	112.2	75	200	75	200	93.8	83.6
Mg^{++}	4.9	332.9	72.9	30	150	30	100	68.4	93.8
Na^{+}	4.2	540.0	118.8	50	200	-	-	133.9	112.7
K^{+}	0.3	5.8	2.0	100	200	-	-	1.2	62.3
HCO_3^-	20.0	516.0	283.2	200	600	200	600	94.1	33.2
Cl^-	8.0	1250.0	184.1	250	600	250	1000	231.2	125.5
SO_4^{--}	0.6	184.0	42.1	200	600	200	400	47.4	112.4
F^-	0.5	1.0	1.5	1.0	1.5	1.0	1.0	0.2	23.7
NO_3^-	0.8	541.9	58.6	-	50	45	100	96.0	163.2

Ions values are presented in mg/l. SD – standard deviation, CV – covariance. DL – Desirable limit; PL – Permissible limit

spars are the geogenic; while the potassium-based fertilizers, household wastes as well as irrigation-return-flows are the anthropogenic sources of K^+ (Subba Rao *et al.*, 2020).

HCO_3^- > Cl^- > NO_3^- > SO_4^{2-} > F^- is the order of abundance of the anions. The HCO_3^- concentration (20.0 – 516.0 mg/l) suggests the incidence of mineral dissolution in the groundwater system (Subba Rao *et al.*, 2017; Subba Rao, 2018); while the anthropogenic sources like domestic wastes, septic tank leakage and irrigation-return-flow are the usual source of Cl^- (8 – 1250.0 mg/l) in groundwater of study area (Laxman *et al.*, 2019). The NO_3^- (0.8 – 541.9 mg/l) have probably been released from the sewage waste, septic pool leakages, agricultural left-overs and decay of animal-bodies (Subrahmanyam and Yadaiah, 2000; Schilling and Wolter, 2007; Raju *et al.*, 2009; He *et al.*, 2019); while the SO_4^{2-} contents (0.6 – 184.0 mg/l) possibly have been released through soil conditioner used in agricultural practices and moreover from oxidation of sulphide minerals fertilizers in groundwater of present study area (Chae *et al.*, 2004; Subba Rao *et al.* 2012; Murkute, 2014). The weathering of fluoride minerals like apatite, fluorite, biotite, hornblende and phosphatic fertilizers are the chief sources of F^- (0.5 - 1.5 mg/l) in groundwater (Nayak and Hota, 2023).

Hydrochemical Facies

The cation-anion position in Piper's trilinear diagram represents the hydrogeochemical types that suggest the modes of reactions occurring groundwater at rock-water interface. The concentrations of the cations and the anions have been subjected to Aquachem-4 software to get the Piper trillinear diagram for the groundwater samples of the study area (Fig. 2a). It has been noticed that the alkaline earths (Ca + Mg) exceed the alkalis (Na + K); however in 42% samples alkalis (Na + K) found to dominate over the alkaline earths (Ca + Mg). In the 66% samples from study area, the strong acid (SO4 + Cl) predominates over the weak acid (CO_3 + HCO_3). The three major facies found out in the analysis from the study area are Mg-HCO_3 (75%), Na-HCO_3 (16%) and Ca-HCO_3 (9%). The distribution of these facies in study area is presented as per diagram (Fig.2b).

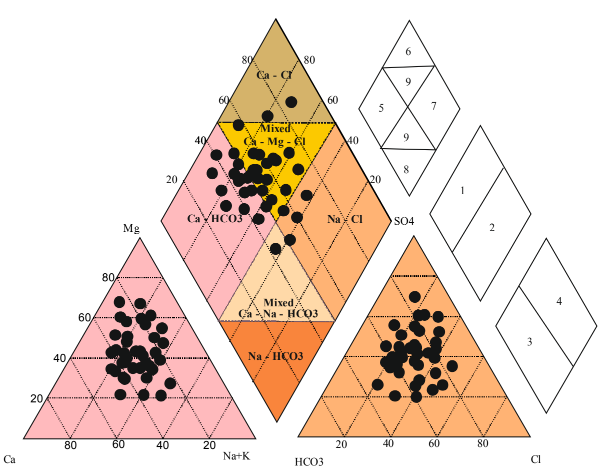

Fig. 2a. Piper's diagram for groundwater samples from study area

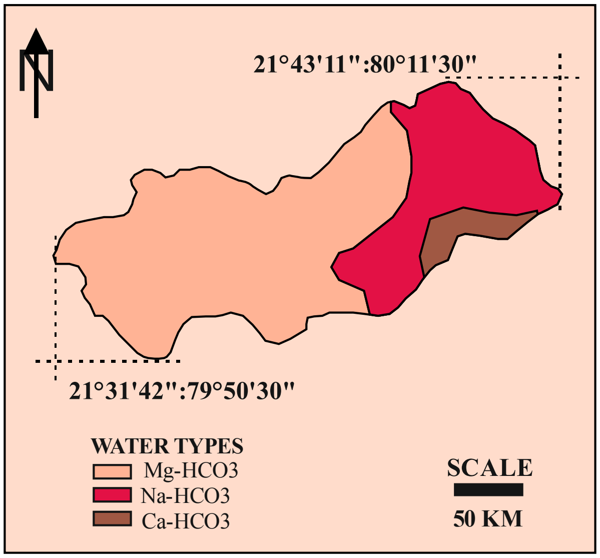

Fig. 2b. Water types from study area

Health Risk Appraisal

The concentration of NO_3^- and F^-, if exceeds the permissible limit, the results are the severe disease of skin referred as methemoglobinemia and fluorosis (dental, skeletal and non skeletal-skin) respectively (USEPA, 2014; Wu *et al.*, 2015b; Subba Rao *et al.*, 2021; Nayak and Hota 2023; Murkute, 2023). The minimum and maximum values of NO_3^- concentration in the present study are 0.8 and 541.9 mg/l respectively, against the permissible limit of 45 mg/l recommended by BIS (2020) and WHO (2017). Correspondingly, the minimum and maximum concentration values of F^- are 0.5 and 1.5 mg/l respectively, against the permissible limit of 1.0 mg/l recommended by BIS (2020). The total health hazard quotient (THI) values (mg/kg/day) due to NO_3^- content ranges from 0.026 to 6972.4 (average: 298.6) and from 0.034 to 1002.7 (average: 428.2) for adult and children respectively (Table 2). Similarly, the health hazard quotient (THI) values due to F^- concentration ranges from 0.01 to 0.19 (average: 0.03) and from 0.02 to 0.52 (average: 0.08) for adult and children respectively (Table 2). The children are more susceptible to the non-carcinogenic risk in comparison to adults and may pose undesirable health effects in the order of children than the adults, which are the probable non-carcinogenic concern, as also been noticed in other part of World (Li *et al.*, 2012; Wu and Sun, 2016 and Zhang *et al.*, 2018).

Conclusion

The following are the significant conclusions of the present study from the part of Balahgat District (MP), Central India:

i) The values of pH and EC concentration, as found to vary from 7.3 to 8.6 and 50 to 5080 µS/cm, depict alkaline nature and distinct processes in groundwater behavioral change. Though the high conductivity in groundwater is due to the ion exchange along with the solubilization processes during the rock-water interaction, the high TDS (average value - 847.5 mg/l) undoubtedly represents the geogenic as well as non-geogenic sources for the salinity in the groundwater of the study area.
ii) The abundance succession of cations is $Ca^{2+} > Na^+ > Mg^{2+} > K^+$; wherein plagioclases present in host rocks are the principal sources of Ca^{2+}. The reverse ion exchange as well as change in precipitation cause the behavioral alteration in Ca^{2+} content in groundwater. $HCO_3^- > Cl^- > NO_3^- > SO_4^{2-} > F^-$ is the order of abundance of the anions. The HCO_3^-concentration (20.0 – 516.0 mg/l) suggests the mineral dissolution in the groundwater system.
iii) The cation-anion position in Piper's trilinear diagram (Piper, 1953) represents the three major facies- $Mg\text{-}HCO_3$ (75%: entire area except eastern portion of the study area), $Na\text{-}HCO_3$ (16%: eastern portion of the study area) and $Ca\text{-}HCO_3$ (9%: south eastern position in study area).
iv) The THI values (mg/kg/day) due to NO_3^- content ranges from 0.026 to 6972.4 while the THI values due to F^- concentration ranges from 0.01 to 0.19. The children are more vulnerable to the non-carcinogenic risk than to adults and may pose undesirable health effects in the order of children than the adults.

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Conflict of Interest

None

Table 2. Health risk assessment of nitrate and fluoride for children and adults from study area

Sample Location	Health Risk Assessment for Nitrate: NO_3^- (mg/l)	Children HQ **O**ral	Children HQ **D**ermal	NO_3^- THI	Adult HQ **O**ral	Adult HQ **D**ermal	NO_3^- THI	Health Risk Assessment for Fluoride: F^- (mg/l)	Children HQ **O**ral	Children HQ **D**ermal	F^- THI	Adult HQ **O**ral	Adult HQ **D**ermal	F^- THI
AP-1	6.23	1.32E+00	9.69E-02	1	9.20E-01	8.57E-02	1	0.090	7.58E-03	3.85E-02	0.0	2.48E-03	1.60E-02	0.0
AP-2	5.83	1.16E+00	9.07E-02	1	8.06E-01	8.02E-02	1	0.250	5.85E-02	1.07E-01	0.2	1.91E-02	4.43E-02	0.1
AP-3	5.99	1.22E+00	9.32E-02	1	8.51E-01	8.24E-02	1	0.110	1.13E-02	4.71E-02	0.1	3.70E-03	1.95E-02	0.0
AP-4	26.64	2.42E+01	4.14E-01	25	1.68E+01	3.66E-01	17	0.060	3.37E-03	2.57E-02	0.0	1.10E-03	1.06E-02	0.0
AP-5	27.12	2.50E+01	4.22E-01	25	1.74E+01	3.73E-01	18	0.050	2.34E-03	2.14E-02	0.0	7.64E-04	8.87E-03	0.0
AP-6	28.93	2.85E+01	4.50E-01	29	1.98E+01	3.98E-01	20	0.210	4.13E-02	8.98E-02	0.1	1.35E-02	3.72E-02	0.1
AP-7	51.24	8.93E+01	7.97E-01	90	6.23E+01	7.05E-01	63	0.100	9.36E-03	4.28E-02	0.1	3.06E-03	1.77E-02	0.0
AP-8	92.62	2.92E+02	1.44E+00	293	2.03E+02	1.27E+00	205	0.320	9.58E-02	1.37E-01	0.2	3.13E-02	5.67E-02	0.1
AP-9	8.67	2.56E+00	1.35E-01	3	1.78E+00	1.19E-01	2	0.050	2.34E-03	2.14E-02	0.0	7.64E-04	8.87E-03	0.0
AP-10	34.29	4.00E+01	5.33E-01	41	2.79E+01	4.72E-01	28	0.070	4.59E-03	2.99E-02	0.0	1.50E-03	1.24E-02	0.0
AP-11	34.21	3.98E+01	5.32E-01	40	2.78E+01	4.71E-01	28	0.080	5.99E-03	3.42E-02	0.0	1.96E-03	1.42E-02	0.0
AP-12	159.23	8.63E+02	2.48E+00	865	6.01E+02	2.19E+00	603	0.070	4.59E-03	2.99E-02	0.0	1.50E-03	1.24E-02	0.0
AP-13	85.72	2.50E+02	1.33E+00	251	1.74E+02	1.18E+00	175	0.090	7.58E-03	3.85E-02	0.0	2.48E-03	1.60E-02	0.0
AP-14	50.76	8.77E+01	7.90E-01	88	6.11E+01	6.98E-01	62	0.060	3.37E-03	2.57E-02	0.0	1.10E-03	1.06E-02	0.0
AP-15	126.12	5.41E+02	1.96E+00	543	3.77E+02	1.73E+00	379	0.220	4.53E-02	9.41E-02	0.1	1.48E-02	3.90E-02	0.1
AP-16	5.52	1.04E+00	8.59E-02	1	7.23E-01	7.59E-02	1	0.080	5.99E-03	3.42E-02	0.0	1.96E-03	1.42E-02	0.0
AP-17	94.59	3.04E+02	1.47E+00	306	2.12E+02	1.30E+00	213	0.100	9.36E-03	4.28E-02	0.1	3.06E-03	1.77E-02	0.0
AP-18	37.68	4.83E+01	5.86E-01	49	3.37E+01	5.18E-01	34	0.080	5.99E-03	3.42E-02	0.0	1.96E-03	1.42E-02	0.0
AP-19	9.10	2.82E+00	1.42E-01	3	1.96E+00	1.25E-01	2	0.260	6.33E-02	1.11E-01	0.2	2.07E-02	4.61E-02	0.1
AP-20	1.97	1.32E-01	3.06E-02	0	9.20E-02	2.71E-02	0	0.180	3.03E-02	7.70E-02	0.1	9.90E-03	3.19E-02	0.0
AP-21	15.57	8.25E+00	2.42E-01	8	5.75E+00	2.14E-01	6	0.140	1.83E-02	5.99E-02	0.1	5.99E-03	2.48E-02	0.0
AP-22	65.43	1.46E+02	1.02E+00	147	1.02E+02	9.00E-01	102	0.100	9.36E-03	4.28E-02	0.1	3.06E-03	1.77E-02	0.0
AP-23	25.62	2.23E+01	3.99E-01	23	1.56E+01	3.52E-01	16	0.160	2.40E-02	6.84E-02	0.1	7.83E-03	2.84E-02	0.0
AP-24	1.14	4.42E-02	1.77E-02	0	3.08E-02	1.57E-02	0	0.550	2.83E-01	2.35E-01	0.5	9.25E-02	9.75E-02	0.2
AP-25	111.54	4.23E+02	1.74E+00	425	2.95E+02	1.53E+00	297	0.120	1.35E-02	5.13E-02	0.1	4.40E-03	2.13E-02	0.0
AP-26	86.71	2.56E+02	1.35E+00	257	1.78E+02	1.19E+00	179	0.160	2.40E-02	6.84E-02	0.1	7.83E-03	2.84E-02	0.0
AP-27	29.32	2.93E+01	4.56E-01	30	2.04E+01	4.03E-01	21	0.100	9.36E-03	4.28E-02	0.1	3.06E-03	1.77E-02	0.0
AP-28	23.02	1.80E+01	3.58E-01	18	1.26E+01	3.17E-01	13	0.160	2.40E-02	6.84E-02	0.1	7.83E-03	2.84E-02	0.0
AP-29	20.89	1.49E+01	3.25E-01	15	1.03E+01	2.87E-01	11	0.120	1.35E-02	5.13E-02	0.1	4.40E-03	2.13E-02	0.0
AP-30	104.05	3.68E+02	1.62E+00	370	2.57E+02	1.43E+00	258	0.160	2.40E-02	6.84E-02	0.1	7.83E-03	2.84E-02	0.0
AP-31	13.68	6.37E+00	2.13E-01	7	4.44E+00	1.88E-01	5	0.100	9.36E-03	4.28E-02	0.1	3.06E-03	1.77E-02	0.0
AP-32	3.94	5.28E-01	6.13E-02	1	3.68E-01	5.42E-02	0	0.12	1.35E-02	5.13E-02	0.1	4.40E-03	2.13E-02	0.0
AP-33	49.19	8.23E+01	7.65E-01	83	5.74E+01	6.77E-01	58	0.060	3.37E-03	2.57E-02	0.0	1.10E-03	1.06E-02	0.0
AP-34	1.58	8.50E-02	2.46E-02	0	5.92E-02	2.17E-02	0	0.080	5.99E-03	3.42E-02	0.0	1.96E-03	1.42E-02	0.0
AP-35	4.97	8.41E-01	7.73E-02	1	5.86E-01	6.84E-02	1	0.090	7.58E-03	3.85E-02	0.0	2.48E-03	1.60E-02	0.0
AP-36	14.27	6.93E+00	2.22E-01	7	4.83E+00	1.96E-01	5	0.060	3.37E-03	2.57E-02	0.0	1.10E-03	1.06E-02	0.0
AP-37	7.88	2.11E+00	1.23E-01	2	1.47E+00	1.08E-01	2	0.140	1.83E-02	5.99E-02	0.1	5.99E-03	2.48E-02	0.0
AP-38	7.88	2.11E+00	1.23E-01	2	1.47E+00	1.08E-01	2	0.140	1.83E-02	5.99E-02	0.1	5.99E-03	2.48E-02	0.0

Table 2. *Continued ...*

Sample Location	Health Risk Assessment for Nitrate							Health Risk Assessment for Fluoride						
	NO_3^- (mg/l)	Children HQ **O**ral	Children HQ **D**ermal	NO_3^- THI	Adult HQ **O**ral	Adult HQ **D**ermal	NO_3^- THI	F^- (mg/l)	Children HQ **O**ral	Children HQ **D**ermal	F^- THI	Adult HQ **O**ral	Adult HQ **D**ermal	F^- THI
AP-39	12.22	5.08E+00	1.90E-01	5	3.54E+00	1.68E-01	4	0.130	1.58E-02	5.56E-02	0.1	5.17E-03	2.31E-02	0.0
AP-40	8.91	2.70E+00	1.39E-01	3	1.88E+00	1.23E-01	2	0.060	3.37E-03	2.57E-02	0.0	1.10E-03	1.06E-02	0.0
AP-41	0.99	3.34E-02	1.54E-02	0	2.32E-02	1.36E-02	0	0.070	4.59E-03	2.99E-02	0.0	1.50E-03	1.24E-02	0.0
AP-42	6.70	1.53E+00	1.04E-01	2	1.06E+00	9.22E-02	1	0.060	3.37E-03	2.57E-02	0.0	1.10E-03	1.06E-02	0.0
AP-43	68.38	1.59E+02	1.06E+00	160	1.11E+02	9.41E-01	112	0.090	7.58E-03	3.85E-02	0.0	2.48E-03	1.60E-02	0.0
AP-44	13.72	6.41E+00	2.13E-01	7	4.46E+00	1.89E-01	5	0.070	4.59E-03	2.99E-02	0.0	1.50E-03	1.24E-02	0.0
AP-45	2.56	2.23E-01	3.98E-02	0	1.55E-01	3.52E-02	0	0.270	6.82E-02	1.16E-01	0.2	2.23E-02	4.79E-02	0.1
AP-46	37.05	4.67E+01	5.76E-01	47	3.26E+01	5.10E-01	33	0.110	1.13E-02	4.71E-02	0.1	3.70E-03	1.95E-02	0.0
AP-47	19.23	1.26E+01	2.99E-01	13	8.77E+00	2.65E-01	9	0.190	3.38E-02	8.13E-02	0.1	1.10E-02	3.37E-02	0.0
AP-48	382.30	4.97E+03	5.95E+00	4980	3.47E+03	5.26E+00	3471	0.070	4.59E-03	2.99E-02	0.0	1.50E-03	1.24E-02	0.0
AP-49	266.43	2.42E+03	4.14E+00	2420	1.68E+03	3.66E+00	1687	0.140	1.83E-02	5.99E-02	0.1	5.99E-03	2.48E-02	0.0
AP-50	3.23	3.55E-01	5.02E-02	0	2.47E-01	4.44E-02	0	0.060	3.37E-03	2.57E-02	0.0	1.10E-03	1.06E-02	0.0
AP-51	226.23	1.74E+03	3.52E+00	1745	1.21E+03	3.11E+00	1217	0.220	4.53E-02	9.41E-02	0.1	1.48E-02	3.90E-02	0.1
AP-52	541.93	9.99E+03	8.43E+00	10003	6.96E+03	7.45E+00	6972	0.180	3.03E-02	7.70E-02	0.1	9.90E-03	3.19E-02	0.0
AP-53	119.81	4.88E+02	1.86E+00	490	3.40E+02	1.65E+00	342	0.120	1.35E-02	5.13E-02	0.1	4.40E-03	2.13E-02	0.0
AP-54	5.91	1.19E+00	9.19E-02	1	8.28E-01	8.13E-02	1	0.060	3.37E-03	2.57E-02	0.0	1.10E-03	1.06E-02	0.0
AP-55	294.02	2.94E+03	4.57E+00	2946	2.05E+03	4.04E+00	2054	0.050	2.34E-03	2.14E-02	0.0	7.64E-04	8.87E-03	0.0
AP-56	15.92	8.62E+00	2.48E-01	9	6.01E+00	2.19E-01	6	0.120	1.35E-02	5.13E-02	0.1	4.40E-03	2.13E-02	0.0
AP-57	19.71	1.32E+01	3.07E-01	14	9.21E+00	2.71E-01	9	0.150	2.11E-02	6.42E-02	0.1	6.88E-03	2.66E-02	0.0
AP-58	117.84	4.73E+02	1.83E+00	474	3.29E+02	1.62E+00	331	0.080	5.99E-03	3.42E-02	0.0	1.96E-03	1.42E-02	0.0
AP-59	219.92	1.65E+03	3.42E+00	1649	1.15E+03	3.02E+00	1150	0.120	1.35E-02	5.13E-02	0.1	4.40E-03	2.13E-02	0.0
AP-60	29.95	3.05E+01	4.66E-01	31	2.13E+01	4.12E-01	22	0.080	5.99E-03	3.42E-02	0.0	1.96E-03	1.42E-02	0.0
AP-61	0.79	2.12E-02	1.23E-02	0	1.48E-02	1.09E-02	0	0.140	1.83E-02	5.99E-02	0.1	5.99E-03	2.48E-02	0.0
AP-62	3.78	4.86E-01	5.88E-02	1	3.39E-01	5.20E-02	0	0.100	9.36E-03	4.28E-02	0.1	3.06E-03	1.77E-02	0.0
AP-63	12.65	5.45E+00	1.97E-01	6	3.80E+00	1.74E-01	4	0.180	3.03E-02	7.70E-02	0.1	9.90E-03	3.19E-02	0.0
AP-64	4.73	7.61E-01	7.36E-02	1	5.31E-01	6.51E-02	1	0.120	1.35E-02	5.13E-02	0.1	4.40E-03	2.13E-02	0.0
AP-65	5.12	8.92E-01	7.96E-02	1	6.22E-01	7.04E-02	1	0.100	9.36E-03	4.28E-02	0.1	3.06E-03	1.77E-02	0.0
AP-66	137.16	6.40E+02	2.13E+00	642	4.46E+02	1.89E+00	448	0.090	7.58E-03	3.85E-02	0.0	2.48E-03	1.60E-02	0.0
AP-67	0.79	2.12E-02	1.23E-02	0	1.48E-02	1.09E-02	0	0.110	1.13E-02	4.71E-02	0.1	3.70E-03	1.95E-02	0.0
AP-68	24.12	1.98E+01	3.75E-01	20	1.38E+01	3.32E-01	14	0.070	4.59E-03	2.99E-02	0.0	1.50E-03	1.24E-02	0.0
AP-69	58.53	1.17E+02	9.11E-01	117	8.12E+01	8.05E-01	82	0.150	2.11E-02	6.42E-02	0.1	6.88E-03	2.66E-02	0.0
AP-70	9.77	3.25E+00	1.52E-01	3	2.26E+00	1.34E-01	2	0.110	1.13E-02	4.71E-02	0.1	3.70E-03	1.95E-02	0.0
AP-71	3.15	3.38E-01	4.90E-02	0	2.35E-01	4.33E-02	0	0.170	2.70E-02	7.27E-02	0.1	8.83E-03	3.01E-02	0.0
AP-72	39.26	5.25E+01	6.11E-01	53	3.66E+01	5.40E-01	37	0.180	3.03E-02	7.70E-02	0.1	9.90E-03	3.19E-02	0.0
AP-73	6.70	1.53E+00	1.04E-01	2	1.06E+00	9.22E-02	1	0.140	1.83E-02	5.99E-02	0.1	5.99E-03	2.48E-02	0.0
AP-74	299.54	3.05E+03	4.66E+00	3058	2.13E+03	4.12E+00	2132	0.260	6.33E-02	1.11E-01	0.2	2.07E-02	4.61E-02	0.1
AP-75	4.10	5.72E-01	6.38E-02	1	3.99E-01	5.64E-02	0	0.180	3.03E-02	7.70E-02	0.1	9.90E-03	3.19E-02	0.0
AP-76	11.08	4.18E+00	1.72E-01	4	2.91E+00	1.52E-01	3	0.100	9.36E-03	4.28E-02	0.1	3.06E-03	1.77E-02	0.0
AP-77	16.83	9.64E+00	2.62E-01	10	6.72E+00	2.31E-01	7	0.090	7.58E-03	3.85E-02	0.0	2.48E-03	1.60E-02	0.0

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