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Spatial interpolation techniques for the determination of utility of groundwater in Perambalur district, Tamil Nadu, India

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Abstract

Water is the main source for domestic, engineering, industrial, agricultural and this multipurpose uses affects the surface as well as the groundwater quality. The study area falls within the semiarid region and frequently facing water scarcity and quality problems. The present study generates the primary data to map the spatial variation of groundwater quality in hard rock terrain of Perambalur district. 42 groundwater samples were collected from different bore wells and major cations and anions. The spatial variations of all the physiochemical parameters are generated from the major ions data by using spatial interpolation method of MapInfo 8.5 software. These maps are further classified according to highest desirable, maximum permissible and not permissible prescribed based upon WHO 2011, standard for drinking water. It was observed that the groundwater in the area is hard and alkaline in nature. The study findings also suggest that, the groundwater is of good quality for drinking and is suitable for domestic usage.

Keywords: Groundwater geochemistry, Interpolation, Physiochemical parameters, Perambalur

Introduction

Groundwater quality is mainly affected by the geological formations that the water passes through its course and anthropogenic activities (Kelepertsis, 2000; Siegel 2002; Stamatis, 2010; Sullivan *et al.* 2005, Khadri and Kanak Moharir 2014) [17, 25, 26, 28, 19]. Groundwater pollution occurs when used water is returned to the hydrological cycle. The quality of groundwater in a particular region depends on various chemical constituents present and their concentration. Generally, the quality of groundwater depends on the composition of recharge water, the interaction between the water and the soil, the soil-gas interaction, the rock with which it comes into contact in the unsaturated zone, the residence time, and reactions that take place within the aquifer (Freeze and Cherry 1979; Hem 1989) [10, 15]. Groundwater quality in a region is largely determined by both natural processes (dissolution and precipitation of minerals, groundwater velocity, quality of recharge water, and interaction with other types of water aquifer) and anthropogenic activities (Andrade *et al.* 2008) [1]. The natural chemical quality of groundwater is generally good, but elevated concentrations of a number of constituents can cause problems for water use. The geochemistry of groundwater data gives crucial evidence of the geologic history of rocks and indications of groundwater recharge, movement, and storage (Walton 1970) [33]. The hydrochemical study reveals the quality of water that is suitable for drinking, agriculture and industrial purposes and helps in understanding the change in quality due to rock-water interaction or any type of anthropogenic influence (Kelley 1940; Wilcox 1948) [18, 36]. The chemical parameters of groundwater play a significant role in classifying and assessing water quality. It was observed that the criteria used in the classification of waters for a particular purpose considering the individual concentration may not find its suitability for other purposes and better results can be obtained only by considering the combined chemistry of all the ions rather than individual or paired ionic characters (Handa 1964, 1965; Hem 1985) [13, 14]. Many researchers across the globe (Babiker *et al.*, 2007; Vennila *et al.*, 2008; Shomar *et al.*, 2010, Khadri and Chaitanya Pande (2015), Khadri and Kanak Moharir (2015) [3, 32, 24, 20, 21] have

carried out studies with spatial technologies and interpreted the quality of groundwater. But localized attempt to study groundwater quality is still lacking. This paper mainly concentrates on the chemical composition of the groundwater and investigates the possible geogenic and anthropogenic sources for chemical solutes of groundwater. Furthermore, the present study also attempts to determine the spatial variation of groundwater quality by using interpolation techniques.

Study area description

Perambalur is a centrally located district of the state of Tamil Nadu, India, with a geographical extent of 1755 sq km. Perambalur falls between the latitude of 11°14' N and the longitude of 78°56' E. The area is bounded by Cuddalore district in the north, Tiruchirappalli district in the south, Thanjavur in the east and Namakkal district in the west. The district includes 121 village panchayats, four town panchayats and one municipality (pure enviro engineering pvt. Ltd. 2011). This district enjoys a typical semi arid climate with hot summers and moderately cool winters. The hottest season is from March to May. During the period the maximum temperature often exceeds 40°C. The winter season is spread over two months viz. January and February and the nights are cool and pleasant. The district generally has a high humidity. The average rainfall of this district is 908 mm/year (CGWB 2012).

Geology, hydrogeology and soil type

Geologically this district comprises of Archaean, cretaceous, tertiary and quaternary formation. Formations of upper Gondwana age are also found in a limited extent. The Archaeans consist of biotite and, hornblende gneisses, charnockites etc., Upper jurassic formations are represented by equivalents of Gondwana in small patches in parts of Perambalur taluk. The major aquifer systems in the district are constituted by (1) Basal crystalline rocks consisting mainly of Charnockites, Granites and Gneisses of Archean age and (2) Sedimentary formations ranges in age from Cretaceous to Recent. The soil is predominantly red loamy and black soil. The main crops grown in the district are Cashew, groundnut, paddy, millet and sugarcane. Cashew is the major plantation crop. At present, maize and onion (small) are produced in large quantity in Perambalur District.

Methodology

Groundwater samples were collected randomly from 42 bore wells of the study area (Fig. 1). Using clear acid-washed polythene bottles. The GARMIN GPS was used to locate the exact coordinates of the sampling location for continuous monitoring purposes. Before taking a sample, water was pumped for 10–15 min to ensure complete homogeneity. Then, it was sealed and brought to the laboratory for analysis, stored properly at 4°C, and filtered with 0.45-µm filter paper before analysis. pH, total dissolved solid (TDS) and electrical conductivity (EC) were measured in the field analyses using in electrode (Thermo Orion). The samples collected were analyzed for major cations and anions like Calcium (Ca) and magnesium (Mg) were determined titrimetrically using standard EDTA. Chloride (Cl) by standard AgNO₃ titration and bicarbonate (HCO₃) concentration were determined by acid titration of 0.02 N H₂SO₄. Sodium (Na) and potassium (K) were

determined by flame photometry (ELCO CL378). Sulphate (SO₄), phosphate (PO₄), Nitrate (NO₃) and Silicate (H₄SiO₄) by spectrophotometry (SL 171 Minispec). Fluoride determined by using Orion fluoride ion electrode model (94-09, 96-09). The analytical procedures are as suggested by the American Public Health Association (APHA 1995) [2]. The base map of the study area was prepared using the Survey of India topographic sheets and digitized using Map info software. Coordinates collected for each sampling site were imported to map info plat form for preparation of the interpolation maps. Interpolation maps were prepared using inverse distance weightage (IDW) techniques, in Mapinfo platform. Mapinfo (8.5) version with vertical mapper was used for preparing all the above described maps.

Results and discussion

The concentration of all physicochemical parameters for the groundwater samples of the study area are given in (Table 1). Compared with WHO (2011) [38]. Spatial distribution maps for all the parameters are plotted and classified according to WHO (2011) [38] standards for drinking water (Figs. 2, 3, 4, 5, 6, 7, 8, 9, 10, and 11). It has been classified into 3 categories the desirable, maximum permissible and the values exceeds maximum permissible limit are termed as not permissible (NP).

pH

pH is one of the most important operational water qualities. The acidity and alkalinity of groundwater are described by the pH of groundwater and also, pH mostly controls the quantity and chemical structure of several organic and inorganic matters dissolved in groundwater. The standards for the pH ranges from 6.5 to 8.5, and desirable limit is 6.5 (WHO 2011) [38]. Groundwater from the study area is neutral to alkaline. It was ranged between 6.7 to 8.3. Here neutralization of pH is not required because the pH in all the places of study area is within the permissible limit (WHO 2011) [38].

Electrical Conductivity (EC)

The permissible limit of electrical conductivity (EC) is 1500 µS/cm (WHO 2011) [38]. The EC for the study area ranged from 341 to 9970 µS/cm for study area, out of 42 sampling points, 20 places samples are within permissible limit (1500 µS/cm) and 6 samples comes under desirable limit (<500) and remaining samples have maximum permissible limit (Fig. 2). EC is low in some stations like sample no 10, 37 and 42 where TDS and EC values are 181, 235 and 237 mg/l and 341, 460 and 495 µS/cm respectively, Lower concentration of Total dissolved salts (TDS) influences the normal range of EC of the study area.

Total Dissolved Solids (TDS)

TDS in the groundwater vary from 181 to 2550 mg/l. Spatial distribution of TDS is categorized on the basis of highest desirable, maximum permissible and not permissible, and indicated that majority of the samples are having higher TDS which cannot be used for safe drinking purpose (Fig. 3). The NP limit of TDS is 1500 mg/l and desirable limit is 500 mg/l (WHO, 2011) [38]. The higher concentration of TDS (Not permissible) observed in eastern, SE and NE portion of the study area and a small portion in the SW part below (Fig. 3). Higher value of TDS may be due to the nature of geological formations or due to higher residence time of

groundwater with aquifer body and leaching of salts from soil and also by anthropogenic activities. The water along with domestic sewage may percolate into the groundwater, which may lead to increase in TDS values (Ward 1994)^[34].

Calcium (Ca²⁺)

Calcium concentration varies between 12-156 mg/l with an average of 60.37 mg/l. Most of the samples have Ca concentration above maximum permissible limit. The spatial distribution of calcium is shown in (Fig. 4). The NP limit of Ca²⁺ (>200mg/l) and the desirable limit of Calcium is 75 mg/l (WHO, 2011)^[38]. The samples have concentration falls in NP limit is observed in north eastern portion, and a small isolated portion NW and SW part of the study area.

Magnesium (Mg²⁺)

The spatial distribution map of Magnesium is shown in (Fig. 5). It varies from 7.20 to 76.80 mg/l in the study area. According to the WHO, 2011^[38] standard, the permissible limit of magnesium is 50 mg/l. Here most of the samples fall within the permissible limit, but along SW part, a small portion falls in NP limit Mg is higher, indicating the sources from dissolution of magnesium calcite (MgCaCO₃), gypsum (CaSiO₄) and/or dolomite (CaMg(CO₃)₂) from source rock (Garrels RM 1967)^[11]. Mg²⁺ exceeds the permissible limit in some location and may be due to weathering from silicate-rich rocks and leaching from soil due to infiltration of anthropogenic activities. Further the exceeding limit of Mg²⁺, it reduces the soil fertility which causes impact on agricultural activity.

Sodium (Na⁺)

Sodium in the groundwater ranges from 6.4 to 606 mg/l. Out of 42 samples, 22 samples fall within desirable limit and 19 samples comes under permissible category. spatial distribution map indicates the higher values are noted in a small portion of northern part of the study area. The NP limit of Sodium is >200 mg/l which is observed in location number 1, but there is much anomaly observed in the locations near to the agricultural area, may be due to contamination from a septic system, sewage and agricultural runoff that can leach and enter into the groundwater (Fig. 6). Excess of sodium in drinking water may be harmful to persons which causes cardiac, renal, and circulatory diseases (CPCB 2008)^[8].

Potassium (K⁺)

Potassium in many respects is similar to sodium. In ground water, potassium is released due to weathering of igneous rocks rich in orthoclase, microcline and biotite etc. The Potassium value in study area ranges between 0.10 to 48.10 mg/l. the desirable limit of K⁺ is 10 mg/l and the permissible limit is 12 mg/l (WHO, 2011)^[38]. spatial distribution map (Fig. 7) indicates that higher value noted towards the southeastern part and also in a small patch along the north western part of the study area.

Chloride (Cl⁻)

The concentration of Chloride varies between 17-771 mg/l. The desirable and permissible limit of chloride is 75 and 250 mg/l (WHO, 2011)^[38]. The maximum amount of chloride (771 mg/l) is present in northern part of the area (location no 1) (Fig. 1). Chloride is higher due to industrial, domestic wastages and leaching from upper soil layers in dry

climates. However, chloride concentrations in excess of about 250 mg/l can give rise to a detectable taste in water (WHO 2004; Sawyer and McCarty 1978)^[35, 23]. High chloride concentration causes heart and kidney problems and may be injurious to some people suffering from diseases of the heart and kidneys. Taste, indigestion, corrosion, and palatability are affected (CPCB 2008)^[8]. Chloride in excess imparts a salty taste to water, and people who are not accustomed to high chloride can be subjected to laxative effects. Sample 1 located in the north portion of the study area recorded as the highest value of 771.04 mg/l of chloride lower values are located in the southeastern part of the area as illustrated in (Fig. 8).

Bicarbonate (HCO₃⁻)

Figure 9 showed that the spatial distribution of HCO₃⁻ in the study area. The HCO₃⁻ in this area ranges from 84 to 420 mg/l for (Table. 1). The permissible limit of HCO₃⁻ is 500 mg/l and desirable limit is 200 mg/l (WHO, 2011)^[38]. It is observed that almost all the samples are within the limit except locations 12, 13, 24.

Nitrate (NO₃⁻)

Nitrate concentration of the study area varies between 0.1-112 mg/l. 30.95% of the samples are having nitrate concentration above 45 mg/l. Higher Nitrate may be from the sources of plant nutrient leaching and application of nitrate fertilizers. The spatial distribution of nitrate is shown in (Fig. 10). The effect of precipitation followed by dissolution of fertilizers remains, which is known to be highly soluble and mobile (Freeze and Cherry 1979)^[10] may results high concentration of nitrates. High concentration (>45 mg/l) of nitrate causes infant methaemoglobinaemia (blue babies) and also gastric cancer which adversely affects CNS and cardiovascular system (CPCB 2008)^[8].

Sulphate (SO₄²⁻)

Sulphate concentration is found to vary between 0.36-40 mg/l with an average of 2.92 mg/l. The concentration above 500 mg/l will affect human health. The sulphate value for all the samples are found to be within the maximum permissible limits. The lesser concentration may be due to its lesser breaking down of organic substances from weathered soil/water. The spatial distribution of sulphate concentration is shown in (Fig. 11).

Gibb's Diagram

Three important natural mechanisms are controlling the major ion chemistry of the groundwater like atmospheric precipitation, rock weathering and evaporation which were plotted by Gibbs present two plots, 1) TDS versus Cl/(Cl+HCO₃) and 2) TDS versus (Na+K)/(Na+K+Ca) (Fig. 12). From these Gibbs plot, it could be confirm that the chief mechanism which is controlling the chemistry of ground water is weathering which is the leading chemical process in the study area. Weathering of rocks of different origin produces various combinations of cations and anions in the groundwater (Garrels and Mackenzie, 1967)^[11]. The study area is mainly dominated by rock water interaction and some locations also fall in evaporation zone. This diagram strongly favors the concentration of ions from rock water interaction. Hence the present amount of ionic concentration mainly from the subsurface formation such as

clay, sandy clay, sand, shale by realizing element into the groundwater.

Irrigational suitability

In US Salinity Laboratory (USSL) plot most of the samples fall in C3S1 and C2S1 (Fig. 6). The C3 category is identified to high salinity hazard, C2 medium salinity hazard and S1 category is indicates the low sodium hazard. This category is predominant in the study area and is suitable for irrigations purposes. Two samples fall in C4S1 and C4S2 category (Fig. 13) indicating water with very high salinity and high/medium sodium adsorption ratio. These waters can be used to irrigate salt tolerant and semi-tolerant crops under favorable drainage conditions.

Permeability index is an important factor which influences the quality of irrigation water, in relation to soil for development in agriculture.

$$PI = Na + HCO_3 / (Ca + Mg + Na) * 100$$

Where the concentrations are reported in meq/l.

According to PI, water can be classified as Class I, II and III. Class I and II water are categorized as good for irrigation with 75% or more maximum permeability. Class

III water is unsuitable with 25% maximum permeability. About 96% of samples fall in Class I and Class II categories, indicating that the water is good for irrigation purpose (Fig. 14).

Na% classification, most of the samples fall within “permissible” to “excellent” limit with minor representations in good to doubtful category (Wilcox 1955) [37] (Table.2). According to Eaton, 1950 classification of groundwater for irrigation purposes, majority of the samples (88%) grouped in safe zone and minor representations are falling in unsafe zone. In SAR classification (Richards, 1954) [22], all the samples grouped in excellent category except one sample which is the representation of good category. The Scholler water type indicates that all the samples fall in Type I class.

According to Wilcox, 1950 classification for EC most of the samples (73%) fall in permissible category and remaining 27% of samples fall in good, doubtful and unsuitable range. According Stuyfzand, (1989) [27], classification for chloride majority of samples grouped in fresh to fresh brackish category, indicating the usage of the water for agricultural activities.

Table 1: Showing Ionic Concentration in mg/l except pH and EC (µs/cm)

Parameters	Minimum	Maximum	Average	WHO Standard (2011)
pH (on scale)	6.70	8.38	7.36	6.5-8.5
EC (µs/cm)	341	9970	1834.83	1500
TDS (mg/l)	181	2550	642.83	500
HCO ₃ (mg/l)	84	420	231.05	500
Cl (mg/l)	17.73	771.04	180.18	250
SO ₄ (mg/l)	0.36	40	2.92	250
PO ₄ (mg/l)	0	0.61	0.04	-
NO ₃ (mg/l)	0.87	180.72	46.40	45
Ca ²⁺ (mg/l)	12	156	60.37	75
Mg ²⁺ (mg/l)	7.20	76.80	32.14	50
Na ⁺ (mg/l)	6.40	606	85.12	200
K ⁺ (mg/l)	0.10	48.10	5.27	12

Table 2: Summary of geochemical classification by WATCLAST Program (after Chidambaram *et al.*, 2003)

Category	Grade	No of Samples	% of Samples	Category	Grade	No of Samples	% of Samples
Na% Wilcox (1955)				USGS Hardness			
Excellent	0-20	15	36	Soft	<75	0	
Good	20-40	6	14	Slightly Hard	75-150	6	14
Permissible	40-60	16	38	Moderately Hard	150-300	19	45
Doubtful	60-80	4	10	Very Hard	>300	17	41
Unsuitable	>80	1	2	IBE Schoeller (1965)			
Na% Eaton (1950)				(Na+k)rock->Ca/Mg g.w.		15	36
Safe	<60	37	88	(Na+k)g.w.->Ca/Mg rock		27	64
Unsafe	>60	5	12	Schoeller Classification (1967)			
S.A.R. Richards (1954)				Type I		42	100
Excellent	0-10	41	98	Type II		0	
Good	Oct-18	1	2	Type III		0	
Fair	18-26	0		Type IV		0	
Poor	>26	0		Corrosivity Ratio (1990)			
R.S.C. Richards(1954)				Safe	<1	20	48
Good	<1.25	39	93	Unsafe	>1	22	52
Medium	1.25-2.5	3	7	Chloride Classification (Stuyfzand,1989)			
Bad	>2.5	0		Extremely fresh	<0.14	0	
EC Wilcox (1955)				Very fresh	0.14-0.84	1	2
Excellent	<250	0		Fresh	0.84-4.23	18	43
Good	250-750	5	12	Fresh Brackish	4.23-8.46	18	43
Permissible	750-2250	31	73	Brackish	8.46-28.21	5	12
Doubtful	2250-5000	4	10	Brackish-salt	28.21-282.1	0	
Unsuitable	>5000	2	5	Salt	282.1-564.1	0	
				Hyperhaline	>564.1	0	

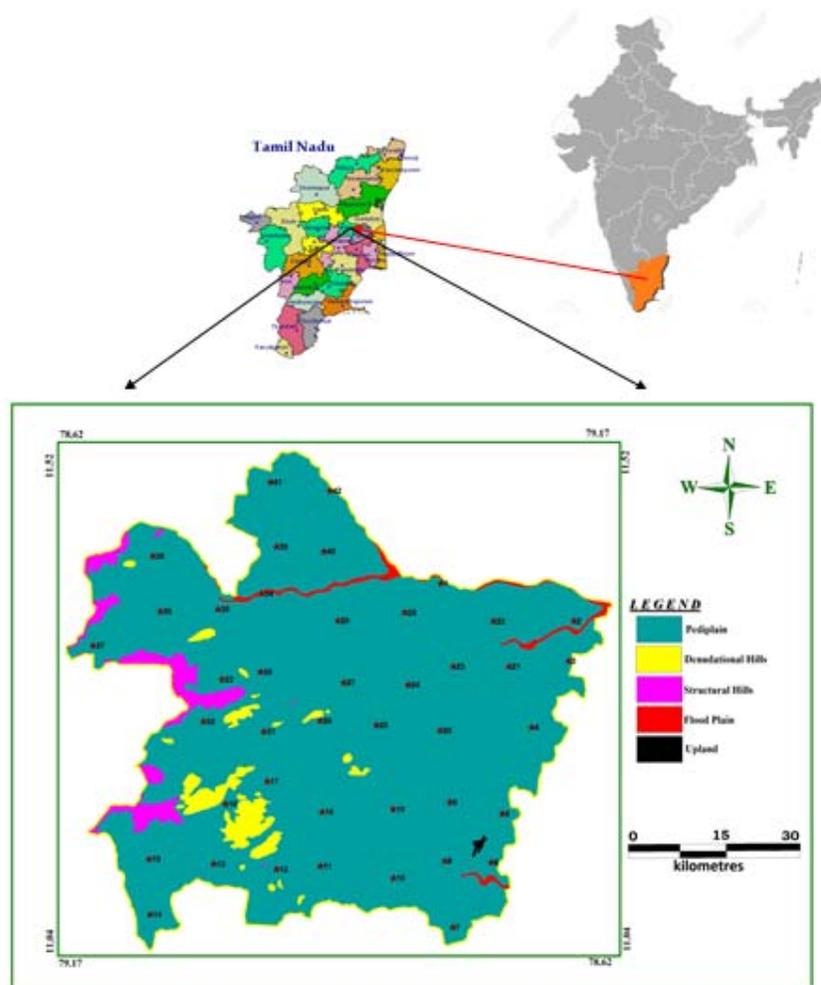


Fig 1: Geomorphology with location map of the study area

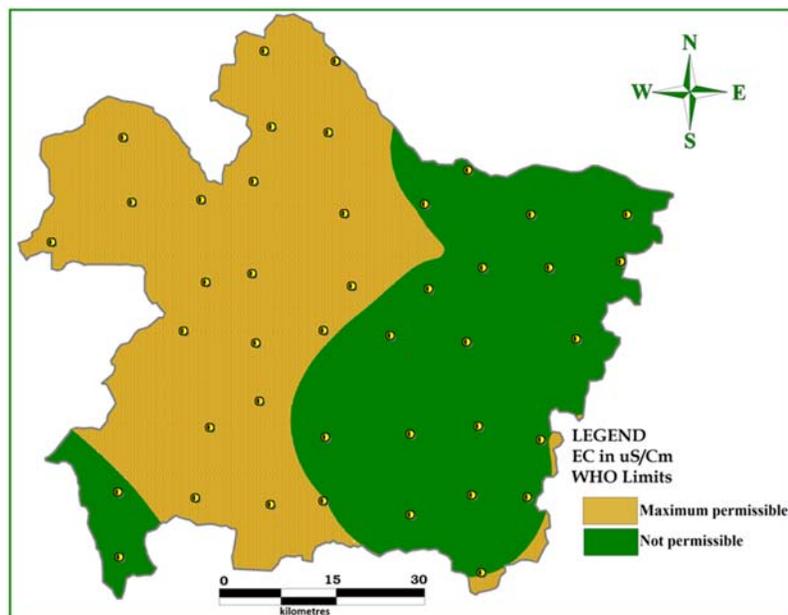


Fig 2: Spatial distribution of electrical conductivity

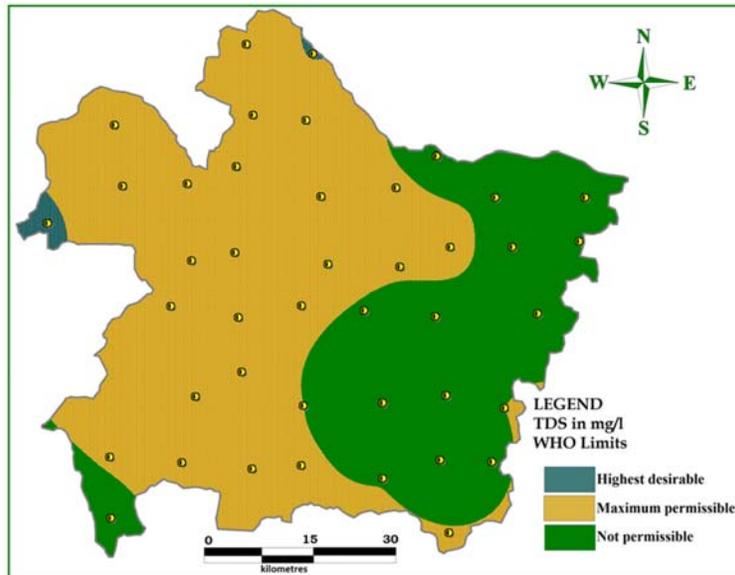


Fig 3: Spatial distribution of Total dissolved solids

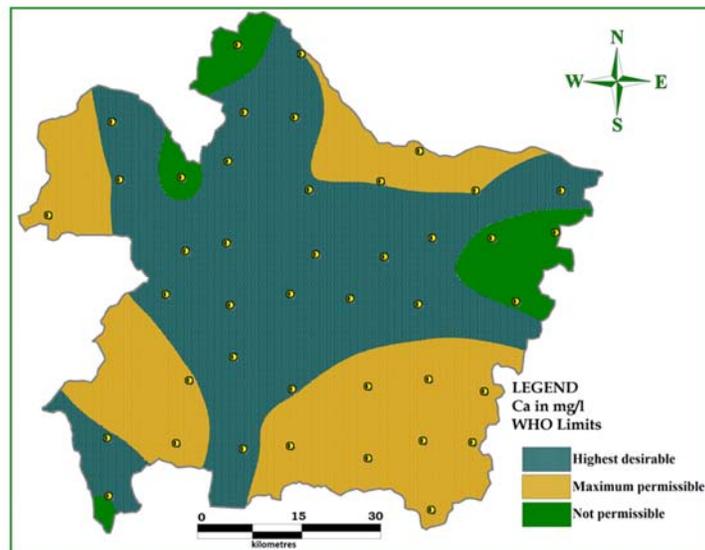


Fig 4: Spatial distribution of Calcium

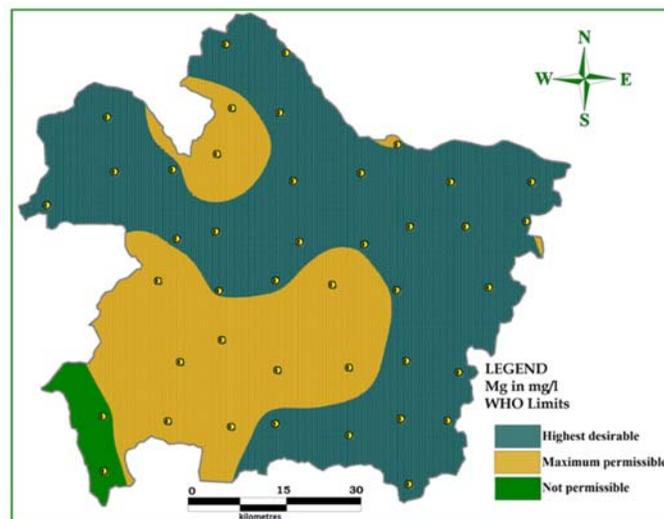


Fig 5: Spatial distribution of Magnesium

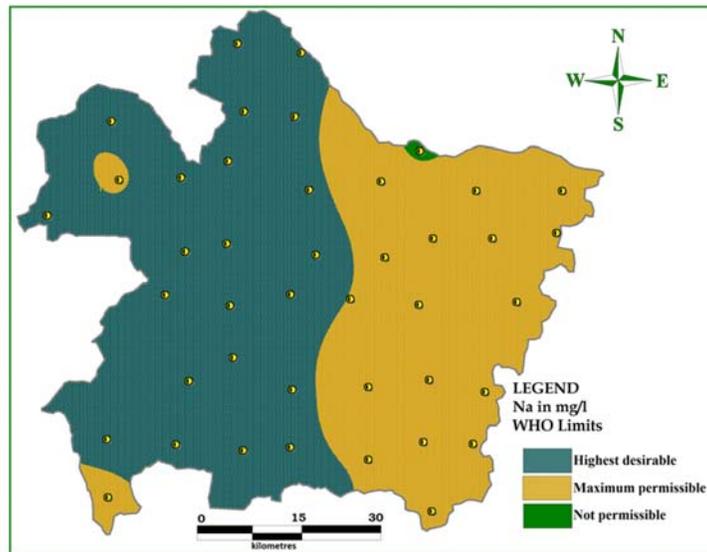


Fig 6: Spatial distribution of Sodium

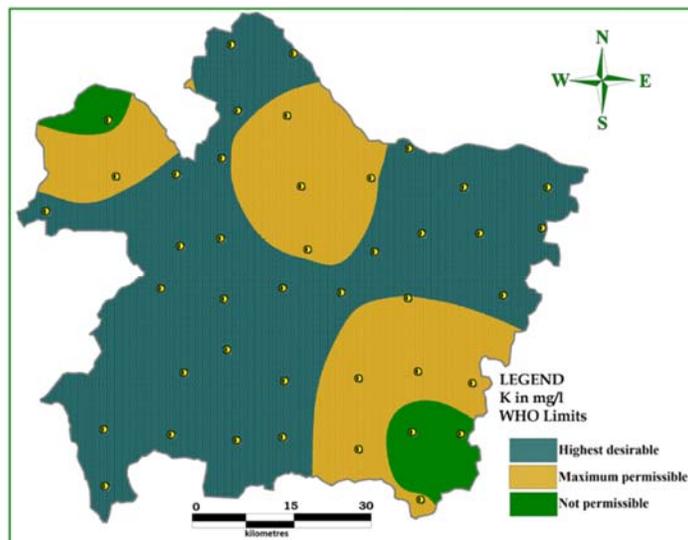


Fig 7: Spatial distribution of Potassium

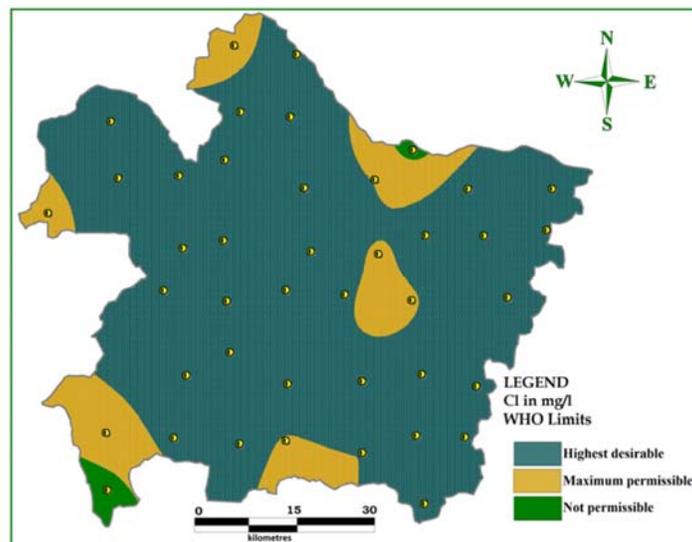


Fig 8: Spatial distribution of Chloride

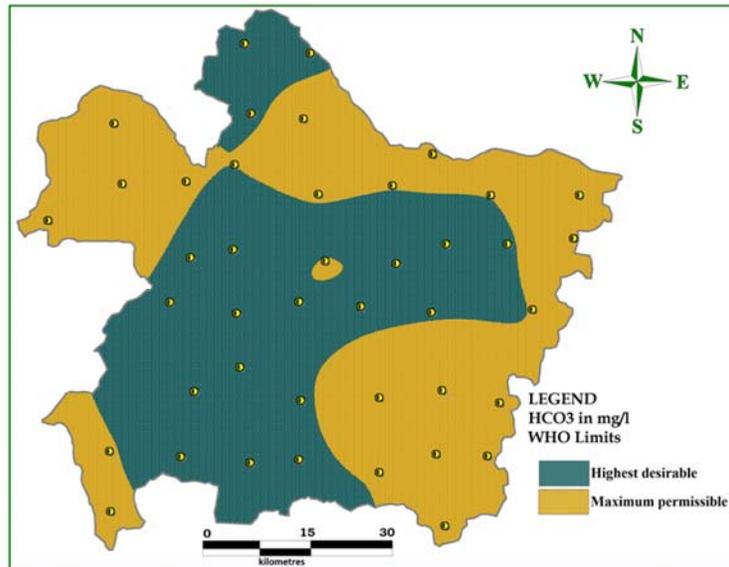


Fig 9: Spatial distribution of Bicarbonate

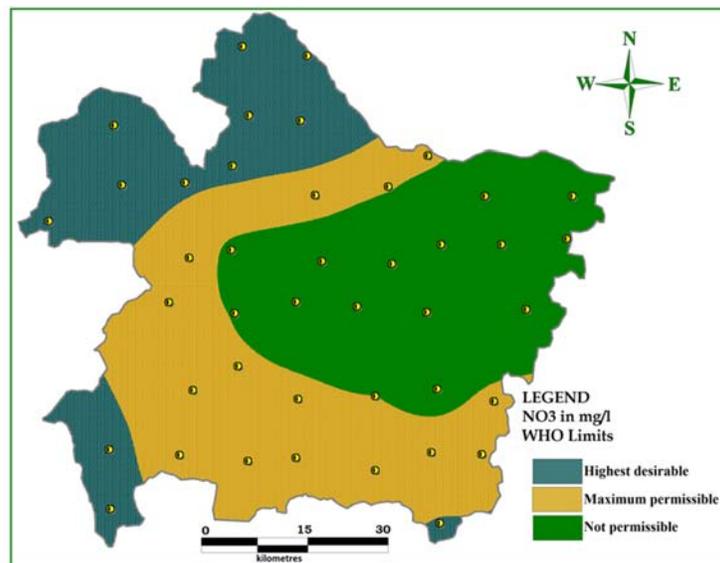


Fig 10: Spatial distribution of Nitrate

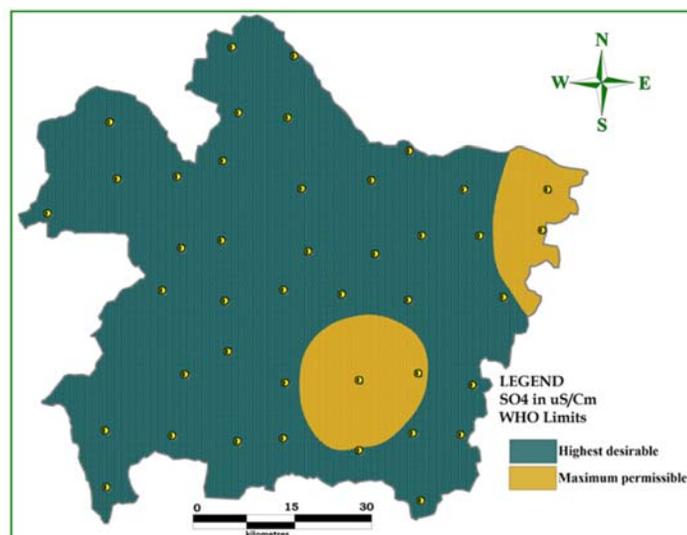


Fig 11: Spatial distribution of Sulphate

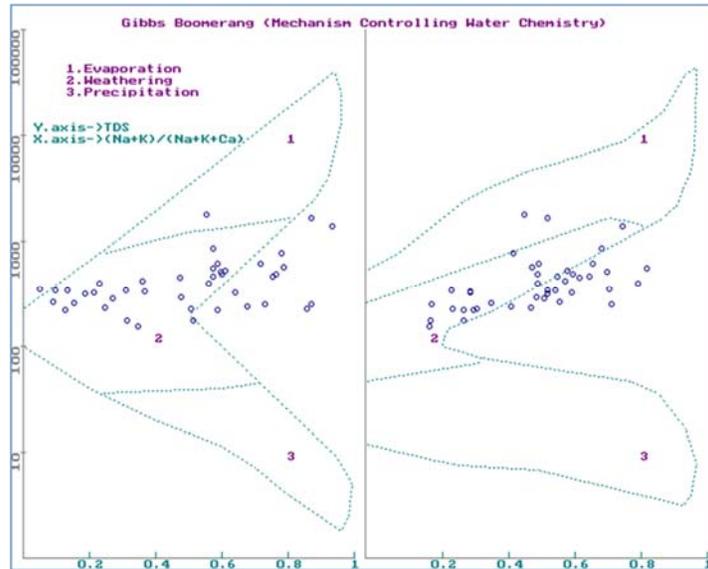


Fig 12: Gibbs plot for the groundwater samples (after Gibbs, 1970)

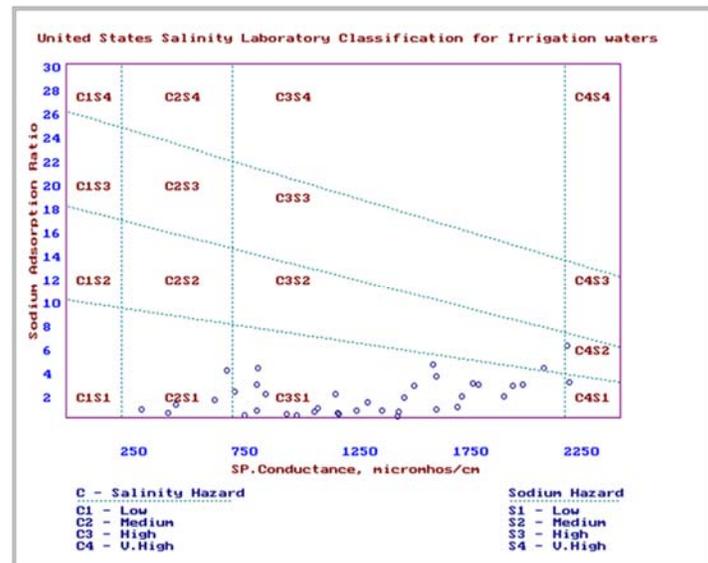


Fig 13: USSL plot for identification of irrigation suitability of water

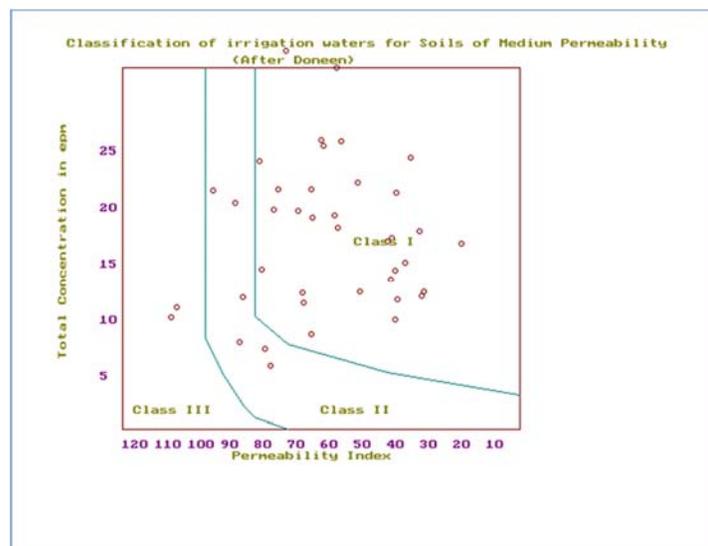


Fig 14: Permeability Index

Conclusion

Spatial analysis using interpolation technique has been proven to be a powerful tool to represent the distribution of major ions in the study area. These methods have successfully identify the ground water quality of perambalur district. The spatial and time variant changes of groundwater quality are assessed through graphical representations. The present study reveals that the influence of geological (geogenic) conditions is found to be more than that of anthropogenic activities and supports the increasing concentration of physico-chemical characteristics in groundwater. The chemistry of groundwater flowing in hard rock terrain is mainly controlled by the rock-water interaction mechanisms. The total dissolved solids are expected to increase along the length of the flow path and also with the time of residence. Groundwater is a major environmental parameter; its quality degradation is an issue of significant societal and environmental concern. About 62% of TDS concentration in groundwater samples of the study area exceeds the maximum permissible limit. Only 52% of the study area was distributed with groundwater within the permissible limit of EC concentration. The spatial distribution map of Chloride concentration illustrates that only 81% of the groundwater samples contain Chlorides within the limit. The chloride ion in certain areas reflects greater residence time of groundwater. Thus spatial distribution maps of various quality parameters are used to demarcate the locational distribution of water quality in a comprehensive manner and help in suggesting the groundwater suitable for domestic purposes. Potassium and Sulphate concentration of all the samples was found to be within permissible limits. 11 samples are having ca above maximum permissible limit and 13 samples exceed maximum permissible nitrate concentration. Based on the study, it was found that most of the samples are suitable for irrigation purpose. Based on Sodium Absorption Ratio value, Percent sodium value and Residual Sodium Carbonate value, the groundwater in the study area is suitable for irrigation purpose. Considering all the chemical parameters it can be concluded that, good water is found along southwestern, northwestern and central part of the study area.

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