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Original Research Paper

GIS Based Groundwater Quality Assessment of Vattamalaikarai Basin, Tamil Nadu, India

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ABSTRACT

A detailed GIS based study on hydrochemistry of groundwater in Vattamalaikarai Basin, Tamil Nadu, India has been carried out to assess the quality of groundwater for determining its suitability for drinking purpose. Further, the spatial variation of various groundwater quality parameters over the basin has also been studied for January 2008. The area is underlained by crystalline rocks of peninsular gneissic complex, comprising of hornblende-biotite-gneiss and charnokite. Black, alluvial, and calcareous soils are major soil types in this region. Fifty nine groundwater samples spread over the basin have been collected from open and tube wells during January 2008. The physicochemical parameters have been compared with the standard guideline values as recommended by the WHO for drinking and public health. The abundance of major ions in groundwater is in the following order: $Na^+ > Mg^{2+} > Ca^{2+} > K^+ = Cl^- > SO_4^{2-} > HCO_3^- > NO_3^- > CO_3^{2-}$. TDS widely varied from 124 to 4270 mg/L with an average value of 1422 mg/L, and at 24 locations it exceeds the maximum allowable limit of 1500 mg/L leading to unsuitability of groundwater in nearly 40% of the total basin area. TDS exhibits good positive correlation with Na^+, Mg^{2+} and Cl^-. Groundwater of the basin belongs to hard to very hard water category since the total hardness (TH) exceeds the permissible limit of 500 mg/L prescribed for drinking water. Nitrate concentration in groundwater also widely varies from 0 mg/l to 647 mg/L with an average value of 125 mg/L. Forty four well samples out of 59 exceed the maximum allowable limit of 45 mg/L (60% of the total basin area). Fluoride is also high (> 1.5 mg/L) in groundwater at 17 locations, which may cause dental fluorosis.

INTRODUCTION

The assessment of groundwater quantity and quality is very much essential for the optimal usage of water resources. In the present scenario, even though there is abundant quantity of water is available, it is rare to get good quality of water. Reddy & Prasad (2005) have studied the chemistry of groundwater in and around the Tadpatri area, Anantapur district in A.P. and compared the groundwater quality parameters with the World Health Organisation (WHO 1983) standards prescribed for domestic and industrial purposes. They also classified the groundwaters based on their hydrochemistry to ascertain their suitability for various purposes, and discussed the mechanism that influences the chemistry of groundwaters. Nageswara Rao & Naga Prapurna (2005) have made correlations among various groundwater quality parameters for Jeedimetla Industrial Estate in Hyderabad city.

Central Ground Water Board (CGWB 1979) has carried out groundwater level fluctuation study, pump-test analysis, rainfall variation analysis and assessment of chemical characteristics of groundwaters in Vattamalaikarai Basin, Tamil Nadu. Public Works Department (PWD 2002) also regularly monitors groundwater level fluctuation and quality at few observation wells. However, spatial variations of various groundwater quality parameters and their interrelationship have not been included. Further, it is observed that the concentration of major ions in groundwater of the area is high at many locations leading to unsuitability of groundwater for drinking. Thus, a GIS based study has been attempted to understand spatial variation of groundwater quality parameters over the basin.

STUDY AREA

Vattamalaikarai basin, covering an area of 436.5 km^2 falls between the latitudes 10°53'N-11°01'N, and the longitudes 77°15'E-77°45'E (Fig. 1). The basin comes under parts of Palladam taluk of Coimbatore district and Dharapuram taluk of Erode district in Tamil Nadu State, India. It is named after the stream 'Vattamalaikarai', which is a tributary of Amaravathi river. Amaravathi river is one of the major tributaries of Cauvery river. Highest altitude from where the trunk system of the Vattamalaikarai river originates is about 439 m above mean sea level (MSL). The minimum ground level is observed near its confluence point with the Amaravathi river, which is about 183 m above MSL. Total length of the main stream is nearly 63 km, having a mean bed slope of 3.68 m/km. The regional slope of the basin is towards east. It is about 15.3 m/km in average.

The basin falls in dry plain area and is in the rainfall shadow regions of Western Ghats (CGWB 1979). The average annual rainfall of the basin is 571 mm. The area is underlained by crystalline rocks of peninsular gneissic complex, comprising of hornblende-biotite-gneiss and charnokite (GSI 1995). Three major soil types viz., black, alluvial and calcareous soils are noticed. In total area of the basin, about 250 km^2 comes under cultivated land, and the remaining fall under the category of barren and uncultivable lands. Paddy, sugarcane and groundnut are the major crops of this region.

MATERIALS AND METHODS

Sampling and analysis of water samples: The groundwater samples from 59 observation wells, spread over the study area (Fig. 1), were collected during January 2008. Field parameters such as pH, electrical conductivity (EC) and total dissolved solids (TDS) were measured immediately at sampling site using portable meters. Collected samples were brought to the laboratory on the same day, and analysed for determining the concentration of various chemical parameters such as sodium, potassium, calcium, magnesium, chloride and total hardness (TH) using standard procedures prescribed in APHA (1995).

Data interpretation using GIS: The study area map was prepared manually from the 1: 50,000 scale Survey of India toposheets (SOI 1981). The prepared hard copy maps were scanned and digitized using Geomedia Professional (2006) software. Zonation maps for TDS and TH were prepared by fixing the suitability limits as prescribed by WHO for drinking purposes. Spatial variation maps (isoline maps) for various major ions were also prepared using the same GIS software. Statistical correlation matrix was prepared for the twelve parameters using SPSS (version 6.0) software. Further, water quality parameters were compared with the international standards for understanding the suitability of groundwater for drinking.

RESULTS AND DISCUSSION

Understanding the quality of groundwater is as important as that of its quantity, since, it is the main factor determining the suitability of water for drinking, domestic, agricultural and industrial purposes (Subramani & Elango 2005). The pH value is an important index of acidity or alkalinity and the concentration of hydrogen ion in groundwaters (Murugesan et al. 2006). The lower value (pH < 4.0) will produce sour taste, and higher value (pH > 8.5) an alkaline taste. The acceptable range of pH is normally 6.5 to 8.5 (WHO 1983). It is observed that the pH values of groundwater samples of the basin lie within the prescribed range showing an average value of 7.53.

The electrical conductivity (EC) is a measure of capability of water to transmit electrical current. It represents the total concentration of soluble salts in water. It is used to measure the salinity hazard to crops as it reflects the TDS in groundwater (Anandakumar et al. 2007). The EC values in the study area vary widely from 210 µS/cm to 6880 µS/cm with an average value of 2355 µS/cm. Higher values are generally noticed in southeastern and northern parts of the basin. The higher values of EC may be due to long residence time and existing lithology of the region (Ballukraya & Ravi 1999).

Summary of the analytical results of various groundwater quality parameters is presented in Table 1, and the undesirable effects caused to humans when the parameters exceed the allowable limits (WHO 1983) are presented in Table 2. It is observed that total hardness, Na^+ and NO_3^- exceed the maximum allowable limits in more than 50% of the well samples.

Total dissolved solids (TDS) range from 124 mg/L to 4270 mg/L with an average value of 1422 mg/L. About 60% of the samples are within the maximum allowable limit for drinking (< 1500 mg/L) based on their TDS values (WHO 1983). The TDS zonation map prepared using GIS (Fig. 2) indicates that groundwater in nearly 40% of the area is unfit for drinking. As per Freeze and Cherry (1979), 25 samples out of 59 represent the freshwater category (TDS < 1000 mg/L), and the remaining brackish water (TDS 1000 mg/L to 10000 mg/L) category (Table 3).

Total hardness (TH) also exhibits wide variation from 75mg/L to 2250 mg/L with an average value of 651 mg/L. Acceptable limit of TH for drinking is 500 mg/L (WHO 1983). The groundwater of the area is hard to very hard in nature because 58 samples (Table 4) have the TH values greater than 150 mg/L (Sawyer & McCartly 1967). The study area is delineated into three zones using GIS, based on the desirable (100 mg/L) and maximum permissible (500 mg/L) limits of TH (Fig. 3). as suggested by WHO (1983). The TH zonation map illustrates that groundwater in approx. 70% of the area is unsuitable for drinking.

Table 1: Minimum and maximum values of physicochemical parameters of groundwater with statistical parameters.

Parameters	Minimum	Maximum	Arithmetic Mean	Median	Standard Deviation
pH	6.80	8.20	7.54	7.50	0.31
EC	210.00	6880.00	2354.58	1920.00	1519.32
TDS	124.00	4270.00	1421.98	1152.00	944.44
TH	75.00	2250.00	651.36	545.00	429.70
Na^+	7.00	840.00	247.92	219.00	188.73
K^+	5.00	258.00	36.98	20.00	45.18
Ca^{2+}	12.00	268.00	92.24	84.00	57.43
Mg^{2+}	7.00	486.00	102.37	75.00	85.00
Cl^-	18.00	2056.00	398.75	269.00	399.90
HCO_3^-	92.00	817.00	455.69	439.00	127.42
SO_4^{2-}	10.00	826.00	190.41	106.00	190.92
NO_3^-	0.00	646.57	125.43	93.00	122.80
F^-	0.08	2.30	1.11	1.10	0.59

The values are in mg/L except pH and EC (micromho/cm).

Sodium content in groundwater of the area varies from 7 mg/L to 840 mg/L with an average value of 248 mg/L. Thirty one out of 59 samples exceeded the maximum allowable limit of 200 mg/L for drinking as per the WHO (1983) standard. Concentration of potassium ion in groundwater ranges from 5 mg/L to 258 mg/L with an average value of 37 mg/L. The groundwater quality data reveal that the calcium ion concentration varies between 12 mg/L and 268 mg/L, with the average value of 92 mg/L. Four samples out of 59 samples exceeded the maximum allowable limit of 200 mg/L. The magnesium ion concentration varies between 7 mg/L and 486 mg/L with the average value of 102 mg/L. Twelve samples contain higher concentration of Mg^{2+} (> 150 mg/L). Magnesium is the second dominant cation in the study area next to sodium.

The chloride concentration varies from 18 mg/L to 2056 mg/L. The average value is 399 mg/L. Fourteen samples (nearly 25%) exceeded the maximum allowable limit of 600 mg/L. The isoline

Table 2: Groundwater samples of the study area exceeding the permissible limits prescribed by WHO standards for drinking purpose and the resulting undesirable effect on humans.

Parameters	WHO International Standards (1971, 1983)		Number of Wells Exceeding Permissible Limits During January 2008	Undesirable Effect on Humans
	Most Desirable Limits	Maxi Allowable Limits		
pH	7-8.5	9.2	Nil	Taste
TDS (mg/L)	500	1500	24	Gastrointestinal irritation
TH (mg/L)	100	500	32	Scale formation
Na^{+} (mg/L)	-	200	31	-
Ca^{2+} (mg/L)	75	200	4	Scale formation
Mg^{2+} (mg/L)	50	150	12	Scale formation
Cl^{-} (mg/L)	200	600	14	Salty taste
SO_4^{2-} (mg/L)	200	400	7	Laxative effect
NO_3^{-} (mg/L)	45	-	44	Blue baby disease
F^{-} (mg/L)	-	1.5	17	Fluorosis

Table 3: Quality of groundwater based on TDS.

TDS (mg/L)	Nature of Water	January 2008 Representing wells	Total No. of wells
<1000	Freshwater	5-11, 15, 16, 22, 25, 27, 32, 35, 39, 40, 42-45, 47, 52, 55, 56, 59	25
1000-10000	Brackish water	1-4, 12-14, 17-21, 23, 24, 26, 28-31, 33, 34, 36-38, 41, 46, 48-51, 53, 54, 57, 58	34
10000-100000	Saline water	Nil	Nil
>100000	Brine water	Nil	Nil

Table 4: Classification of groundwaters based on hardness.

Total Hardness as $CaCO_3$(mg/L)	Water class	January 2008 Representing wells	Total No. of wells
< 75	Soft	Nil	Nil
75-150	Moderately hard	6	1
150-300	Hard	7, 9, 10, 15, 35, 40, 42, 59	8
> 300	Very hard	Remaining wells	50

Table 5: Correlation of physiochemical parameters of groundwaters.

	pH	EC	TDS	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	HCO_3^-	SO_4^{2-}	NO_3^-	F^-
pH	1.00											
EC	-0.29	1.00										
TDS	-0.27	0.99	1.00									
Na^+	-0.14	0.92	0.94	1.00								
K^+	-0.29	0.49	0.49	0.40	1.00							
Ca^{2+}	-0.49	0.66	0.65	0.52	0.25	1.00						
Mg^{2+}	-0.22	0.87	0.86	0.69	0.35	0.42	1.00					
Cl^-	-0.33	0.97	0.96	0.86	0.52	0.65	0.87	1.00				
HCO_3^-	-0.06	0.43	0.44	0.52	0.17	-0.04	0.42	0.30	1.00			
SO_4^{2-}	-0.16	0.87	0.88	0.86	0.24	0.67	0.70	0.78	0.36	1.00		
NO_3^-	0.01	0.41	0.46	0.41	0.22	0.22	0.37	0.30	0.18	0.27	1.00	
F^-	0.11	0.31	0.33	0.37	0.28	-0.22	0.36	0.22	0.63	0.19	0.35	1.00

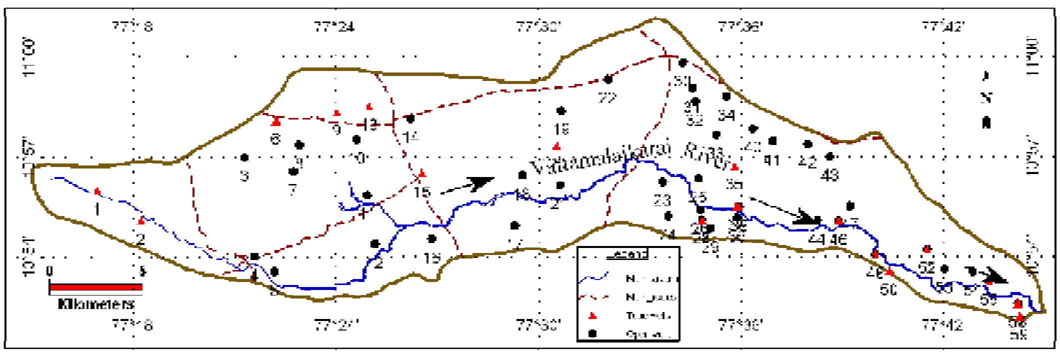

Fig. 1: Map of the study area.

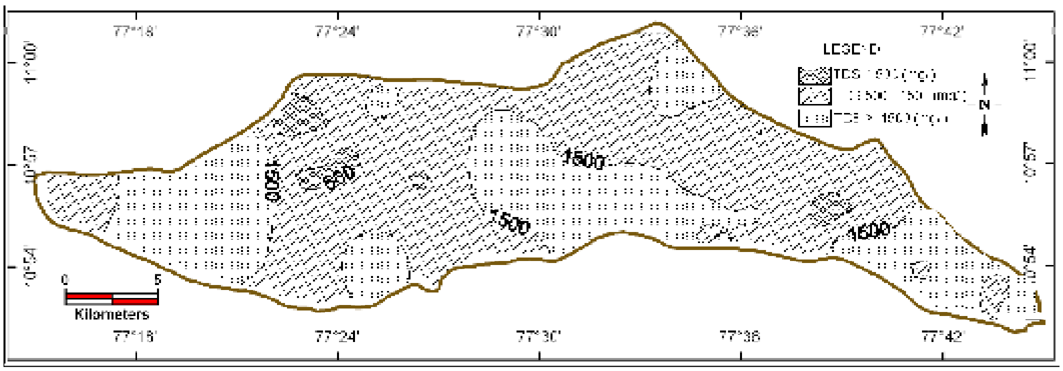

Fig. 2: TDS zonation map of January 2008.

map indicates that there is no uniform spatial variation of chloride in the basin (Fig. 4).

The nitrate concentration in groundwater samples range from 0 mg/L to 647 mg/L with an average value of 125 mg/L. Seventy five percent of the samples exceed the desirable limit of 45 mg/L for drinking as per the WHO standard. The high concentration of nitrate in drinking water is toxic and causes blue baby disease (methaemoglobinaemia) in children and gastric carcinomas (Comly 1945, Gilly et al. 1984). The spatial variation of nitrate is illustrated in Fig. 5.

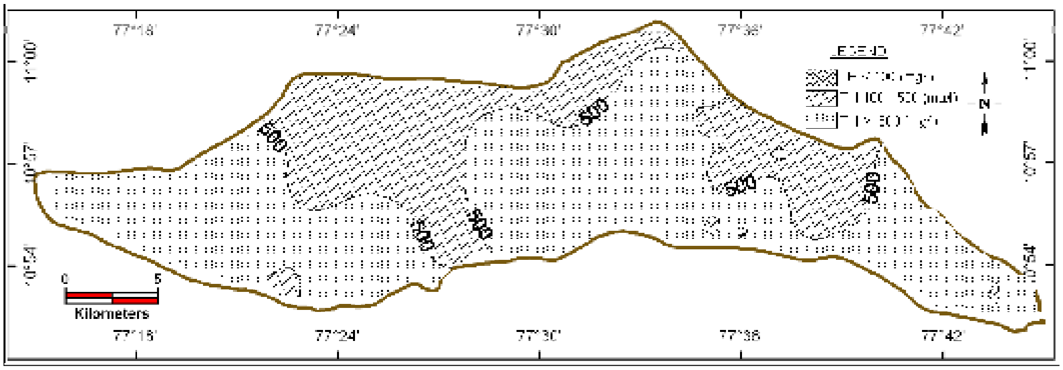

Fig. 3: TH zonation map of January 2008.

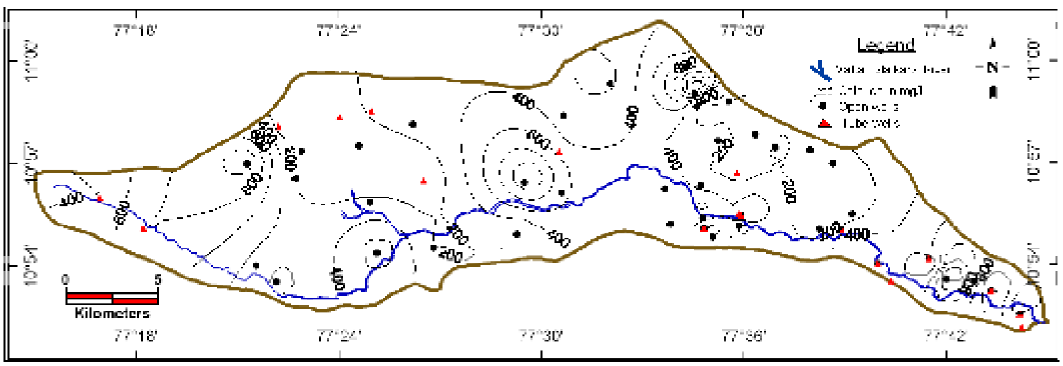

Fig. 4: Isoline map of chloride.

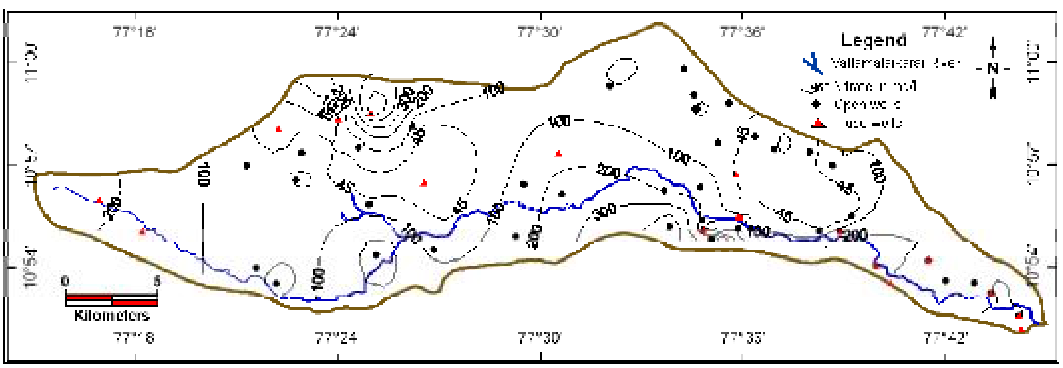

Fig. 5: Isoline map of nitrate.

Sulphate, if exceeds the maximum allowable limit of 400 mg/L, causes a laxative effect on humans (Subramani & Elango 2005). Seven samples exceeded the prescribed limit. The spatial variation of sulphate concentration over Vattamalaikarai basin is illustrated using the isoline map (Fig. 6).

Bedrock containing fluoride minerals is generally responsible for its high concentration in groundwaters (Handa 1975, Wenzel & Blum 1992, Bardsen et al. 1996). The concentration of fluoride in groundwater of the basin varied from 0.08 mg/L to 2.3 mg/L with an average value of 1.11 mg/L. Sixty percent of the samples (17 out of 59) exhibited suitability for drinking purposes. The

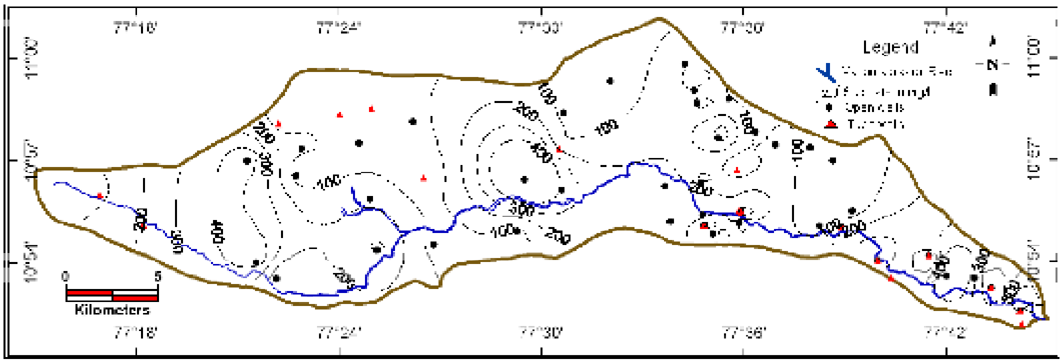

Fig. 6: Isoline map of Sulphate.

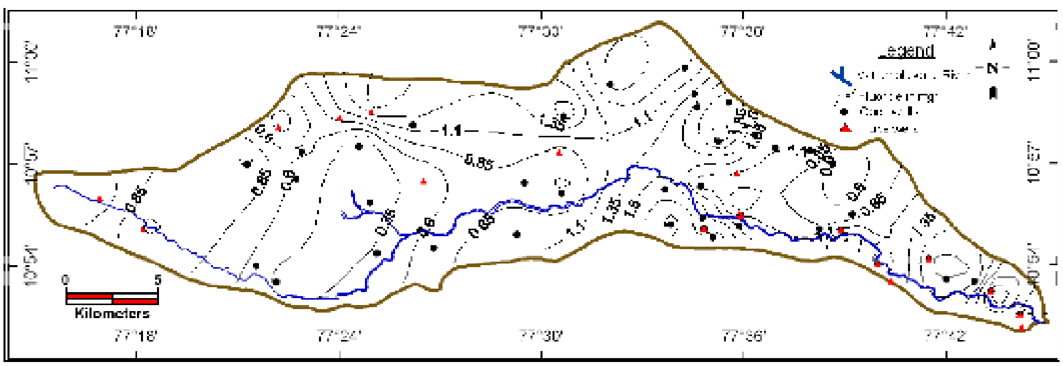

Fig. 7: Isoline map of fluoride.

spatial distribution of fluoride concentration in groundwater during January 2008 is illustrated in Fig. 7.

The correlation matrix has been prepared using SPSS software for 12 variables (Table 5). It shows that EC and TDS exhibit good positive correlation with Na^+, Mg^{2+}, Cl^- and SO_4^{2-}. Na-Cl, Na-SO_4 and Mg-Cl are the more significant correlation pairs in the matrix. pH exhibited negative correlation with most of the variables.

CONCLUSIONS

1 Interpretation of hydrochemical data reveals that the groundwater in Vattamalikarai basin is hard, fresh to brackish, and slightly alkaline in nature.

2 The abundance of major ions in the groundwaters during January 2008 is in the following order: Na > Mg > Ca > K = Cl > SO_4 > H CO_3 > NO_3 > CO_3.

3 Higher concentration of TDS (> 1500 mg/L), noticed in 40% of the samples (24 out of 59), is mainly due to higher concentration of sodium, magnesium and chloride in groundwater. Thus, these three ions exhibit good positive correlation with TDS and EC.

4 Groundwater in 70% of the basin area is having higher TH values (> 500 mg/L), which lead to unsuitability for drinking.

5 Higher concentration of TH is mainly due high concentration of magnesium in the basin.

Magnesium ions may be contributed to groundwater form the existing rocks by weathering and rock-water interaction.

6 Nitrate concentration is high (> 45 mg/L) in most of the groundwater samples (44 out of 59), which may cause blue baby syndrome in infants.

7 Fluoride concentration is high (> 1.5 mg/L) in 17 wells, which may lead to dental and skeletal fluorosis.

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