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Evaluation of groundwater quality and its suitability for drinking and agricultural use in Thanjavur city, Tamil Nadu, India

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Abstract

As groundwater is a vital source of water for domestic and agricultural activities in Thanjavur city due to lack of surface water resources, groundwater quality and its suitability for drinking and agricultural usage was evaluated. In this study, 102 groundwater samples were collected from dug wells and bore wells during March 2008 and analyzed for pH, electrical conductivity, temperature, major ions and nitrate. Results suggest that in 90% of groundwater samples, sodium and chloride are predominant cation and anion, respectively, and NaCl and CaMgCl are major water types in the study area. The groundwater quality in the study site is impaired by surface contamination sources, mineral dissolution, ion exchange and evaporation. Nitrate, chloride and sulphate concentrations strongly express the impact of surface contamination sources such as agricultural and domestic activities, on groundwater quality and 13% of samples have elevated nitrate content (> 45 mg/l as NO_3). PHREEQC code and Gibbs plots were employed to evaluate the contribution of mineral dissolution, and suggest that mineral dissolution, especially carbonate minerals, regulates water chemistry. Groundwater suitability for drinking usage was evaluated by WHO and Indian standards and suggests

that 34% of samples are not suitable for drinking. Integrated groundwater suitability map for drinking purposes was created using drinking water standards based on a concept that if the groundwater sample exceeds any one of the standards, it is not suitable for drinking. This map illustrates that wells in zones 1, 2, 3 and 4 are not fit for drinking purpose. Likewise, irrigational suitability of groundwater in the study region was evaluated and results suggest that 20% samples are not fit for irrigation. Groundwater suitability map for irrigation was also produced based on salinity and sodium hazards and denotes that wells mostly situated in zones 2 and 3 are not suitable for irrigation. Both integrated suitability maps for drinking and irrigation usage provide overall scenario about the groundwater quality in the study area. Finally, the study concluded that groundwater quality is impaired by man made activities and proper management plan is necessary to protect valuable groundwater resources in Thanjavur city.

Introduction

Due to the ever increasing demand for potable and irrigation water, and inadequacy of available surface water, the importance of groundwater is increasing exponentially everyday. Further, about 80% of the diseases and deaths in the developing countries are related to water contamination (UNESCO 2007). In recent days, Thanjavur city is facing an acute shortage for good drinking water owing to poor quality of groundwater unless good potable water supplied by the municipality. Hence, evaluation of groundwater quality is necessary and immediate task for present and future groundwater quality management in Thanjavur city due to the non-perennial nature of Cauvery River and frequent failure of monsoon. In addition, numerous studies concentrated on groundwater quality monitoring and evaluation for domestic and agricultural activities (Al-Bassam and Al-Rumikhani, 2003; Al-Futaisi et al. 2007; Elampooranan et al. 1999; Elango et al. 1998; Elango et al. 2003; Jeevanandam et al. 2006; Pritchard et al. 2008; Rajmohan et al. 1997; Subramani et al. 2005; Sujatha and Rajeswara Reddy 2003). Ma et al. (2009) evaluated water quality and identified the source of water pollution in the Wuwei basin of Shiyang river in northwest China and reported high salinity and nitrate in groundwater. These studies emphasized that groundwater quality monitoring and evaluation is a necessary task to protect valuable groundwater sources and management. Generally, the concentrations of dissolved ions in groundwater are governed by lithology, groundwater flow, nature of geochemical reactions, residence time, solubility of salts and human activities (Bhatt and Saklani

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1996; Karanth 1987; Nisi et al. 2008; Schot and Wal 1992). Moreover, the groundwater quality is mostly affected by either natural geochemical processes such as mineral weathering, dissolution/precipitation reactions, ion exchange or various manmade activities such as agriculture, sewage disposal, mining and industrial wastes, etc. The surface runoff from the agricultural field is one of the main sources for nutrients and salinity in the groundwater and occurrence of nitrate and nitrite in the groundwater above the permissible limit is not conductive for the drinking purpose (Lee et al. 2003; Rajmohan and Elango 2005). Nitrate is resulted mostly by surface contamination sources. Nitrate (> 300mg/l) poisoning may result in the death of livestock consuming water (Canter 1997). In humans, a condition called methaemoglobinaemia, also known as blue baby syndrome results from the ingestion of high concentration of nitrate in its inorganic form. Nitrate contamination is strongly related to land-use pattern and reported in several studies throughout the world (Ator and Denis 1997; Elhatip et al. 2003; Jeong 2001; Kalkhoff 1992; Rajmohan et al. 2009). Further, groundwater with low pH values can cause gastrointestinal disorder and this water cannot be used for the drinking purposes (Laluraj and Grish Gopinath 2006). Total dissolved solids (TDS) values are also considered as an important parameter in determining the usage of water and groundwater with high TDS values are not suitable for both irrigation and drinking purposes (Fetters 1990; Freeze and cherry 1979). Like drinking, groundwater quality is an important criterion to decide the water for irrigation activities. Several researchers evaluated the suitability of groundwater for irrigation using various parameters e.g. Na%, SAR, RSC, Wilcox and USSL classifications, etc. (Al-Bassam and Al-Rumikhani 2003; Al-Futaisi et

al. 2007; Elampooranan et al. 1999; Elango et al. 1998; Elango et al. 2003; Jeevanandam et al. 2006; Rajmohan et al. 1997; Subramani et al. 2005; Sujatha and Rajeswara Reddy 2003).

The present study was carried out to evaluate the groundwater quality and its suitability for domestic and agricultural activities in Thanjavur city, Tamil Nadu, India as the groundwater is the only major source of water for agricultural and domestic purposes due to the lack of surface water.

Study area

The study region is Thanjavur city, which is located 300 km far from Chennai, in the Cauvery Delta Zone of eastern part of Tamil Nadu, India (Fig.1). The city extends between North latitudes 10° 8'-10° 48' and east longitudes 79° 09' - 79° 15' with an altitude of 59m and it has an average elevation of 2 meters. The study region has an area of 36.31 km^2 and being developed in the adjacent villages. Total population in the study site is about 2,26,830 (Census of India, 2001). The Cauvery delta zone has a tropical climate and the average annual rainfall in Thanjvur city is 1114 mm. The average temperature in this region is varying between 36.6°C and 32.5°C in summer, and between 23.5°C and 22.8°C during winter, respectively. The most important economic activity of this area is agriculture and the major crops are paddy, sugarcane, coconut, plantain, etc. The irrigation system mostly feed by groundwater as well as the canal system (Grand Anaicut Canal) in this Cauvery delta area. It consists of grand and upper anaicuts across the Cauvery River. This great system of canals is covering the whole delta in the districts

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of Thiruchirapalli and Thanjavur. The total length of the canal exceeds 6000 km and 400,000 hectares of land are being irrigated.

Geology and Hydrogeology

Figure 2 illustrates the geology of the study site. The area consists of alluvial flood plain and includes paleo-channel deposits, sandstone, gravels and patches of kankar formations which is belongs to Tertiary to Quaternary age **(**Tamil Nadu Agricultural University 2002-2004**).** The study area consists of two distinct formations namely Quaternary alluvial flood plain deposits in the northern part and Miocene sediments in the southern part of the study area. The alluvial thickness ranges from 30m to 400m. The alluvial soil is clayey textured with 40 – 45% of clay fraction particularly montmorillonite, which has good capacity for adsorption and retention of water and plant nutrients (Tamil Nadu Agricultural University 2002-2004). The Cretaceous Formations occur as small patch in South-western sides but not within the study area. These formations have a very thick lateritic cap, consisting of impure argillaceous and calcareous clay. The Pliocene formations are formed to occur on the south eastern side of Thanjavur town overlying the Miocene formations. This formation includes sand, variegated clay and gravel. The water level fluctuates between 10.50m to 23.00m during summer and between 6.15m to 10.90m during winter. Thickness of shallow aquifer ranges from 10 to 30 mts and deep aquifer ranges from 60mts to 120 mts.

Methodology

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Thanjavur city was divided into 10 zones based on Panchayat wards for administration purposes. In this study, we have considered same administration zones for groundwater sampling and further discussion. In the study area, 102 bore and dug wells were selected for groundwater sampling based on field survey. Figure 1 shows the groundwater sampling locations and administration zones. Groundwater samples were collected during March 2008 and analyzed for major ions and nitrate. The groundwater samples were collected in 2 Liter HDPE containers pre-washed with 1:1 HCL and rinsed three to four times before sampling using sampling water. Collected samples were transported to laboratory within the same day and stored at 4°C. Samples for laboratory analysis were filtered in the laboratory in the same day through 0.45 μm cellulose membranes prior to the analyses. Groundwater samples for cations analysis were acidified to pH < 2 with several drops of ultra-pure HCl in the laboratory. Groundwater samples were analyzed based on standard methods (APHA 1995). Electrical conductivity (EC) and pH were measured in the field immediately after the collection of the samples using portable field meters. The analyses were carried out in Regional water testing laboratory, TWAD Board, Thanjavur. In the laboratory, Na and K were analyzed by flame photometer, and Ca, Mg, Cl and alkalinity (HCO_3) were estimated by titration. Sulphate and nitrate were analyzed using spectrophotometer. Measurement reproducibility and precision for each analysis were less than 2%. The analytical precision for the total measurements of ions was checked again by calculating the ionic balance errors, and was generally within ±5%.

The geochemical computer code PHREEQC (Parkhurst and Appelo 1999) with thermodynamic database PHREEQC and WATEQ4F were used to calculate the distribution of aqueous species and mineral saturation indices. In addition, groundwater quality data were employed to create integrated groundwater quality maps.

Results and discussion

General water chemistry

The hydrochemistry of groundwater for all the zones is given in the table 1 with minimum, maximum, mean and standard deviation values. The chemical composition of the groundwater samples (n=102) in the study region shows a wide range. The electrical conductivity (EC) in the study region is varied from 190 µS/cm to 6000 µS/cm with an average of 1101 µS/cm (n=102). The total dissolved solids (TDS) ranged from 133 to 4200 mg/l with a mean value of 783 mg/l. According to the TDS classification, 29.4% of the groundwater samples belong to the brackish type (TDS > 1000mg/l) and the remaining comes under fresh water category (TDS < 1000mg/l) (Freeze and Cherry, 1979). Among the cations, the concentrations of Na, K, Ca, and Mg ions ranged from 18 to 740, 1-60, 12-240 and 3-154 mg/l with an average value of 133, 8, 67 and 20 mg/l, respectively. Cation chemistry indicates that 94% of the samples are Na>Ca>Mg>K, while the remaining 6% of samples are Ca>Na>Mg>K. The dissolved anions such as alkalinity, Cl, SO_4 and NO_3 lie in between 40 and 688, 28 and 1660, below detection

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limit (BDL) and 133, and 2 and 176 mg/l with an average value of 196, 204, 44 and 23 mg/l, respectively. The pH of the groundwater samples in the study area varies from 6 to 9.6 with an average value of 7.1 which indicates that the dissolved carbonates are predominantly in the HCO_3 form (Adams et al. 2001). About 62% of samples show the pH variation between 7 and 8.2, indicating an alkaline nature.

Both EC and chloride have high standard deviation compared to other parameters and suggest that water chemistry is not homogeneous in the study region and regulated by distinguished processes. Moreover, the nitrate concentration indicates that 13% of samples exceed 45 mg/l and 11% of samples lie between 25 and 45 mg/l. The concentrations of chloride and nitrate firmly evident the influences of surface contamination sources such as agricultural activities (irrigation return flow, fertilizers and farm manure) and domestic waste waters (septic tank leakage, sewage water, etc) in the study region. However, alkalinity concentration (196 ±129, Mean ± SD) reveals the influences of mineral dissolution on water chemistry in the study region.

Processes regulating water quality

Zone wise groundwater quality data (Table 1) indicates that zones 2, 3 and 4 have high concentrations of major ions, nitrate and EC. Especially, groundwater samples in zone 2 extremely affected by surface contamination sources because the average chloride (357 mg/l) and nitrate (52 mg/l) concentrations are very high compared to other zones.

Regional groundwater quality maps, prepared by GIS, also apparently illustrate that wells in the zone 2 contain elevated concentration of TDS, nitrate and Cl (Fig. 3). Like nitrate and Cl, similar trend is observed in other major ions and in EC. Further, zones 3 and 4 are also express high concentrations of most of the ions next to zone 2. Alkalinity generally represents dissolution of carbonate and silicate minerals. However, it is also very high in zones 2, 3 and 4 (Table 1). The average concentration of alkalinity in zone 2, 3 and 4 are 394, 294 and 210 mg/l, respectively. This observation suggests that the water chemistry in these zones (2, 3 and 4) could be affected by infiltration of waste water originated from surface contaminations sources, which causes dissolution of carbonate and silicate minerals indirectly.

In order to understand the chemical characteristics of groundwater in the study region, groundwater samples were plotted in Piper trilinear diagram (Piper 1944) using AquaChem software (Fig. 4). Figure 4 displays that groundwater samples are classified as various chemical types on the piper diagram. The dominant water types are in the order of Na–Cl > Ca-Mg-Cl > Mix CaNaHCO$_3$ > Ca HCO$_3$. However, most of the samples are clustered in Na–Cl and Ca-Mg-Cl segments. Water types (Ca-Mg-Cl and Na-Cl) suggest the mixing of high salinity water, caused from surface contamination sources such as irrigation return flow, domestic waste water and septic tank effluents, with existing water followed by ion exchange reactions. However, Mixed CaNaHCO$_3$ and CaHCO$_3$ water types express mineral dissolution and recharge of fresh water. In addition with piper diagram, Gibbs plots were also used to gain better insight into hydrochemical processes

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such as precipitation, rock-water interaction and evaporation on groundwater chemistry in the study region (Fig. 5). Gibb's (1970) demonstrated that if TDS is plotted against Na/(Na+Ca) this would provide information on the mechanism controlling chemistry of waters. Figure 5 display that groundwater samples were plotted mostly in the rock-water interaction zone and few samples in the evaporation zone. This observation suggests that dissolution of carbonate and silicate minerals are mostly controlled the groundwater chemistry in the study region. However, few samples plotted in the evaporation zone reveal that surface contamination sources, for example irrigation return flow, seem to be affected the groundwater quality in the study region. Both Piper and Gibbs plots suggest that water chemistry is regulated by mixing of salinity water, caused by surface contamination sources, with existing water, ion exchange reactions, mineral dissolution and possibly evaporation.

Ion exchange process

The evolution of groundwater towards a Na-rich type generally occurred by the precipitation of calcite and/or cation exchange. In contrast, Ca-Cl type water commonly produced by reverse ion exchange reaction (Na + Ca-Clay = Na-Clay + Ca). Both cation exchange and reverse ion exchange are encouraged by aquifer materials, especially montmorillonite, which leads to the release of Na or Ca into groundwater and adsorption of Ca or Na, respectively (Alison et al. 1992; Blake 1989; Cerling et al. 1989; Foster 1950). As Piper plot indicates the possibility of ion exchange reactions, Schoeller chloro-

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alkaline indices were employed to understand the ion exchange reactions. The ion exchange reactions between the groundwater and its host environment during residence or travel can be understood by studying the chloro-alkaline indices, Chloro-alkaline indices 1 and 2 (CAI 1 and CAI 2) calculated for the groundwater samples of the study region using the following relations (Schoeller 1965, 1967).

$$CAI\ 1\ =\ Cl^- - (Na^+ + K^+) / Cl^- \qquad (3)$$

$$CAI\ 2\ = Cl^- - (Na^+ + K^+) / SO_4^{2-} + HCO_3^- + CO_3^{2-} + NO_3^- \qquad (4)$$

$$(All\ values\ are\ expressed\ in\ meq/l)$$

If the indices values are negative, Na^+ and K^+ ions in the aquifer materials are exchanged with Mg^{2+} and Ca^{2+} ions in water where as reverse process will give positive value (Cl > Na+K) . During this process, the host rocks are the primary sources for dissolved solids in the water. Schoeller (1965; 1967) indices indicate that all samples in the study region have positive values except few samples, and explain that reverse ion exchange reaction is dominant in the study region. But in few sites where the values are negative, suggest the influences of normal ion exchange reactions.

Effect of mineral dissolution and surface contamination sources

As per the geology, soil information and Gibbs plots, mineral dissolution is one of the major process regulates water chemistry in the study region. Dissolution of carbonate minerals seems to be largely affected the water chemistry because kankar formation is

observed in the study site. Saturation indices (SI) of carbonate (calcite, dolomite), sulphate (gypsum, anhydrite) minerals and halite were calculated using PHREEQC. Saturation indices of calcite vary between -3 and 1 (Fig. 6) while SI value of dolomite ranges from -5 to 2. SI values of sulphate minerals and halite suggest that groundwater samples are highly undersaturated with respect to gypsum (SI<-2), anhydrite (SI<-2) and halite (SI<-6). This observation reveals that influences of sulphate minerals and halite are not significant on groundwater chemistry and there is no known geological information about the occurrence of sulphate minerals and halite in the study region. However, application of gypsum (fertilizer) in the irrigation field may contribute sulphate content in groundwater through irrigation return flow. Likewise, NaCl salt from domestic waste water can affect water chemistry by infiltration.

Saturation indices of carbonate minerals (calcite, dolomite) show that these are varying with groundwater zones (Fig. 6). Groundwater samples may be classified into three groups: over saturated (SI>0), saturated (SI≤0) and undersaturated (SI<-1). Figure 6 illustrates that wells located in zones 1, 2 and 3 come under group 1 (SI>0). Wells existed in zones 4, 5, 6 and 7 are classified as group 2 (SI≤0) where as wells situated in the remaining zone (8, 9 and 10) come under group 3 (SI< -1). The variation of carbonate minerals saturation in the study site may be due to three major reasons: 1) variation in the occurrence of carbonate minerals, 2) external sources of Ca, Mg and alkalinity entering into the groundwater system by recharge process and 3) infiltration of waste water, originated from surface contamination sources, enhances the dissolution of

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carbonate minerals existing in the aquifer materials. In the study region, there is no heterogeneity in geological formation, which ruled out the first reason. Moreover, figure 6 also shows that total dissolved solids (TDS) and calcium behave similarly, and group 1 followed by group 3 wells have high concentrations compared to group 2. Other major ions (Mg, Na, K, Cl and SO_4) also express similar trend like calcium and TDS. However, alkalinity and nitrate are contrary to other ions and these are very high in group 1 wells compared to groups 2 and 3 wells. These observations suggest that alkalinity in group 1 wells may be originated from surface contamination sources in addition with carbonate mineral dissolution (Adams et al. 2001). Generally, alkalinity can enter the aquifer from the dissolution of carbonate minerals, soil CO_2 or from the bacterial degradation of organic material (Jeong 2001). In this study site, alkalinity can also come from surface contamination sources such as bacterial degradation of organic material, anthropogenic CO_2 gas caused from municipal wastes dumped in the unlined dumping sites, oxidation of organic materials leaked from old latrines and sewage systems in the study area (Clark and Fritz 1997). Hence, the second and third reasons are more reliable for over-saturation of groundwater with respect to carbonate minerals in group 1 wells because the influences of domestic waste water and irrigation return flow are apparently observed in zones 2-4 which enhances saturation of carbonate minerals in the study region.

As mentioned earlier, the study region is covered by both urban and agricultural activities. The study area is mostly irrigated with paddy crops. Hence, application of fertilizers and irrigation return flow may also affect the groundwater quality in the study

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region. It is strongly observed in potassium, sulphate and nitrate. Generally, potassium is retained with aquifer material, especially in clay formation and several studies reported very low concentration in groundwater (Sarin et al. 1989; Subba Rao 2002). In the study region, potassium is generally less than 8 mg/l (average) except zones 2, 3 and 4 (K > 11 mg/l, average) (Table 1). This observation suggests that potassium concentration in zones 2, 3 and 4 is entered into the groundwater system from external sources in addition with mineral dissolution because there is no heterogeneity in geology. Like potassium, the average sulphate concentration is less than 45 mg/l in the study region except wells in zones 1, 2, 3 and 4 where $SO_4 > 60$ mg/l (Table 1). Application of potassium fertilizers (Potash (KCl) and NPK (Nitrogen-Phosphorus-Potassium, mixed fertilizer) and gypsum seems to be contributed well in potassium and sulphate concentrations in addition with domestic waste water (sewage, septic tank effluent, etc). Like potassium and sulphate, nitrate also illustrates very large variation with respect to zones (Table 1, Fig. 3). The average nitrate is generally less than 16 mg/l except zones 2, 3 and 4 (Table 1). The average concentrations in zones 2, 3 and 4 are 52, 51 and 39 mg/l, respectively. Generally, nitrate is originated from distinguished processes such as irrigation practice, organic material oxidation, soil mineralization, urban contamination, etc (Elhatip et al. 2003; Jeong 2001; Subba Rao 2002). In the study region, infiltration of domestic waste water, septic tank effluents, irrigation return flow, fertilizer (mainly urea) and farm manure are the major sources for nitrate in groundwater. The study area is dominantly covered by old settlements, and constructed septic tanks in this settlement area are older

than a decade. Hence, leakage of effluent from these septic tanks is one of the major sources for nitrogen.

Evaluation of groundwater quality

Drinking usage

The analytical results have been evaluated to ascertain the suitability of groundwater in the study area for domestic and agricultural purposes based on the WHO (1993) and Indian Standards (1991) (Table 2). The average values of individual parameters of groundwater are within the permissible limit when compared to the WHO (1993) and Indian Standard (1991) where as individual samples are having higher concentration which have shown in the table by comparing WHO and Indian standards. According to the Freeze and Cherry (1979), 70.6% of samples are considered as fresh water type. Classification based on Davis and DeWiest (1966), 42% of samples are desirable for drinking and 28% of samples are considered as permissible for drinking purposes based on TDS (Table 3). Among the cations, sodium is the most dominant cation in groundwater. Sodium concentration of more than 50 mg/l, make the water unsuitable for domestic use. Hardness is an important criterion for determining the usability of water for domestic, drinking and many industrial supplies (Karanth 1987). Hardness can be classified as temporary due to carbonate and bicarbonates or permanent due to sulphate and chlorides of calcium and magnesium. Total hardness varies between 50 and 1240 with an average of 239 mg/l. The groundwater with total hardness (TH)

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value less than 75 mg/l is considered as soft. According to the classification using total hardness, 20% of groundwater samples show moderate quality and 75% come under hard to very hard category (Table 4). Very low percentage about 4.90% of samples shows good quality. Hard water is mainly an aesthetic concern because of the unpleasant taste. It also reduces the ability of soap to produce lather, and causes scale formation in pipes and on plumbing fixtures. Magnesium is one of the constituents responsible for hardness of water. Further, higher magnesium concentration may be cathartic and diuretic (WHO 1997). Also the values of magnesium combined with sulphate act as laxative to human beings. The maximum permissible and highest desirable limit given by the WHO (1993) and ISI (1991) is 100 and 30mg/l, respectively. The magnesium ranges between 3 mg/l and 154 mg/l with an average of 20 mg/l (n=102, Table 1). Most of the samples are with in the permissible limit. Sulphate is one of the least toxic anions, even though dehydration is observed at high concentrations. ISI (1991) suggested that highest desirable and maximum permissible limit of sulphate is 200 and 400 mg/l, respectively. If the limit of sulphate exceeds, it may cause gastro intestinal irritation and laxative effect at higher level (WHO 1993). Sulphate values in the study area varies from BDL to 133 mg/l with an average of 44 mg/l (n=102, Table 1). Mostly all the samples show the sulphate content within the recommended limit.

Integrated groundwater suitability map for drinking purposes in the study site is created by combining all the quality parameters e.g. TDS, TH, pH, Na, K, Ca, Mg, Cl, SO_4 and NO_3 (Figure 7). This map is produced based on the concept that if the

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groundwater samples exceed the recommended limits (ISI 1991; WHO 1993) of any one of the parameters, they are not suitable for drinking usage. In the study region, 34 wells (34% in total wells) exceed any one of the drinking water standards recommended by WHO (1993) and ISI (1991) which are not suitable for drinking purpose.

Irrigational suitability

In the study region, the surface water facility for irrigation is available only for limited time or season due to frequent failure of monsoon. For other season irrigation mainly depends on groundwater. Irrigational suitability of groundwater in the study site was evaluated by EC, SAR, RSC, USSL classification, Na% and Wilcox diagram. The total content of soluble salts such as Na to Ca and Mg and its relative proportion affects the suitability of groundwater for irrigation. The EC and Na concentration are important in classifying irrigation water. According to Richards (1954), the irrigation water is classified into four groups such as low (EC = <250 µS/cm), medium (250 – 750 µS/cm), high (750 – 2250 µS/cm), and very high (2250 – 5000 µS/cm) salinity. High EC in water leads to form saline soil, where as high Na content in water causes alkaline soil. In addition, SAR (Sodium Absorption Ratio) and RSC (Residual Sodium Carbonate) are used to evaluate the groundwater quality for irrigation. The irrigation water containing a high proportion of sodium will increase the exchange of sodium content of the soil, affecting the soil permeability, and the texture makes the soil hard to plough and unsuitable for seedling emergence (Trivedy and Goel 1984). Features that generally need to be considered for evaluation of groundwater suitability for irrigation are salinity,

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sodium percentage and SAR. The sodium or alkali hazard in the use of water for irrigation is expressed by determining the SAR and it was estimated by the equation:

$$SAR = Na / [(Ca + Mg)/2]^{0.5}$$

Units are expressed in meq/L

The calculated values of SAR in the study area vary between 0.97 and 9.17 (Table 5). A more detailed analysis, however, with respect to the irrigation suitability of the groundwater, was made by plotting the data on the diagram of U.S Salinity laboratory of the Department of Agriculture (United States Salinity Laboratory (1954)). According to this classification, low-salinity water (<200mg/l) may be used for all types of soils (Figure 8). The groundwater of the study area falls into the good to moderate category (Figure 8; Table 6). In overall, 76 % of samples fall in C2S1 and C3S1 fields, indicating medium to high salinity and low alkalinity water which can be used for irrigation, where moderate amount of leaching occurs and moderate permeability with leaching soil. Besides, 18% of samples fall in C3S2 field indicating high salinity and medium sodium hazard, which restrict its suitability for irrigation. Classification of groundwater based on salinity hazard (EC) and SAR is presented in Table 6. It is found that only 5 samples to be unsuitable for irrigation purposes. High salinity and medium hazard type of water in fine textured soil of high cation exchange capacity, especially under low leaching conditions, unless gypsum is present in the soil, presents appreciable sodium hazard. But it may be used on coarse textured or organic soils which have good permeability. The rating of water samples in relation to salinity and sodium hazard reflects that the high

sodium ion concentration in the water at some of the stations may produce harmful levels of exchangeable sodium in the soil.

In all natural waters, percent of sodium content is a common parameter to assess its suitability for agricultural purposes (Wilcox 1948). Sodium combines with carbonate can lead to the formation of alkaline soils, while sodium combining with chloride form saline soils. Both these soils do not help for plant growth. Na % was calculated using the following equation.

$$Na\% = \frac{Na X 100}{Ca + Mg + Na + K}$$

A maximum of 60% sodium in groundwater is allowed for agricultural purposes (Ramakrishna, 1998). Percentage of sodium calculated for groundwater in the study region is plotted against specific conductance in Wilcox diagram (Fig. 9). Figure 9 shows that 45 samples are excellent to good, 32 samples are good to permissible, 19 samples are permissible to doubtful and 6 are doubtful to unsuitable. Residual Sodium Carbonate (RSC) index of water samples in the study site is estimated by the equation

$$RSC = (CO_3^{--} + HCO_3) - (Ca^{++} + Mg^{++}),$$

Units are expressed in meq/L (Eaton 1950)

Lloyd and Heathcote (1985) have classified irrigation water based on RSC as suitable (<1.25), marginal (1.25-2.5) and not suitable (>2.5). According to RSC values,

96% of groundwater samples are suitable for irrigation and 3% of samples are marginal and the remaining is not suitable for irrigation.

In overall, groundwater suitability map for irrigational activities for the study region is produced based on irrigational quality parameters such as EC and SAR (Fig. 10). This map is created based on the same classification like USSL classification (Excellent (C1S1), Good (C2S1, C3S1), Unsuitable (C3S2), Highly unsuitable (C4S3, C4S2, C5S3)). This image will provide the insight of current groundwater quality scenario and helps to groundwater planners and government sectors for present and future groundwater management.

Summary and Conclusions

Groundwater quality and its suitability for drinking and agricultural use in Thanjavur city is evaluated since groundwater is a major source of water for domestic and agricultural activities in the study site due to lack of surface water resources. For this study, 102 groundwater samples were collected from dug and bore wells during March 2008 and analyzed for pH, electrical conductivity, temperature, major ions and nitrate. Results suggest that in 90% of groundwater samples, sodium and chloride are predominant cation and anion, respectively, in the study area. Further, Piper plot also indicates that NaCl and CaMgCl water types are dominant in the study area. Electrical conductivity and chloride concentration show large variations and have high standard deviation, which suggests that water chemistry is not homogenous and regulated by

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distinguished processes. The groundwater quality in the study site is influenced by surface contamination sources, mineral dissolution, ion exchange and evaporation. Nitrate and chloride concentrations strongly express the impact of surface contamination sources such as agricultural and domestic activities, and 13% of samples have elevated nitrate content (> 45 mg/l as NO_3). Besides, groundwater wells in zones 2, 3 and 4 have high concentration of potassium and sulphate, which also evident the impact of surface contamination sources especially application of fertilizers and farm manures. Influences of mineral dissolution was evaluated by PHREEQC and Gibbs plots and suggests that mineral dissolution, especially carbonate minerals, regulate water chemistry. Saturation indices of carbonate minerals reveal that recharge of waste water from surface contamination sources enhances saturation of carbonate minerals. Chloro alkaline indices indicate that reverse ion exchange reaction is a dominance process in the study region. Groundwater suitability for drinking usage was evaluated by WHO and Indian standards and proposes that 34% of samples are not suitable for drinking. Integrated groundwater suitability map for drinking purposes was created using TDS, TH, pH, Na, K, Ca, Mg, Cl, SO4 and NO3, based on a concept that if the groundwater sample exceeds the recommended limit of any one of these parameters, it is not suitable for drinking usage. Further, this map illustrates that wells in zones 1, 2, 3 and 4 are not fit for drinking purpose. Likewise, irrigational suitability of groundwater in the study region was evaluated using quality parameters e.g. EC, SAR, RSC, USSL classification, Na% and Wilcox diagram. Result suggests that 20% samples are not fit for irrigation. Groundwater suitability map for irrigation was also produced based on salinity and sodium hazard and

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expresses that wells mostly existed in zones 2 and 3 are not suitable for irrigation. Both integrated suitability maps for drinking and irrigation usage give overall scenario about the groundwater quality in the study area. Further, these maps will help for people who are dedicated to groundwater quality management and planning. In overall, the study concluded that groundwater quality is impaired by man made activities and proper management plan is necessary to protect valuable groundwater resources in Thanjavur city.

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Table 1 Statistical summary of groundwater quality data in Thanjavur City

		TDS	EC	pH	TH	Ca^{2+}	Mg^{2+}	Na$^+$	K$^+$	NO$_3^-$	Alk	Cl$^-$	SO$_4^{2-}$
Zone 1	Min	560	800	7.2	160	48	5	84	4	2	180	112	33
	Max	1400	2000	7.9	512	152	32	264	12	11	478	352	120
	Mean	977	1395	7.5	310	93	19	169	7	7	299	234	64
	SD	292	417	0.2	108	35	9	59	3	3	89	81	28
	n	10	10	10	10	10	10	10	10	10	10	10	10
Zone2	Min	504	720	6.7	88	24	7	92	6	8	120	140	10
	Max	4200	6000	9.6	1240	240	154	740	60	102	688	1660	133
	Mean	1413	2018	7.8	383	104	34	265	17	52	394	357	66
	SD	981	1402	0.7	289	55	39	186	15	35	151	425	39
	n	12	12	12	12	12	12	12	12	12	12	12	12
Zone 3	Min	168	240	6.5	74	20	6	20	1	5	50	40	8
	Max	2100	3000	7.9	540	180	62	368	32	176	540	504	120
	Mean	1023	1461	7.3	264	89	25	167	11	51	294	226	62
	SD	539	770	0.5	120	51	16	111	9	49	144	131	37
	n	10	10	10	10	10	10	10	10	10	10	10	10
Zone 4	Min	749	1070	6.2	224	56	19	95	6	17	160	156	28
	Max	1253	1790	7.6	500	131	48	220	16	56	324	384	90
	Mean	1099	1570	6.6	390	104	31	166	11	39	210	304	69
	SD	192	275	0.5	88	25	10	34	3	12	48	87	25
	n	10	10	10	10	10	10	10	10	10	10	10	10
Zone 5	Min	420	600	7.1	156	40	12	65	3	8	122	86	23
	Max	805	1150	7.5	170	48	15	174	12	21	160	272	44
	Mean	535	764	7.4	163	42	13	98	6	16	137	137	33
	SD	160	229	0.1	6	3	1	46	4	4	13	77	7
	n	10	10	10	10	10	10	10	10	10	10	10	10
Zone 6	Min	308	440	7.0	120	29	11	46	1	13	76	66	BDL
	Max	721	1030	8.0	186	44	19	144	10	18	160	232	38
	Mean	432	617	7.4	149	37	14	70	4	15	118	109	18

		11	47	30	2	3	29	3	6	23	0.3	172	120
	SD	11	47	30	2	3	29	3	6	23	0.3	172	120
	n	10	10	10	10	10	10	10	10	10	10	10	10
Zone 7	Min	15	66	68	2	3	51	10	26	110	6.4	460	322
	Max	45	316	170	18	10	148	26	82	312	8.0	1290	903
	Mean	28	120	113	12	5	73	13	42	159	7.5	655	459
	SD	10	71	31	6	2	28	5	16	57	0.6	234	164
	n	10	10	10	10	10	10	10	10	10	10	10	10
Zone 8	Min	14	36	60	3	1	24	3	25	72	6.1	250	175
	Max	108	488	260	11	12	248	42	136	480	7.6	2100	1470
	Mean	45	189	131	7	5	104	17	63	228	6.6	935	655
	SD	27	166	57	3	4	69	13	39	146	0.4	610	427
	n	10	10	10	10	10	10	10	10	10	10	10	10
Zone 9	Min	BDL	28	40	5	1	18	4	12	50	6.0	190	133
	Max	48	574	270	13	16	256	48	120	500	7.0	2300	1610
	Mean	19	178	123	9	5	102	16	45	178	6.6	838	587
	SD	18	182	84	3	5	91	14	36	148	0.3	725	508
	n	10	10	10	10	10	10	10	10	10	10	10	10
Zone 10	Min	8	40	52	4	1	24	6	24	84	6.0	270	189
	Max	108	356	160	18	12	220	34	84	350	8.1	1470	1029
	Mean	35	151	100	11	5	88	14	46	171	6.7	754	528
	SD	33	104	40	5	4	57	9	20	85	0.7	394	276
	n	10	10	10	10	10	10	10	10	10	10	10	10
Total	Min	BDL	28	40	2	1	18	3	12	50	6.0	190	133
	Max	133	1660	688	176	60	740	154	240	1240	9.6	6000	4200
	Mean	44	204	196	23	8	133	20	67	242	7.1	1119	783
	SD	32	191	129	26	8	104	17	42	158	0.6	783	548
	n	102	102	102	102	102	102	102	102	102	102	102	102

Table 2. Range in concentration of chemical parameters of the study area and compared with WHO and Indian Standards for drinking purposes

Water quality Parameters	WHO (1993)		Indian standard (IS 10500, 1991)		No. of samples exceed the standards		Concentration in the study area	Undesirable effect produced beyond max allow limit
	Highest accept limit (mg/l)	Max allowable limit	Highest desirable	Max permissible	According to WHO (1993)	According to (ISI 1991)		
TDS	500	1500	500	2000	13, 18, 21, 29, 92	21, 29	133 – 4200 (Avg. 771)	Taste, gastro-intestinal irritation
pH	6.5	8.5	6.5 - 8.5	6.5-9.5	11	11	6 – 10 Avg. 7	Taste effects mucus membrane and water supply system
TH (as CaCO3)	100	500	300	600	8, 21, 29	21	50 – 1240 Avg. 239	Encrustation in water supply and adverse effect on domestic use
Ca^{2+}	75	200	75	200	12, 21	12, 21	12 – 1132 Avg. 76	
Mg^{2+}	50	150	30	100	21	21	3 – 154 Avg. 19	
Na^{+}	-	200	-	200	1, 4, 7, 12, 15, 16, 18, 20, 21, 28, 29, 30, 36, 79, 85, 87, 92, 94	1, 4, 7, 12, 15, 16, 18, 20, 21, 28, 29, 30, 36, 79, 85, 87, 92, 94	18 – 748 Avg. 137	
K^{+}	-	12	-	-	13, 15, 18, 20, 21, 28, 29, 30, 36, 40, 92		1 – 60 Avg. 8	
NO$_3^-$	45	-	45	45	13, 14, 15, 18, 21, 23, 24, 27-29, 32, 40, 41	13, 14, 15, 18, 21, 23, 24, 27-29, 32, 40, 41	2 – 176 Avg. 22	Blue baby diseases in children
Cl$^-$	200	600	250	1000	21	21	28 – 1660 Avg. 199	Salty taste indicates pollution
SO$_4^{2-}$	200	400	200	400**	Nil	Nil	0 – 133 Avg. 44	Cause, gastro-intestinal irritation when Mg and Na sulphate

Units = mg/l, except pH.   **upto 400 mg/l if Mg does not exceed 30mg/l

Table 3. Classification of groundwater based on TDS (Davies and DeWiest, 1966)

TDS	Water type	Percentage
Up to 500	Desirable for drinking	42
500–1000	Permissible for drinking	28
<3000	Useful for irrigation	99
>3000	Unfit for drinking and irrigation	1

Table 4. Classification of the groundwater based on Hardness

Total Hardness (as $CaCO_3$, mg/l)	Water classification	Percentage of wells
<75	Soft	5
75 − 150	Moderately Hard	20
150 − 300	Hard	47
> 300	Very hard	28

Table 5. Classification of the groundwater quality according to the USDA method

Sodium Hazard		**Salinity Hazard**			
		Low C1	Medium C2	High C3	Very High C4
Low	S1	5 (4.9%)	40 (39.2%)	36 (35.3%)	0
Medium	S2	0	0	17 (16.7%)	1 (0.98%)
High	S3	0	0	0	2 (1.96%)
Very High	S4	0	0	0	0

Table 6. Relation between SAR and EC of the groundwater samples in the study area

SAR	EC	Water class	Sample Number	Salinity Hazard
<10	250	Excellent	25, 73, 84, 88, 90 (4.90%)	Low
	250-750	Good	11, 26, 43-49, 53, 54, 56-68, 70-72, 74, 75, 80, 81, 83, 86, 91, 93, 98-102 (39.2%)	Medium
	751-2250	Fair	1-10, 12, 14-17, 19, 20, 22-24, 27, 28, 30-42, 50-52, 55, 69, 76-79, 82, 85, 87, 89, 94-97 (51%)	High
	>2250	Poor	13, 18, 21, 29, 92 (4.90)	Very High

Figure 1

Figure 2

Figure 3

TDS mg/l

NO$_3$ mg/l

Cl mg/l
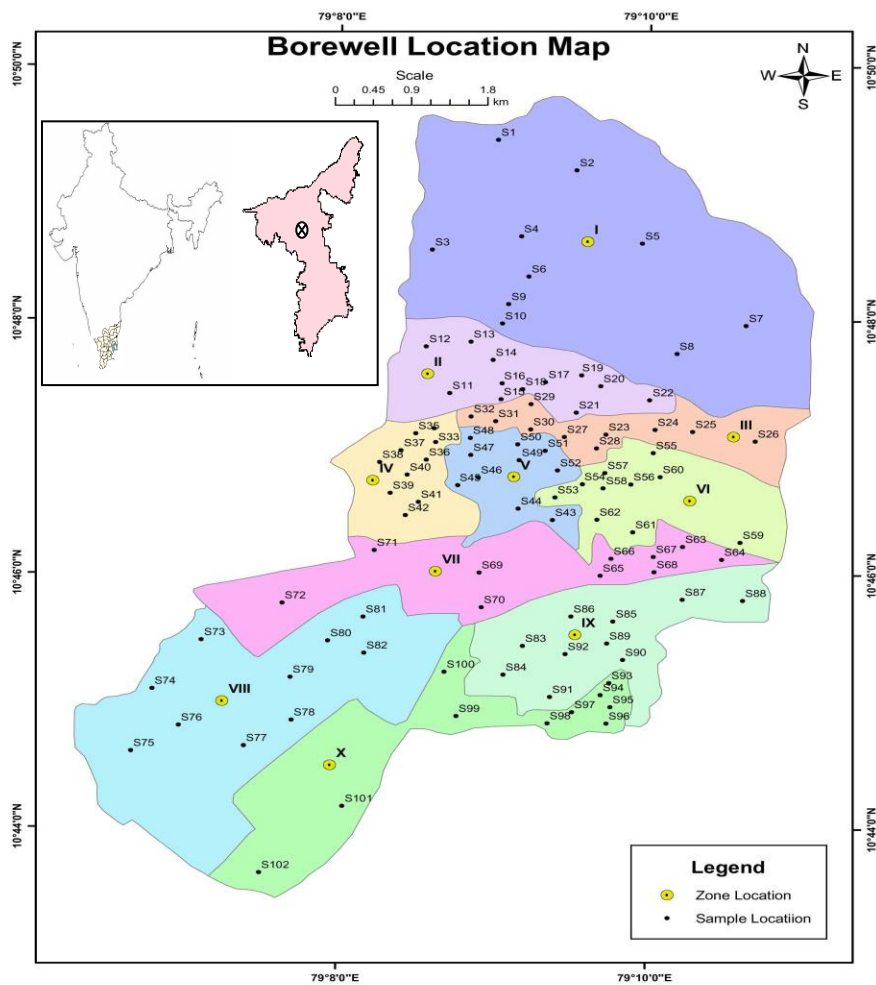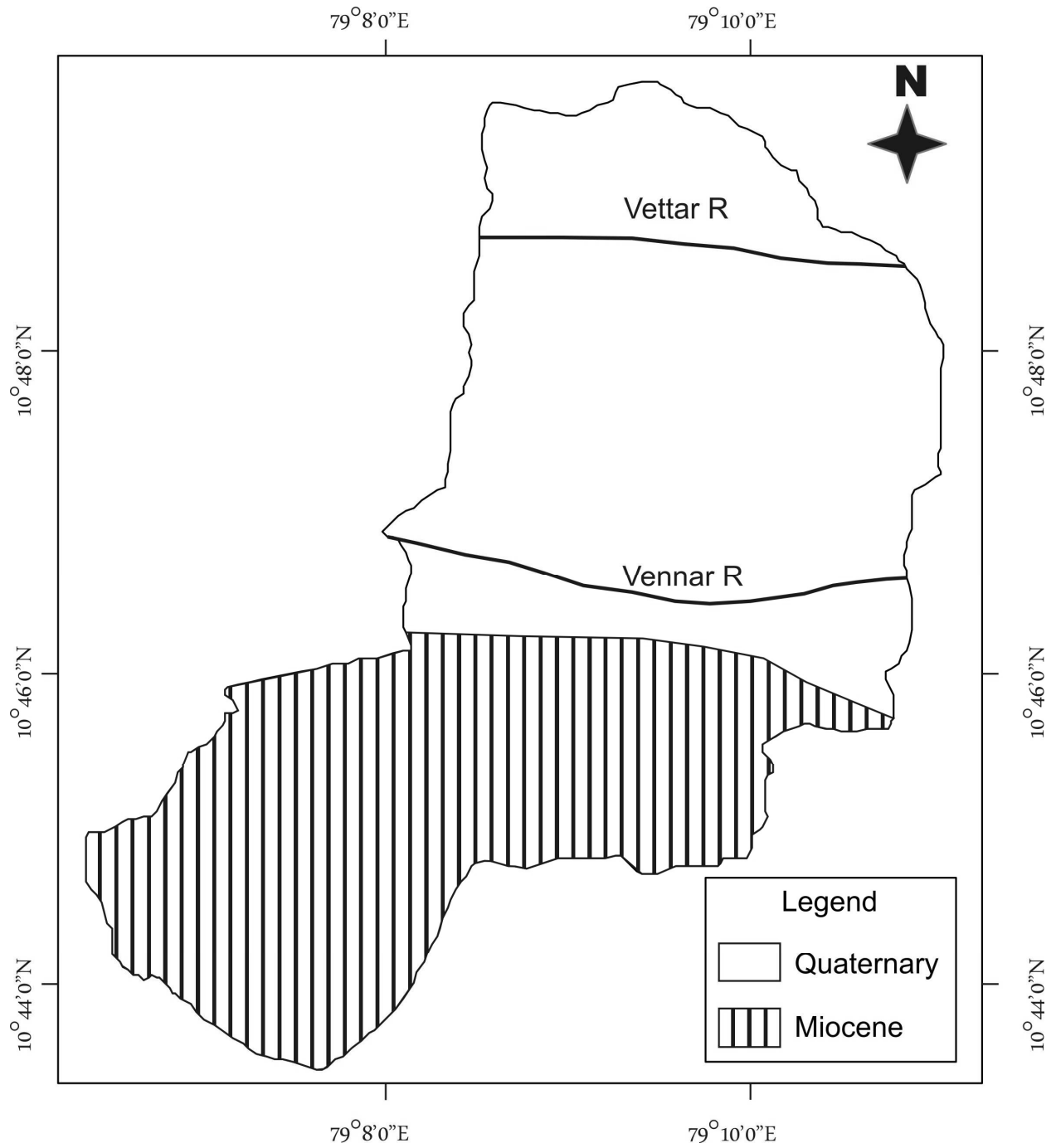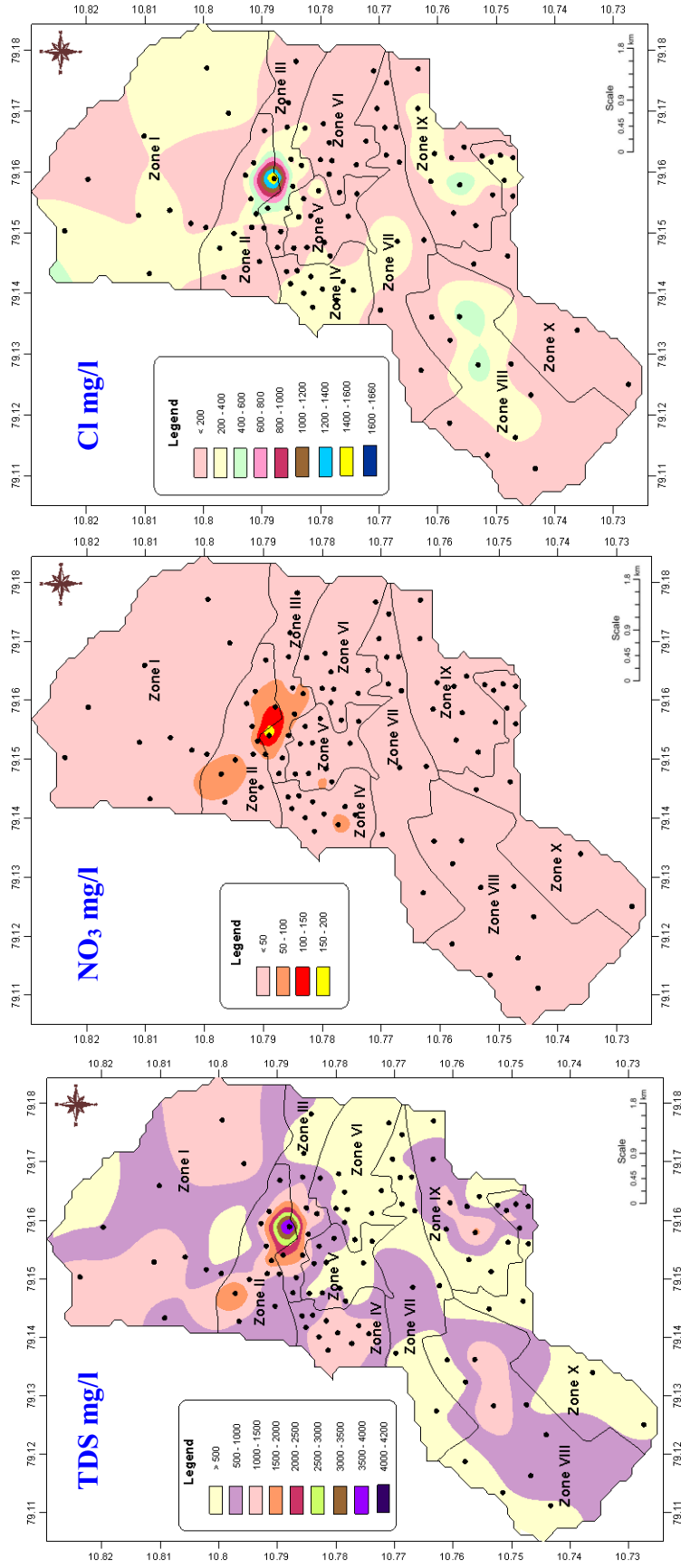
Figure 4
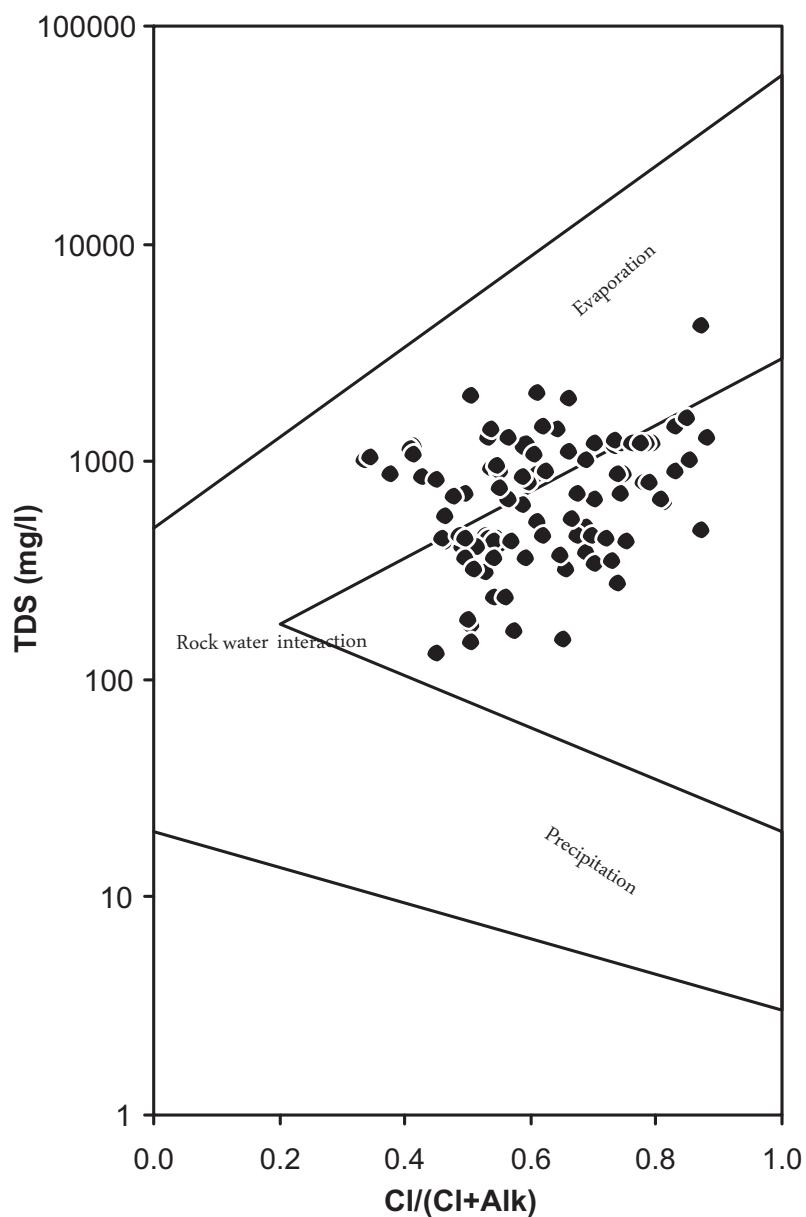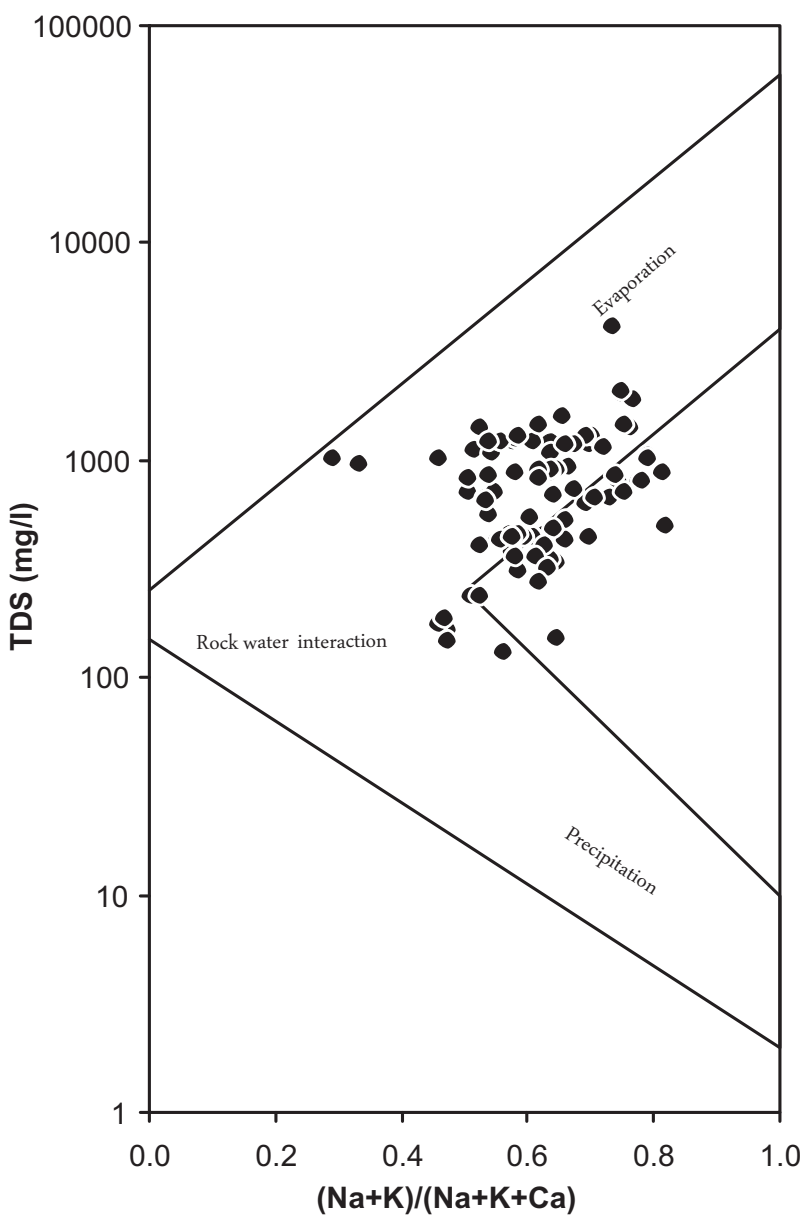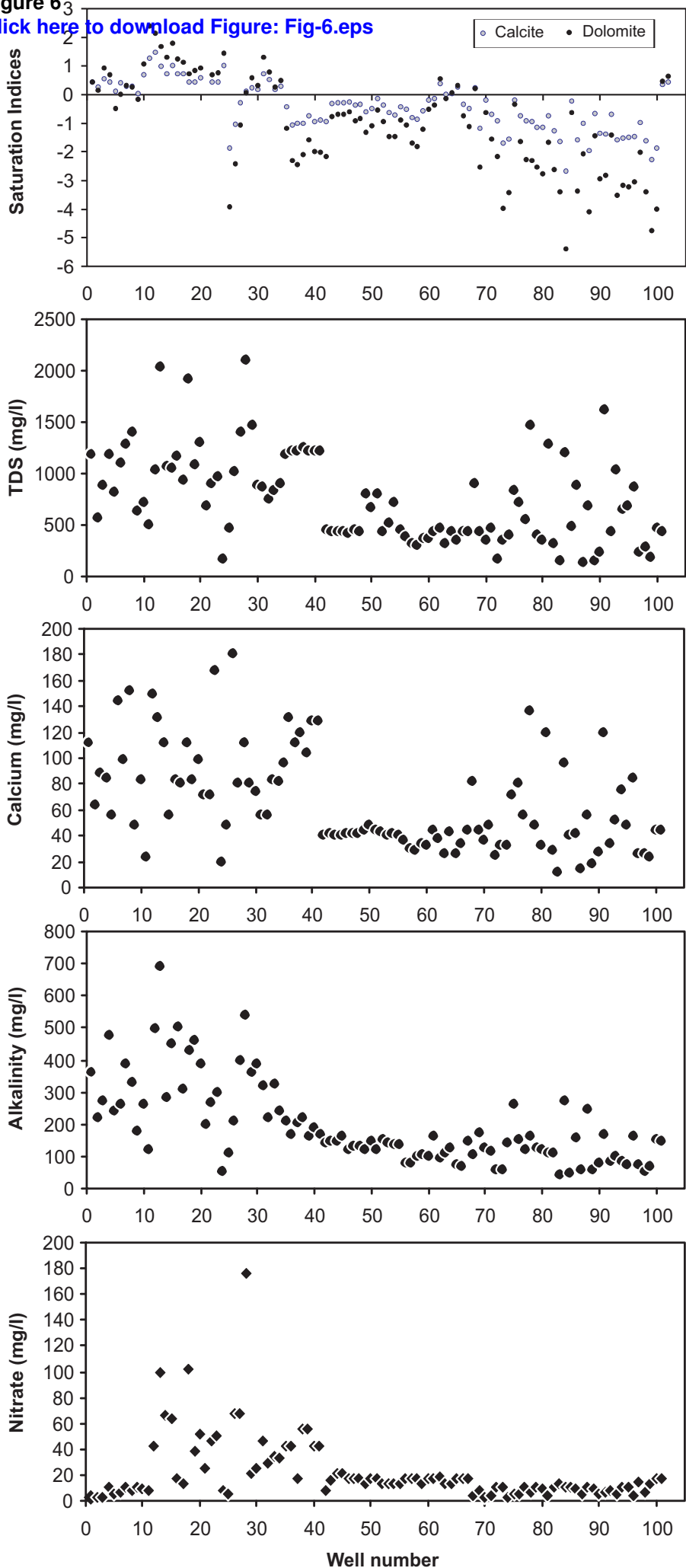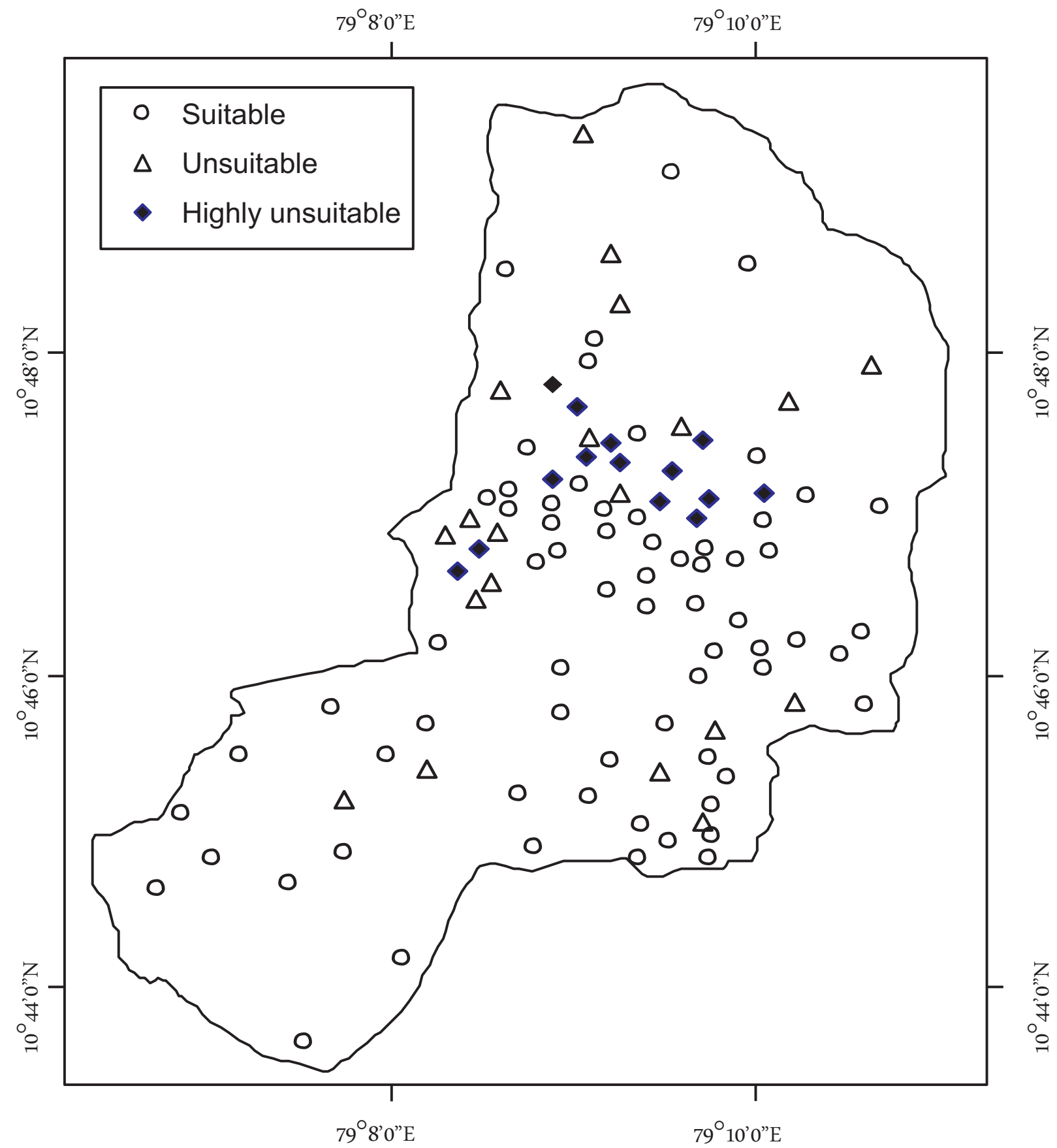**Click here to download Figure: Fig-4.eps**
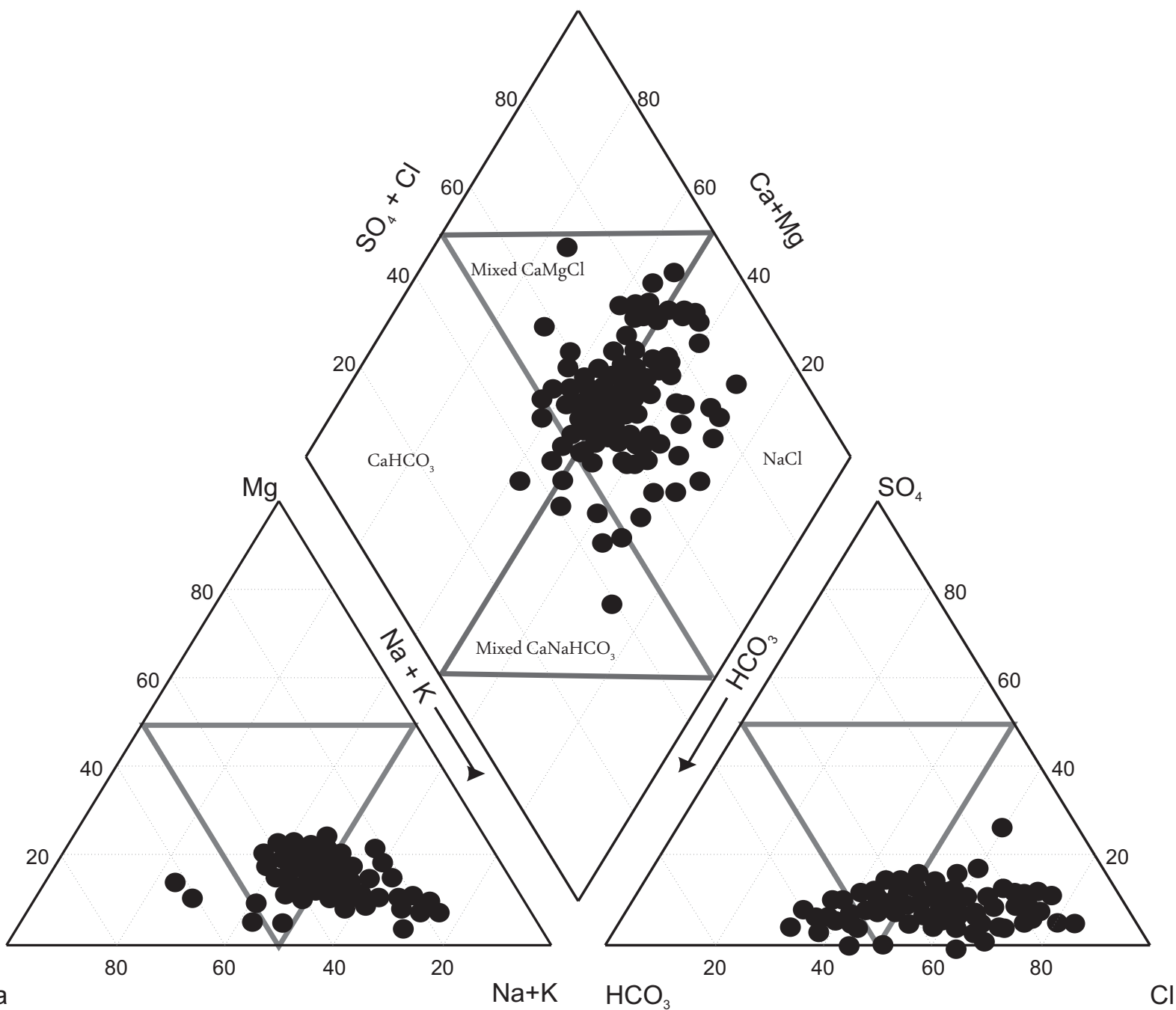
Figure 6

Click here to download Figure: Fig-6.eps
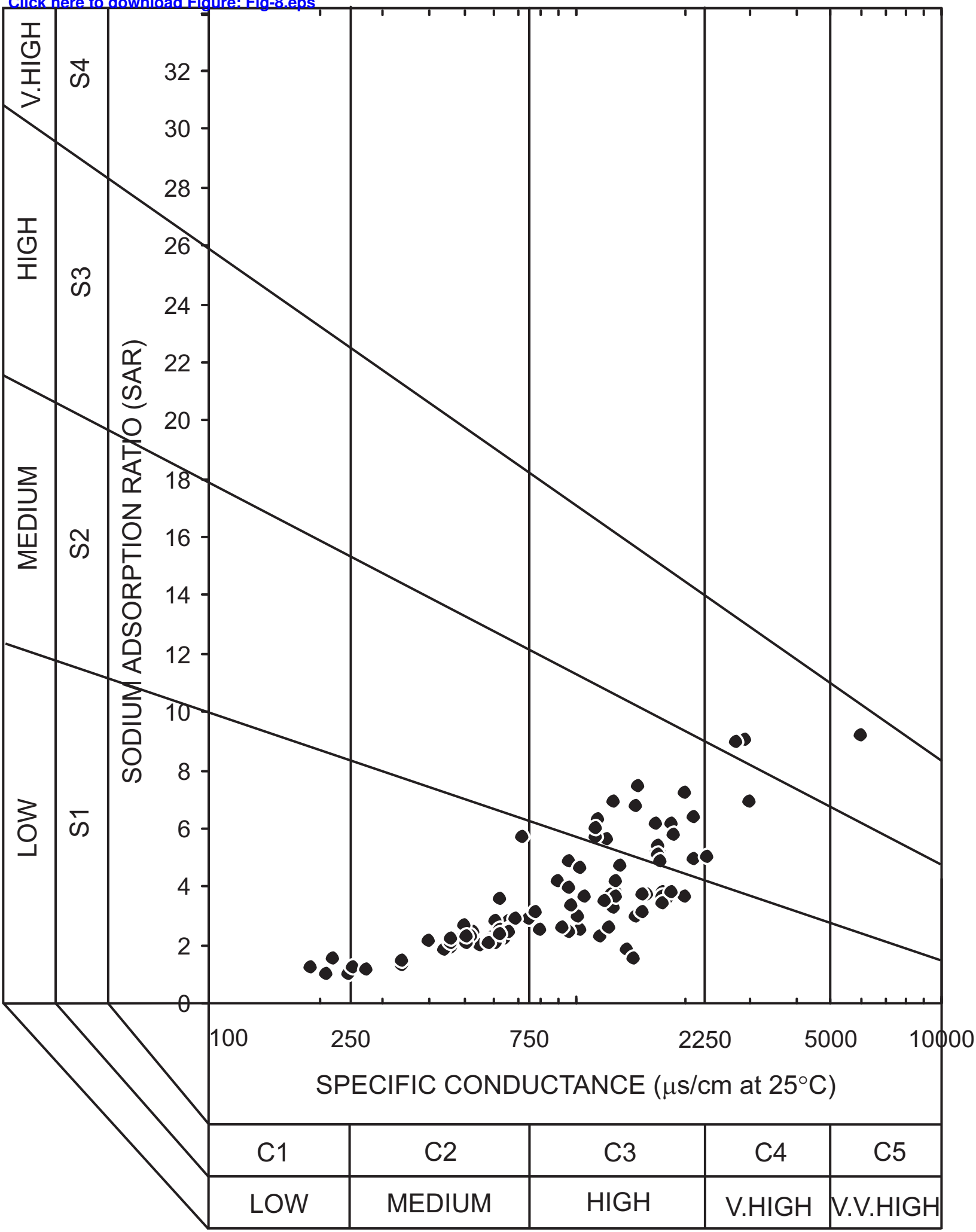
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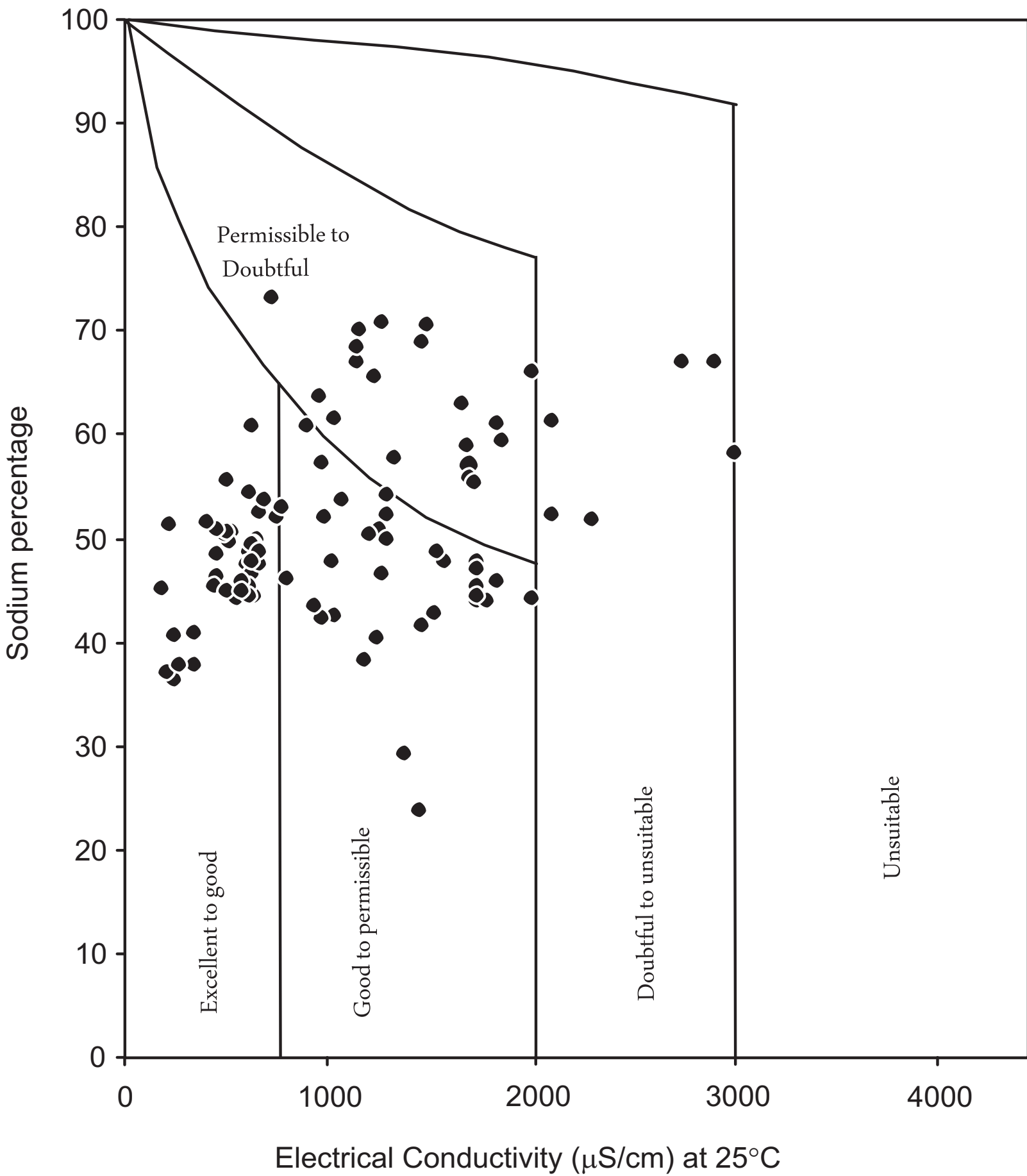Click here to download Figure: Fig-8.eps

Figure 8

Electrical Conductivity (μS/cm) at 25°C