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HYDROGEOLOGY

Hydrochemical characteristics of groundwater for domestic and irrigation purposes in Madhuranthakam, Tamil Nadu, India

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ABSTRACT

Hydrochemical study was carried out in Madhuranthakam located near Chennai in Tamil Nadu, India with an objective of understanding the suitability of local groundwater quality for domestic and irrigation purposes. Twenty groundwater samples were collected in February 2002 and analysed for physical and chemical parameters. Groundwater in this area was found to be within the desirable Bureau of Indian Standards and World Health Organisation limits for drinking water. Ca-HCO_3 was the dominant groundwater type. Groundwater in this area was assessed for irrigation purposes on the basis of sodium percentage (Na%), magnesium hazard (MH), residual sodium carbonate (RSC), sodium absorption ratio (SAR), permeability index (PI) and United States Department of Agriculture (USDA) classification. Most of the groundwater samples were suitable for irrigation, except in a few locations (15%) based on MH. Overall the groundwater quality was suitable for drinking and domestic purposes and permissible for irrigation activities.

Keywords: Groundwater, Madhuranthakam, drinking water quality, irrigation water quality, Tamil Nadu, India.

RESUMEN

Un estudio Hidroquímico fue llevado en la localidad Madhuranthakam cerca Chennai en Tamil Nadu, India, con el propósito de evaluar la calidad de las aguas subterráneas locales para usos domésticos y fines de riego. Veinte muestras de agua subterránea fueron recogidas y analizadas en términos de parámetros físicos y químicos en Febrero 2002. Las aguas subterráneas en esta área fueron encontradas aptas como potables según los limites sugeridos por el Consejo de Estándares de India y los límites permisibles por la Organización Mundial de la Salud para el agua potable. Ca-HCO_3 es dominante en las aguas subterráneas. Las aguas subterráneas en esta área fueron asignadas para propósitos de riego sobre la base del porcentaje de sodio (Na%), magnesio peligroso (MH), carbonato sodico residual (RSC), proporción de absorción de sodio (SAR), índice permeabilidad (PI) y la clasificación del Departamento de Agricultura de los Estados Unidos (USDA). La mayoría de las muestras de las aguas subterráneas son aptas para el riego, excepto en unas pocas ubicaciones (15%), basadas sobre MH. En general, la calidad del agua subterránea fue apta para el consumo, uso doméstico y permisible para las actividades de riego.

Palabras claves: Agua Subterraneas, Madhuranthakam, calidad de agua potable, calidad de agua de riego, Tamil Nadu, India.

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Introduction

Groundwater is a precious source of fresh water, being the most distributed form on the earth, excluding the polar icecaps and glaciers. Groundwater studies are gaining more importance in the present day as it is used for almost all purposes such as domestic, industrial and agricultural activities in most parts of the world. Improper management of this replenishable resource may lead to groundwater contamination and scarcity. When some ions and minerals are present beyond the permissible limit, they become unsuitable for drinking and irrigation purposes, which may be due to natural and also anthropogenic causes. Groundwater quality has been given lot of importance and studied worldwide (Lahermo and Backman, 1999; Omo-Irabor *et al.*, 2008; Baalousha, 2010).

Several regions in India have encountered degradation in groundwater quality too, due to rapid urbanisation and an exponential increase in population (Ramesh and Elango, 2005; Brindha and Elango, 2010; Brindha *et al.*, 2011). The present study was carried out with the aim of understanding groundwater quality and its suitability for drinking and irrigation purposes in Madhuranthakam, located near Chennai in Tamil Nadu, India. Groundwater is the major source for domestic and irrigation practices in this area. There has been an increase in the demand for groundwater due to the growth of the local population.

Groundwater is usually put to direct use in rural areas without proper monitoring and treatment. Groundwater may also become contaminated by the agrochemical products used for irrigation. The groundwater quality in the nearby regions, namely Chennai, Kancheepuram and Chengalpet,

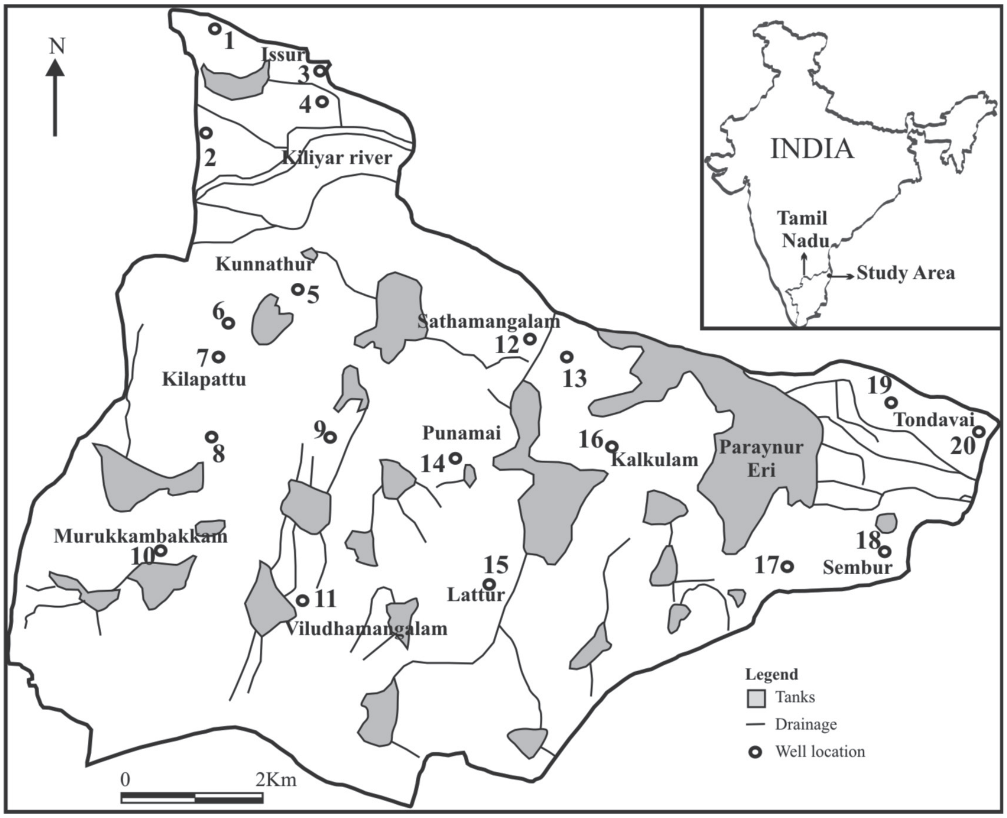

Figure 1. Location of study area and sampling wells.

has been studied earlier (Elango and Manickam, 1987; Ramesh, 1999; Rajmohan *et al.*, 2000; Elango *et al.*, 2003a; Elango *et al.*, 2003b; Kumaresan and Riyazuddin, 2006). However, no studies have been carried out in the Madhuranthakam region pertaining to groundwater quality. The suitability of groundwater for domestic and irrigation purposes thus had to be determined based on the presence of major ions in the groundwater of this region. The present study, which was carried out in 2002, will serve as baseline data for comparing future groundwater quality.

Study area

The study area is situated 76 km south of Chennai city and forms a part of Madhuranthakam taluk, Kancheepuram district, Tamil Nadu, India (Figure 1). Most of the annual rainfall of 1,206 mm is received from October to December and the rest during the southwest monsoon season from June to September. Climatic condition in the study area varies from 39°C to 40°C during summer (April to June) and 20°C to 24°C during winter (October to December). The study area is surrounded by a number of tanks which are used for drinking and agricultural purposes. This area is intensively cultivated by pumping groundwater from dug wells as well as surface water resources. Geologically this area is characterised by charnockites of Precambrian era. Outcrops of these rocks are found in many parts of the study area. Sandy clay and clayey sand overlay the charnockites with thickness ranging from 1.5 to 5m. Groundwater occurs under unconfined condition mainly in the weathered and fractured part of this charnockites in this area.

Table 1. Statistical summary of physicochemical parameters.

Parameter	Unit	Minimum	Maximum	Mean
pH	-	7.2	8.2	7.69
EC	μS/cm	200	1900	807.6
Calcium	mg/l	11.84	93.9	52.21
Magnesium	mg/l	3.65	132.46	24.37
Sodium	mg/l	27.59	82.76	50.35
Potassium	mg/l	0	2.74	1.17
Carbonate	mg/l	6	54.01	28.5
Bicarbonate	mg/l	30.51	256.27	136.9
Chloride	mg/l	20.35	32.41	21.91
Sulphate	mg/l	30.48	44.89	35.64

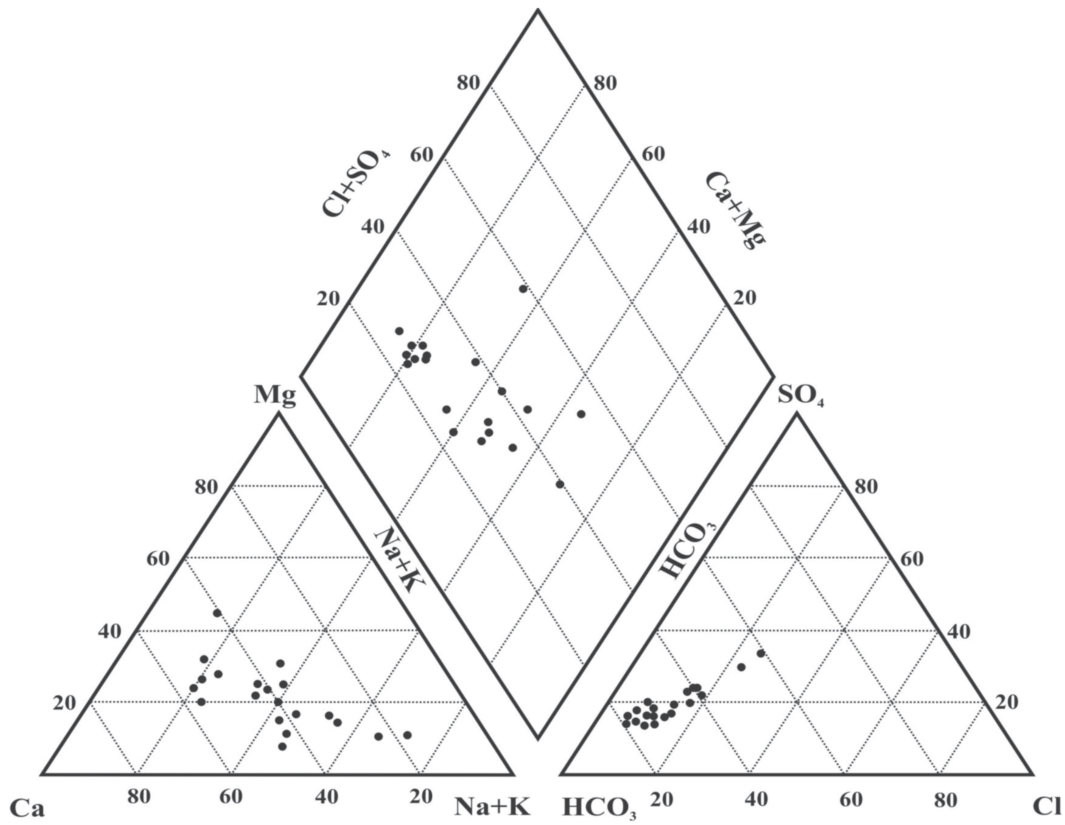

Figure 2. Groundwater type.

Sampling and analysis

A well inventory survey was carried out in February 2002 to obtain background information about the well population, lithology, well use etc. Forty-seven wells were investigated and 20 wells (Figure 1) were chosen as representative wells for groundwater sampling based on electrical conductivity (EC). The groundwater samples were collected in clean 500 ml polyethylene bottles. The sampling bottles were soaked in 1:1 diluted HCl solution for 24 hours and washed twice with distilled water before sampling. They were washed again in the field with groundwater sample filtrates.

The groundwater samples were collected from bore wells after pumping the water for about 10 minutes. Field parameters such as EC and pH were measured in the field using portable digital meters. Samples were analysed for major ions in the laboratory using the standard recommended methods (APHA, 1998). Sulphate concentration in the groundwater samples was analysed using a UV visible spectrophotometer. Sodium and potassium content was determined by using a flame photometer and calcium, magnesium, chloride, carbonate and bicarbonate by titration technique. Total ions measurement precision was checked by calculating the ion balance error (IBE). The IBE was within ±10%. Total dissolved solids (TDS) were calculated by using the formula: TDS (mg/l) = EC (μS/cm) x 0.64; total hardness (TH) was calculated by using: TH = 2.497Ca + 4.115Mg in mg/l.

Results and Discussion

Table 1 shows the maximum, minimum and mean concentrations of various parameters. The order of cation dominance was $Ca^{2+}>Na^{+}>Mg^{2+}>K^{+}$ and $HCO_3^{-}>SO_4^{2-}>CO_3^{2-}>Cl^{-}$ for anions. The general chemical nature of groundwater can be understood by plotting major cation and anion concentrations on a Piper trilinear diagram (Piper, 1944). Ca-HCO_3 was the major water type dominant in this area (Figure 2). The next dominant water type was mixed Ca-Na-HCO_3.

Drinking water quality

Groundwater used for domestic purposes, such as drinking and cooking, should be free from toxic chemicals and pathogens. Domestic water quality indicates that a particular parameter at a given concentration may be suitable for the human body beyond which it is unsuitable. The concentration of various ions in the groundwater samples was compared with Bureau of Indian standards (BIS, 2003) and World Health Organisation (WHO, 1993) standards, which are given in Table 2 wherein all the groundwater samples were found to be within the suitable limits. The groundwater in this area was thus seen to be fit for domestic consumption, based on the major ion analysis carried out in this study. The groundwater samples were classified regarding TDS and TH (Tables 3, 4 and 5). Most of the groundwater was fresh and suitable for drinking purposes based on TDS (Freeze and Cherry, 1979; Davis and DeWeist, 1966). Groundwater in this study area varies from soft to very hard (Sawyer and McCarty, 1967).

Irrigation water quality

Good quality irrigation water is essential for achieving maximum crop productivity. Groundwater suitability for irrigation purpose in this study area was assessed using sodium percentage (Na%), magnesium hazard (MH), residual sodium carbonate (RSC), sodium absorption ratio (SAR), permeability index (PI) and United States Department of Agriculture (USDA) classification. Groundwater in most of the study area was found to be suitable for irrigation.

Irrigation water having high EC content will affect root area and water flow. Groundwater in this area was grouped according to the guidelines

Table 2. Comparison of groundwater samples with BIS and WHO standards.

Parameter	BIS (2003)		WHO(1993)		Percentage of samples above maximum allowable limit
	Highest desirable limit	Maximum permissible limit	Highest desirable limit	Maximum permissible limit	
pH	6.5– 8.5	6.5 – 9.2	6.5 – 8.5	6.5 – 9.2	Nil
TH (mg/l)	300	600	100	w500	Nil
Calcium (mg/l)	75	200	75	200	Nil
Magnesium (mg/l)	30	100	50	150	Nil
Chloride (mg/l)	250	1000	200	600	Nil
Sulphate (mg/l)	150	400	200	400	Nil
Sodium (mg/l)	-	-	-	200	Nil

Table 3. Freeze and Cherry (1979) classification of groundwater based on TDS (mg/l).

TDS (mg/l)	Water type	Number of samples	Percentage
<1,000	Fresh	19	95
1,000 - 10,000	Brackish	1	5
10,000 - 1,00,000	Saline	Nil	Nil
>1,00,000	Brine	Nil	Nil

Table 4. David and DeWeist (1966) classification of groundwater based on TDS (mg/l).

TDS (mg/l)	Classification	Number of samples	Percentage
<500	Desirable for drinking	11	55
500 - 1,000	Permissible for drinking	8	40
1,000 - 3,000	Useful for irrigation	1	5
>3,000	Unfit for drinking and irrigation	Nil	Nil

Table 5. Sawyer and McCarty (1967) classification of groundwater based on TH (mg/l).

Total Hardness (mg/l)	Type of water	Number of samples	Percentage
<75	Soft	2	10
75 - 150	Moderately high	7	35
150 - 300	Hard	7	35
>300	Very Hard	4	20

Table 6. Suitability for irrigation based on USDA classification.

EC (μs/cm)	Salinity Class	Percentage of samples	Remark on quality
<250	C1	5	Excellent or low
250-750	C2	45	Good or medium
750-2250	C3	50	Permissible or high
2250-5000	C4	Nil	Unsuitable or very high

Table 7. Suitability for irrigation based on sodium percent.

% Na	Suitability for irrigation	Number of samples	Percentage
<20	Excellent	5	25
20-40	Good	7	35
40-60	Permissible	6	30
60-80	Doubtful	2	10
>80	Unsuitable	Nil	Nil

established by the United States Salinity Laboratory (Freeze and Cherry, 1979) based on EC (Table 6). This showed that groundwater in this area was permissible for irrigation. Sodium is an important parameter for irrigation water and is denoted as Na% which was calculated from the formula given in equation 1 (Wilcox, 1955) and all concentrations were expressed in meq/l.

$$Na\% = \frac{(Na^{+} + K^{+})X100}{(Ca^{2+} + Mg^{2+} + Na^{+} + K^{+})} \quad (1)$$

The Na% in this area is given in Table 7. Groundwater was suitable for irrigation in 60% of the samples while 40% were permissible to doubtful. EC and Na% are plotted in Figure 3 which showed that most of the groundwater samples were good for agriculture.

The concentration of bicarbonate and carbonate higher than calcium and magnesium will influence the suitability of water for irrigation purposes. The RSC value was computed using the following formula (equation 2) where ions were expressed in meq/l.

$$RSC = (CO_3^{2-} + HCO_3^{-}) - (Ca^{2+} + Mg^{2+}) \quad (2)$$

However, regarding RSC, all samples fall within the safe category for irrigation.

SAR is another important parameter for determining the desirability of irrigation water. The SAR values were calculated by using equation 3 (Richards, 1954),

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \quad (3)$$

where all the concentrations were given in meq/l. All the groundwater samples collected from this area were excellent on the basis of SAR. Water used for irrigation can be classified into four types- C1, C2, C3 and C4 based on salinity hazard and S1, S2, S3 and S4 based on sodium hazard. Figure 4 shows the plot of groundwater samples grouped on the above basis. Most groundwater samples fall under C1S1 and C2S1 which are suitable for irrigation. Comparatively few samples were grouped under C3S1 (which is permissible for irrigation). Thus the groundwater in this area was seen to be suitable for irrigation based on salinity hazard and sodium hazard.

MH for irrigating water was calculated using the formula MH = Mg/(Ca + Mg) x 100, where concentrations were given in meq/l (Szabolcs and Darab, 1964). MH above 50 is considered to be unsuitable for irrigation. Groundwater had an MH above 50 in 15% of the samples, thus not being fit for irrigation.

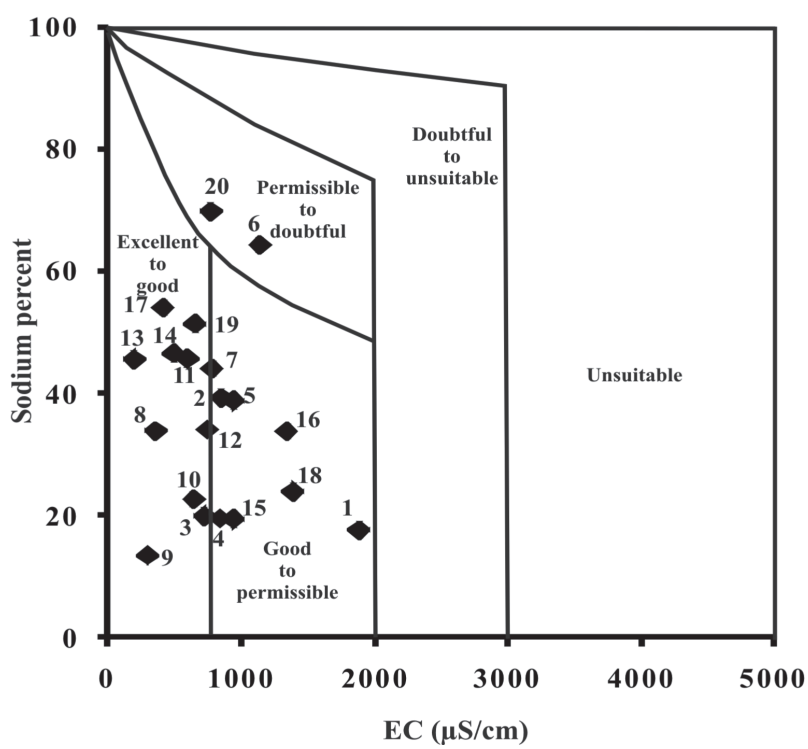

Figure 3. Suitability of irrigation water, based on EC and sodium percent.

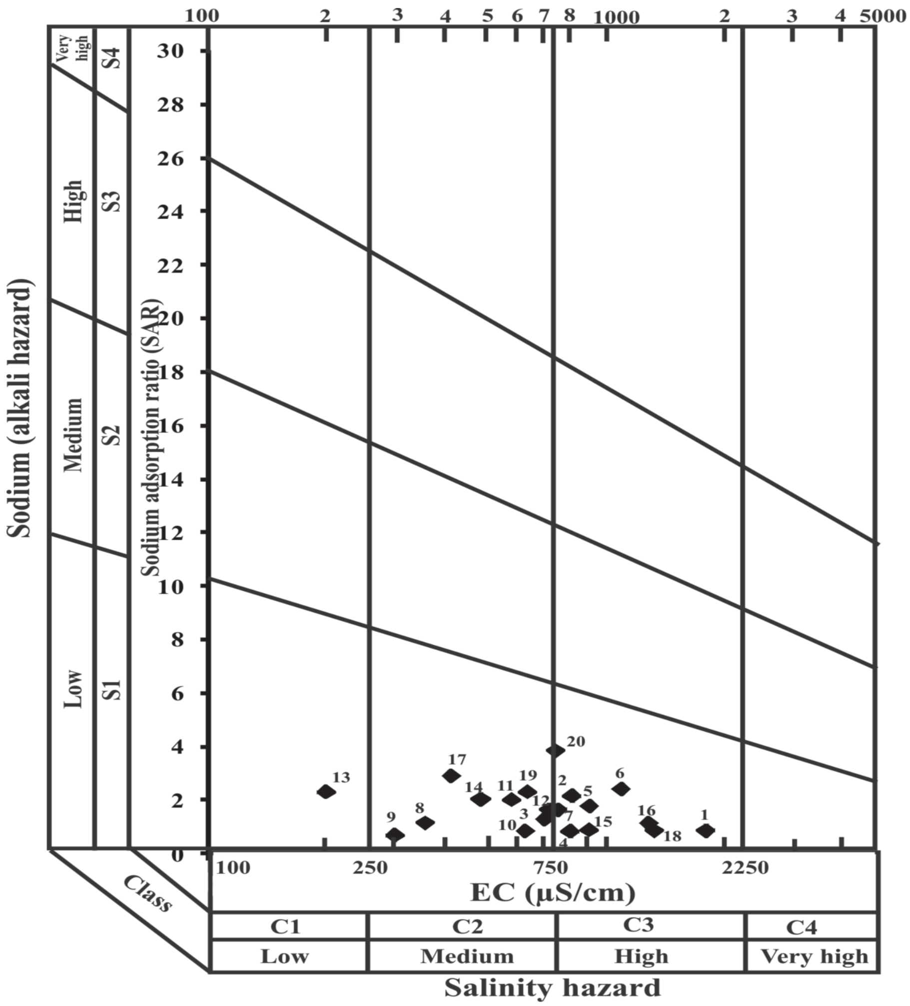

Figure 4. Irrigation water salinity and alkalinity hazard.

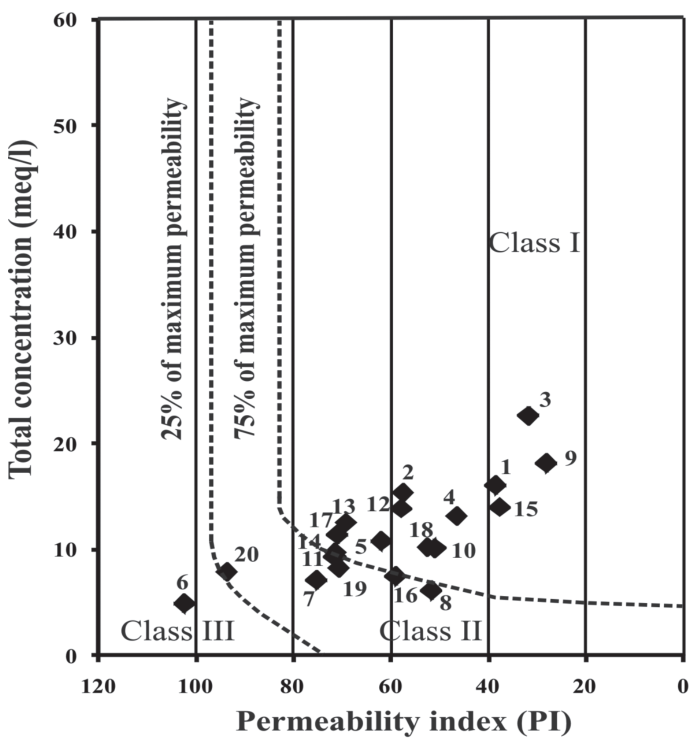

Figure 5. Classification of irrigation water based on permeability index.

The suitability of groundwater for irrigation based on PI was calculated using equation 4,

$$PI = \frac{Na^{+} + \sqrt{HCO_3^{-}}X100}{(Ca^{+} + Mg^{+} + Na^{+})} \tag{4}$$

where concentrations were in meq/l. Class I and class II waters are considered to be good and suitable for irrigation while class III water is unsuitable for irrigation (Doneen, 1964). Figure 5 shows that one groundwater sample was not suitable for irrigation based on PI whereas the rest of the samples were good. In general, the groundwater fall within the permissible category for irrigational use, except for a few locations where it was unsuitable based on MH.

Conclusion

Groundwater quality of an area must be studied to understand its suitability for domestic and irrigation purposes. All the groundwater samples collected from the Madhuranthakam area, Tamil Nadu, India, showed that the major ions fall within the permissible range. The dominant groundwater type was Ca-HCO_3. Based on TDS, 95% of the groundwater was fresh and permissible for drinking. The groundwater varied from soft to very hard on the basis of TH. The suitability of groundwater for irrigation was assessed from Na%, EC, RSC, SAR, MH, PI and USDA classification. The groundwater in this area was seen to be good and suitable for drinking and domestic purposes. However, the groundwater was unsuitable for irrigation in a few places, based on MH. Overall, groundwater in the Madhuranthakam area remains usable. The present groundwater quality status must be maintained by taking precautionary measures such as rainwater harvesting, less use of chemical fertilisers and the ongoing monitoring of groundwater quality in this region.

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