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Geo-environmental analysis of the groundwater quality in the vicinity of textile industrial zone

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Abstract. The increase in inhabitants and development of advantageous economic behavior undoubtedly leads to escalating water demand for different uses. Improper planning, mismanagement, inappropriate standards and procedure for discharging the industrial effluents are prime causes for deterioration of groundwater quality in industrial zone. The study vicinity is exaggerated by subsurface water quality problem. To evaluate the water quality of aquifer, sixty two samples were collected, analyzed and the results of the data are evaluated according to the standards. Hydro-chemical facies, rock-water process, factor analysis, correlation matrix studies were carried out for assessing the associated hydro-chemical process operating in the progress of salinity concentration. The analysis reveals that water belongs to highly brackish type. In this study zone, groundwater is influenced by water-rock interaction and evaporation process. Factor analysis shows that the groundwater is greatly deteriorated by anthropogenic activities. Based on hydrochemical study, the subsurface water is not fit for domestic purposes.

Keywords: Factor analysis, Geo-environment, Groundwater, Piper diagram, Salinity.

1. Introduction

Quality of water in an aquatic ecosystem is determined by loads of physico-chemical parameter along with biological factors. With existing development of water demand, shortage for water will happen to more intensive. Virtually, fifty percentages of the world's population will suffer from foremost water shortage by 2035 (UNESCO-WWAP 2009). Effluents from yard goods processing include a bulky variety of chemical superfluities that create an environmental distress for fabric industry due to their variety of toxic chemicals (Shashi et al. 2013). The groundwater is believed to be rationally much fresh and free from toxic waste than surface water (Patil and Patil 2010). But prolonged release of domestic sewage, industrial wastes and solid waste dumping cause aquifer to turn into pollution and twisted health harms⁴ (Ahmad and Faizan 2014). Assessments of the most important parameters of cations along with anions have been used to classify the hydro-chemical facies of the groundwater. The hydrochemistry primarily reflects the composition of mass rocks and intensity of water-rock exchanges to greatly influence the concentration of parameters initial from the zone of recharge to discharge point (Ayenew et al. 2008). The hydrogeochemical studies on groundwater included the water rock interaction and element evolution of groundwater in the stratum. The water-rock interface



in the subversive environment possibly will cause the disbanding of primary as well as secondary minerals precipitation-fracture-filling mineral deposits in the rock strata (Chan-Ho Jeong 2001). Additional desertion due to process of anthropogenic activities increase the concentration of total dissolved solids and groundwater sample are liable to progress from the state of rock dominance to process of evaporation (Subba Rao 1998). Remote sensing is an authoritative tool that has been very useful to water value assessment and monitoring (Chopra et al. 2001, Samson Okongo Mabwoga et al. 2010). Consideration of the geochemical progression of subsurface water is critical for sustainable water resources advancement (Artimes Ghassemi Dehnavi et al. 2018). Major part of the effluents discharged in the study zone are untreated or improper treated with high concentrated chemical parameters (Arumugam et al. 2020). In this regard research work has been conceded with the aim of assessing the hydro chemical elements of groundwater in Tirupur region.

2. Study area

The Tirupur study zone falls between $11^{\circ} 12'$ North to $11^{\circ} 25'$ North longitudes and $77^{\circ} 25'$ East to $77^{\circ} 51'$ East latitudes and located at 55 km east of Manchester city - Coimbatore in south India (Figure 1). Temperature varies from 20°C to 46°C with normal rainfall of 605 mm. The study area is covered within 425 km^2 . Tirupur has become a significant textile center and marked as textile valley. Physiographically, the region is characterized by an undulated topography with the different altitude ranging from 285 to 320 m above MSL and slopes progressively from west to the east direction. The Noyyal and Nallar rivers have been tied by water quality issues and releasing unprocessed industrial wastes keen to the river course has been upsetting. Geomorphic units in the study are shallow pediments, buried pediments, duri crust, etc. The region is metamorphic gneissic rocks. The common rock of the zone is multifaceted gneiss, charnockite and pinky colored granite all along with the limestone and alluvial deposits.

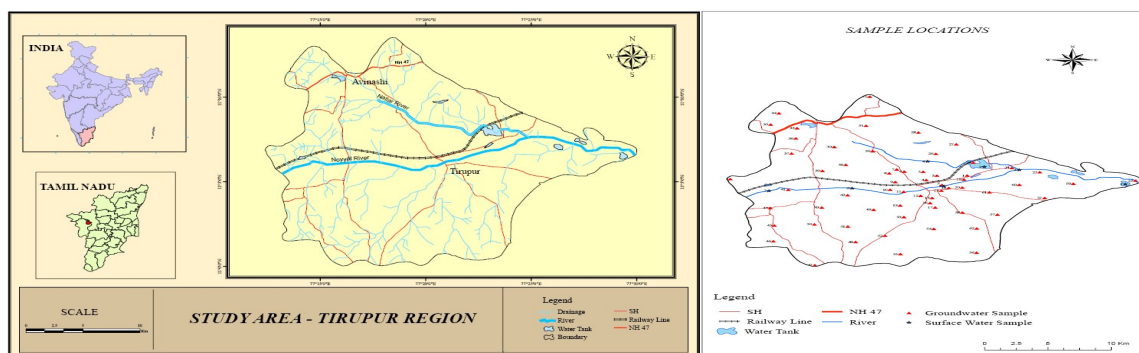


Figure 1. Study area and sampling location map

3. Methodology

For assessing the quality, subsurface water samples were collected from the study region. About thirty three percent of the sample locations were within urban limit where contamination more expected. For physico-chemical parameter examination, the required instruments/equipments were prepared appropriately according to the possible grade calibration. Water samples were examined for concentration pH values, conductivity, total dissolved solids, Cation ion categories of calcium, magnesium, sodium, potassium; Anion ion categories of bicarbonate, chloride, nitrate, carbonate, sulphate and trace elements such as fluoride, iron, copper, lead, zinc and manganese, using the typical measures as specified (APHA 1998). Incidence of errors in chemical parameter study of groundwater is moreover owing to the reagents engaged and confines of the analytical procedures (Prasanna et al. 2010). The correctness of the chemical parameter tests were confirmed via manipulating ion-

balance nevertheless the common errors are approximately 10% (Arumugam et al. 2015). The correctness of groundwater chemical parameter result is illustrated (Figure 2).

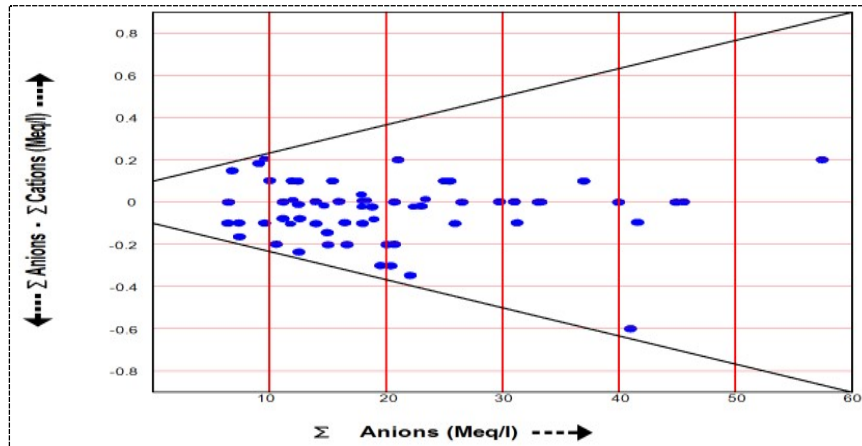


Figure 2. Anion and cation balances representing data quality of groundwater analysis

4. Result and Discussion

4.1 Groundwater Chemistry

Geo-environmental settings have a notable influence on quality of groundwater. The groundwater is initially as meteoric and then afterward modified to the current brackish state (Subba Rao 2002). Summing up of the analyzed parameter results of water samples of the area is given (Table 1). pH ion concentrates from 6.20 to 8.01 with average values of 7.56 and all the samples are within the range of the allowable limits. However, the pH concentration value indicates that the region is generally alkaline environment. Conductivity values are between 858 and 9,935 ($\mu\text{S}/\text{cm}$) with the mean of 2,739 at 25°C . The concentration value of salinity (TDS) ranges from 546 to 5,995 with mean and median of 1,768 and 1,45 mg/l respectively. The majority of the elevated TDS concentration is observed within the urban limit of Tirupur area (Figure 3) and most of the subsurface leads brackish water (Total dissolved solids: 1,000 - 10,000). The TH standards range from 214 to 5,995 with average of 778 mg/l. Groundwater varies from (TH 150 - 300) type to very hard (TH > 300) type (Sawer and Mc Carrtly 1967) in the zone. However, greater part of the groundwater belongs to very hard (Figure 4). Calcium, magnesium, sodium, potassium concentrations ranges are from 29 to 914, 48 to 485, 22 to 1,122, 7 to 272 mg/l respectively. The major anions viz. chloride, bicarbonate, sulphate, nitrate ranges from 37 to 3,193, 141 to 791, 69 to 1212, 36 to 573 mg/l correspondingly. Based on domination of cation (+) ions and anion (-) ions are $\text{Na}^+ > \text{Ca}^{++} > \text{Mg}^{++} > \text{K}^+ = \text{SO}_4^{2-} > \text{HCO}_3^- > \text{Cl}^- > \text{NO}_3^- > \text{CO}_3^-$ respectively. Fluoride mineral in bedrock is liable for concentration in groundwater. However, contamination of the atmosphere has been a severe dilemma. This study shows that 33.30 % of the groundwater are within the allowable limit (0.60 - 1.20 mg/l); 53.25% of water exceeding the allowable value (< 0.60 mg/l) and 14.45% exceeds the maximum permissible limit (> 1.20 mg/l). The spatial variation of fluoride is exposed (Figure 5). Trace metal of iron is measured upto 2.11 mg/l with average of 0.18 mg/l and 6.13% of the groundwater exceeds the acceptable level of 0.30 mg/l. The spatial distribution of iron concentration is explained (Figure 6). Copper and zinc are vital for animal and plant metabolism. However the limited occasion in groundwater is useful for water quality. 40% of copper in the groundwater samples exceeded the highest desirability 0.05 mg/l and 4.84% of samples exceed the most tolerable maximum value of 1.50 mg/l for consumption purpose. Zn concentrates from 0.72 to 16.25 mg/l. 32.26% of zinc exceeds the highest acceptable limit of 5.0 mg/l and 4.84% of exceeds the highest allowable limit of 15 mg/l. Trace

elements of lead exists between 0.01 and 0.22 mg/l with mean value of 0.13 mg/l and 51.62% of Pb exceeds the maximum limit of 0.1 mg/l. 13.35% of manganese surpassed the highest desirability of 0.1 mg/l and 16.13% overshoot the most acceptable margin of 0.3 mg/l in the study zone.

Table 1. Drinking water standards and statistics of parameter analysis of the groundwater

Parameters	Indian Standard Institution (2012)		WHO International Standard (1993)		Results of chemical analysis			
	Max. desirable	Max, permissible	Max. desirable	Max. permissible	Min.	Max.	Mean	Median
pH	6.5-8.5	6.5-9.2	7-8.5	6.5-9.5	6.60	8.01	7.56	7.58
EC ($\mu\text{S}/\text{cm}$)	-	-	-	-	858	9,935	2,739	2,242
TDS (mg/l)	500	1,500	500	1,500	546	5,995	1,768	1,455
TH (mg/l)	300	600	100	500	214	3,606	778	627
Ca ⁺⁺ (mg/l)	75	200	75	200	29	914	167	124
Mg ⁺⁺ (mg/l)	30	100	50	150	48	485	94	78
Na ⁺ (mg/l)	-	-	-	200	22	1,122	226	159
K ⁺ (mg/l)	-	-	-	12	07	272	71	54
Cl ⁻ (mg/l)	250	1,000	200	600	37	3,193	549	397
HCO ₃ ⁻ (mg/l)	-	300	-	-	141	791	414	399
SO ₄ ²⁻ (mg/l)	150	400	200	400	69	1,212	161	99
NO ₃ ⁻ (mg/l)	-	-	45	-	36	573	79	57
F ⁻ (mg/l)	0.6	1.2	-	1.5	0.1	2.11	0.71	0.62
Fe (mg/l)	0.3	1.0	0.3	1.0	0	1.12	0.18	0.15
Cu (mg/l)	0.05	1.5	0.5	1.0	0.02	1.72	0.36	0.05
Pb (mg/l)	0.1	-	-	0.1	0.01	0.22	0.13	0.12
Zn (mg/l)	5	15	-	15	0.72	16.25	5.20	3.52
Mn (mg/l)	0.1	0.3	-	0.3	0.01	0.62	0.14	0.04

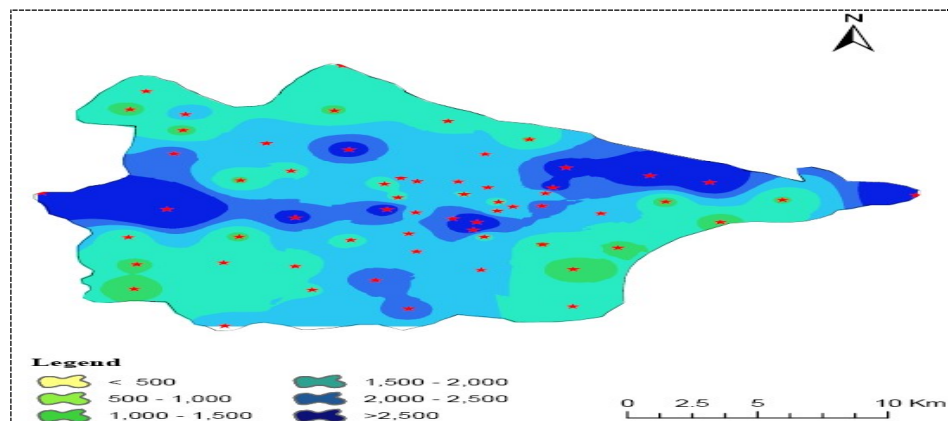


Figure 3. Spatial distribution of TDS

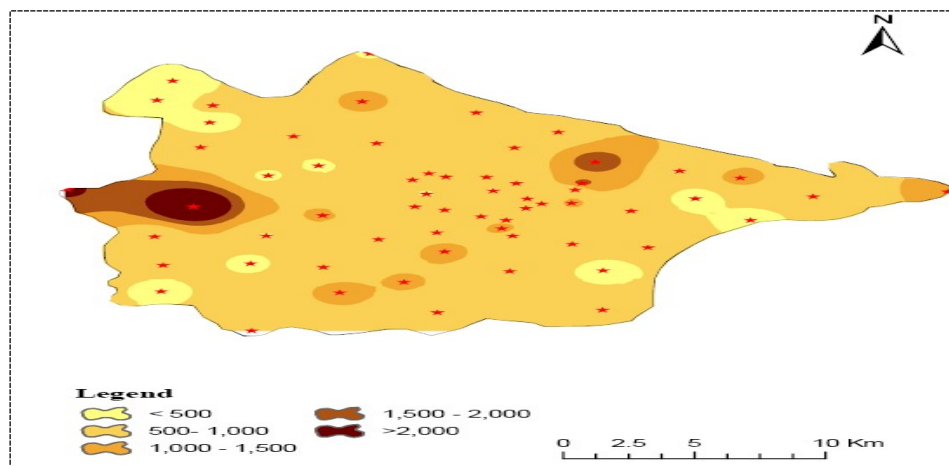


Figure 4. Spatial distribution of TH

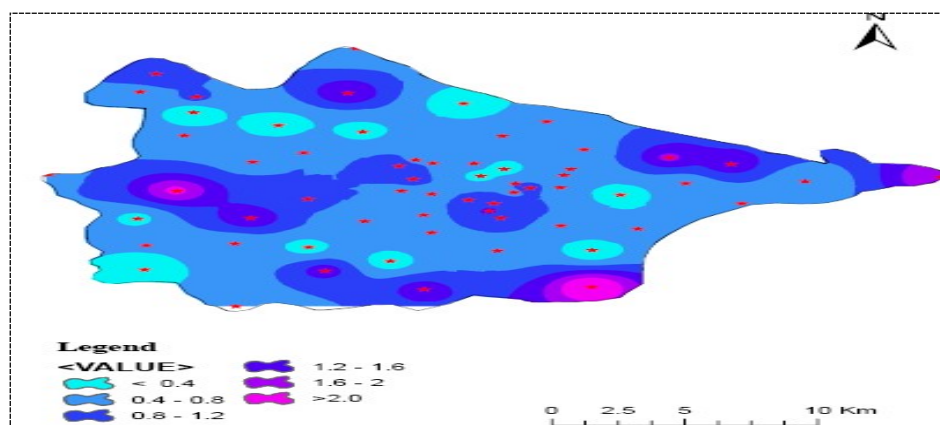


Figure 5. Spatial distribution of fluoride

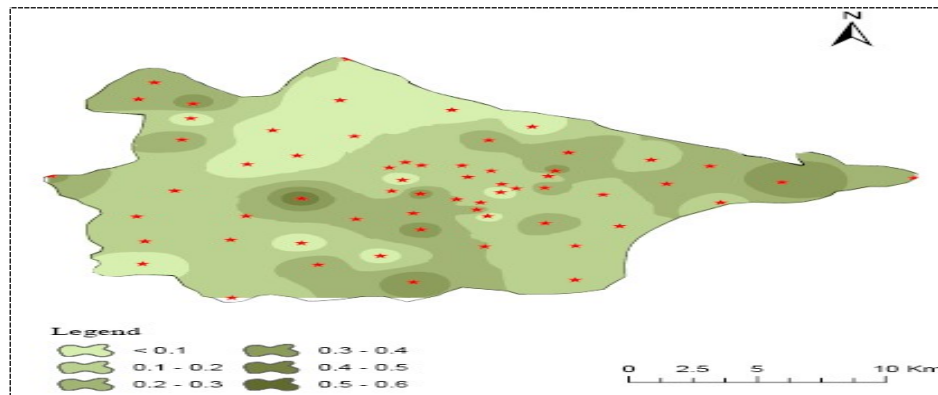


Figure 6. Spatial distribution of iron

4.2 Hydro-chemical facies

The substance composition of subsurface water is determined by the major inorganic compounds specifically with reference to calcium (Ca^{++}), magnesium (Mg^{++}), sodium (Na^+), potassium (K^+) of cations, bicarbonate (HCO_3^-), chloride (Cl^-), sulphate (SO_4^{2-}) and nitrate (NO_3^-) of anions. Nearly all of the graphical procedures for representation had been considered to concurrently to signify the TDS ion concentration and their relative extent of certain major ionic group (Hem 1989). Piper trilinear diagram (Piper 1953) is a graphical form for understanding the problem relating to the hydrochemical progress of groundwater. The trilinear Piper diagram (Figure 7) shows nine different water categories and their distributions obtained for the groundwater samples: calcium- sodium – bicarbonate - chloride type, calcium – sodium - chloride type, calcium – bicarbonate - chloride type, sodium – bicarbonate - chloride type, calcium - chloride type, calcium - bicarbonate type, sodium - chloride type, calcium, - sodium - bicarbonate type and sodium - bicarbonate type etc. The water types details are illustrated (Table.2). The distribution of the hydrochemical facies are depicted (Figure 8). The water bodies identified based on relative dominance of parameters is presented (Table. 3). The results of chemical weathering process are due to anthropogenic input of the region (Chan 2001).

Table 2. Types of groundwater based on hydrochemical facies

Water types	Number of samples	Percentage of samples
Ca - Na - HCO_3 - Cl	20	32.26
Ca - Na - Cl	09	14.52
Ca - HCO_3 - Cl	09	14.52
Na - HCO_3 - Cl	08	12.90
Ca - Cl	07	11.29
Ca - HCO_3	03	04.84
Na - Cl	03	04.84
Ca – Na - HCO_3	02	03.23
Na - HCO_3	01	01.61

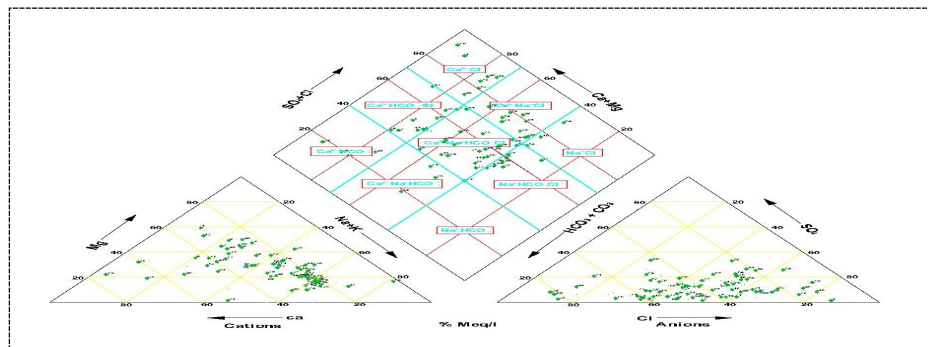


Figure 7. Piper trilinear diagram for hydro-chemical facies of groundwater

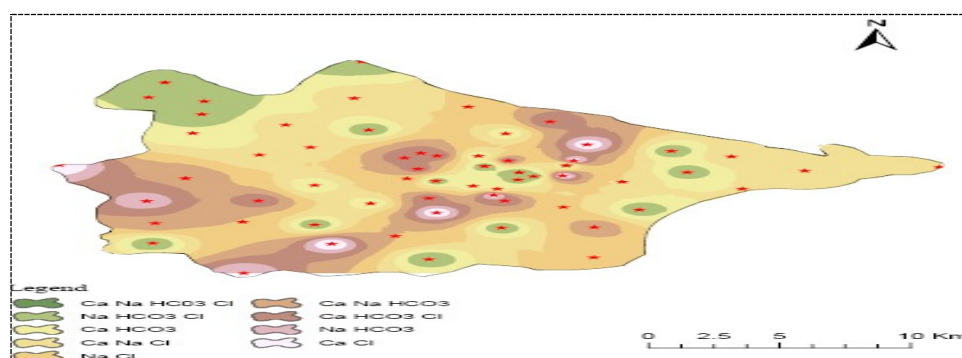


Figure 8. The spatial variation of the hydro-chemical facies of groundwater

Table 3. Relative abundance of main cations (+) and anions (-) of the groundwater

Cations (+)			Anions (-)		
Parameters	Number of samples	Percentage of samples	Parameters	Number of samples	Percentage of samples
Na>Ca ≥K>Mg	20	32.26	Cl>HCO ₃ >SO ₄ >NO ₃	17	27.42
Na>Ca>Mg>K	15	24.19	HCO ₃ >Cl>SO ₄ >NO ₃	15	24.19
Ca>Mg>Na>K	08	12.90	HCO ₃ >Cl>NO ₃ >SO ₄	14	22.58
Ca>Na ≥Mg>K	06	09.68	Cl>HCO ₃ ≥NO ₃ >SO ₄	06	09.68
Na>K>Ca>Mg	06	09.68	Cl>SO ₄ >HCO ₃ >NO ₃	04	06.45
Na>Mg ≥Ca>K	03	04.84	HCO ₃ >SO ₄ >Cl>NO ₃	03	04.84
Mg>Ca>Na>K	02	03.23	HCO ₃ >NO ₃ >Cl>SO ₄	02	03.23
Mg>Na>Ca>K	01	01.61	SO ₄ >Cl>HCO ₃ >NO ₃	01	01.61
Ca>Na>K>Mg	01	01.61	-	-	-

4.3 Mechanism governing groundwater chemistry

Mechanism governing groundwater chemistry is a extensively used method for assessing the constructive sources of dissolved process such as natural precipitation, evaporation and rock - dominance. Plot of total dissolved solids against the proportion of $\text{Na}^+ / (\text{Na}^+ + \text{Ca}^{++})$ and $\text{Cl}^- / (\text{Cl}^- + \text{HCO}_3^-)$ to distinguish the relationship of rock-water interaction, evaporation and precipitation levels

(Figure 9) on groundwater chemistry (Gibbs 1970). The analytical results put forward that substance weathering of rock forming mineral elements and evaporation process are prevailing controlling factors. Process of evaporation toward a great extent increases the iron concentration produced by the process of chemical weathering which leading to elevated salinity level. Consequently the groundwater samples position moves towards the precinct of evaporation-dominance.

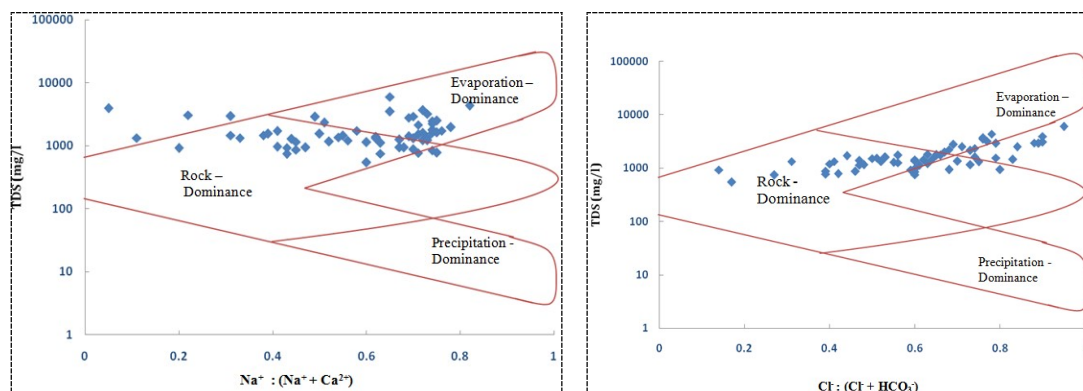


Figure 9. Mechanism controlling groundwater quality

Factor analysis is used as multivariate statistical method which is employed for the function of data reduction with a vision for determining the sources of various elements and the controlling factors. Groundwater quality monitoring was conducted. The preferred physico-chemical parameters for assessing the groundwater quality distinctiveness are: Turbidity, pH values, TH, TDS, Ca^{++} , Mg^{++} , Na^+ , K^+ , HCO_3^- , SO_4^{2-} , Cl^- , NO_3^- , F^- and Fe. The rotated factor loadings, eigen values, communalities and the variations in percentage are determined by factor analysis system (Table. 4). On the basis of these significant factors, the factor analysis shows that the three factors are explained as 72.88% of the variance in the data sets as given below.

Factor 1 (F1) : TDS, TH, Ca^{++} , Mg^{++} and K^+ ,

Factor 2 (F2) : Cl^- , F^- , SO_4^{2-} , Na^+ and HCO_3^-

Factor 3 (F3) : Turbidity, pH, Fe and NO_3^-

Factor1, Factor 2 and Factor3 have been explained as 38.81%, 20.40% and 13.68% of the variance respectively. The Factor1 has an elevated positive loading in TH, Mg^{++} , Ca^{++} , TDS and K^+ which are 0.963, 0.841, 0.838, 0.813 and 0.291 respectively. The elevated positive load indicated the strong linear correlation between the factor and the ion concentrations. The correlated matrix for the selected parameters is depicted (Table 5) and the associations of factor loadings of variable on the groundwater are explained (Figure 10). The data set shows that the subsurface water of the area is greatly deteriorated by different anthropogenic activities.

Table 4. Rotated factor loadings of groundwater

Parameters	Factor (s)			Communalities
	1	2	3	
Turbidity	0.139	0.073	0.781	0.635
TDS	0.813	0.544	0.098	0.967
pH	-0.266	0.111	0.788	0.704
TH	0.963	0.139	0.073	0.934
Ca^{++}	0.838	0.813	0.544	0.715
Mg^{++}	0.841	-0.266	0.111	0.709
Cl^-	0.910	0.963	0.067	0.960

F ⁻	-0.084	0.838	0.047	0.223
SO ₄ ²⁻	0.738	0.841	0.014	0.852
Na ⁺	0.518	0.910	0.359	0.928
K ⁺	0.291	-0.084	-0.013	0.788
HCO ₃ ⁻	-0.122	0.738	0.334	0.525
Fe	0.771	0.518	0.793	0.603
NO ₃ ⁻	-0.003	0.291	0.838	0.661
Eigen value	5.433	2.855	1.915	10.203
% of Variance	38.808	20.395	13.676	72.879
Cumulative %	38.808	59.203	72.879	-

Table 5. Correlation matrix for analyzed parameters

Parameters	Turbidity	TDS	pH	TH	Ca ²⁺	Mg ²⁺	Cl ⁻	F ⁻	SO ₄ ²⁻	Na ⁺	K ⁺	CO ₃	Fe	NO ₃ ⁻
Turbidity	1.000													
TDS	0.218	1.000												
pH	0.410	-0.075	1.000											
TH	0.108	0.817	-0.274	1.000										
Ca ⁺⁺	0.172	0.767	-0.150	0.836	1.000									
Mg ⁺⁺	-0.066	0.708	-0.171	0.801	0.591	1.000								
Cl ⁻	0.104	0.950	-0.235	0.910	0.789	0.803	1.000							
F ⁻	-0.227	-0.070	-0.183	-0.022	-0.019	-0.027	-0.039	1.000						
SO ₄ ²⁻	-0.209	0.709	-0.487	0.726	0.585	0.582	0.769	0.004	1.000					
Na ⁺	0.056	0.810	-0.232	0.545	0.367	0.427	0.752	-0.048	0.754	1.000				
K ⁺	0.153	0.669	-0.001	0.309	0.201	0.170	0.571	-0.068	0.495	0.841	1.000			
CO ₃ ⁻	0.212	0.272	0.360	-0.093	0.020	0.026	0.089	-0.153	-0.124	0.294	0.323	1.000		
Fe	0.196	0.575	-0.070	0.679	0.475	0.596	0.634	-0.061	0.546	0.456	0.347	-0.116	1.000	
NO ₃ ⁻	0.166	0.464	0.279	0.087	0.137	0.026	0.261	-0.020	0.172	0.538	0.515	0.345	-0.032	1.000

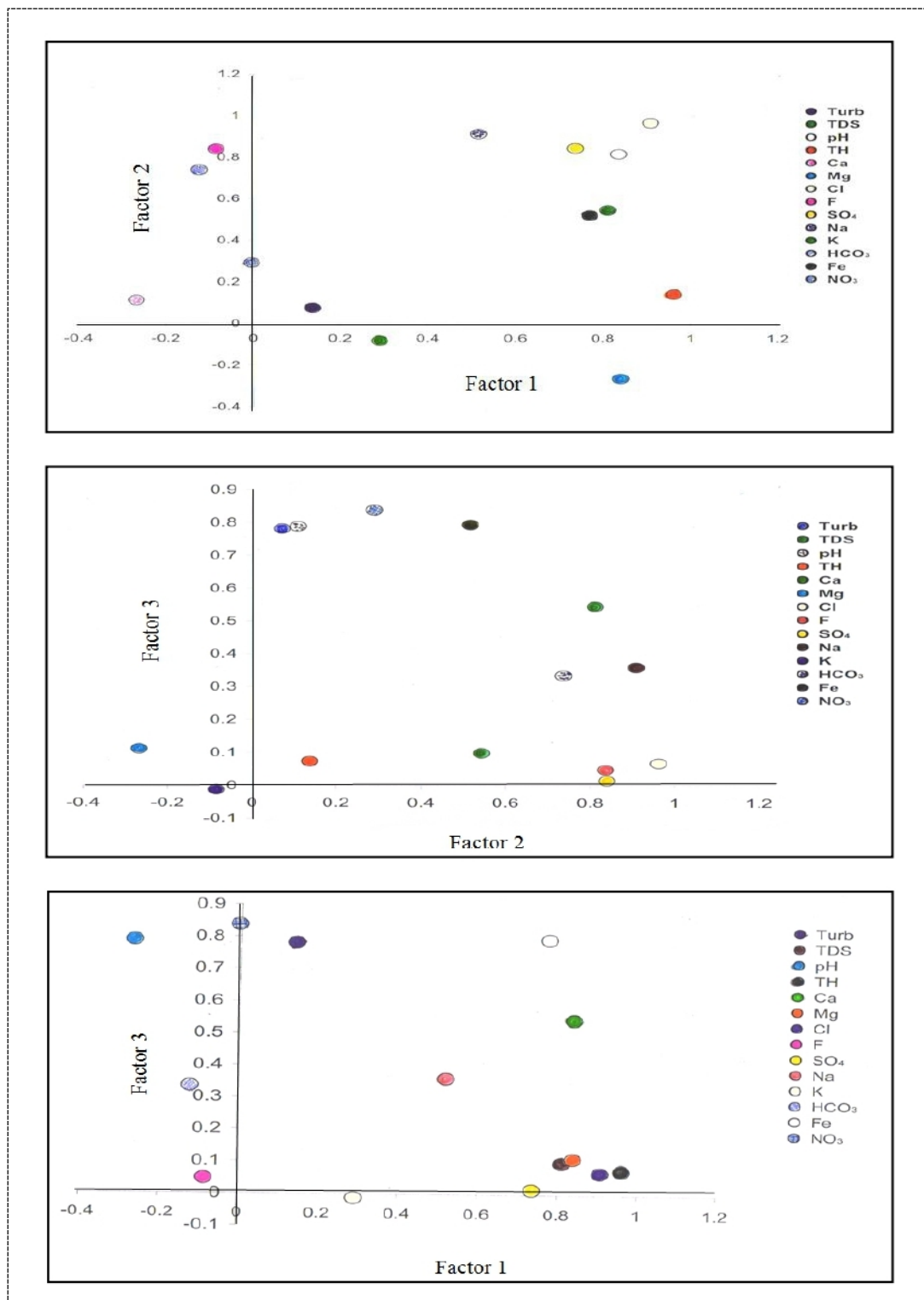


Figure 10. Distribution of variables between factors as given by factor analysis

5. Conclusions

The groundwater chemistry of zone reveals that nearly all of the water samples in the area is brackish water type as well as very hard water category. 67.70% of fluoride concentration exceeds the permissible limit. The piper diagram, nine different categories of water quality developed. The process of chemical weathering and evaporation progression are overriding controlling factors of the hydrochemistry and the groundwater samples position moves from the zone of rock-dominance to the evaporation-dominance. The factor analysis shows that the three factors are explained as 72.88% of the variation within the data sets. The data set shows that the subsurface water of the area is greatly deteriorated by different anthropogenic actions and it is not suitable for drinking as well as domestic purposes.

Acknowledgments

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