

Evaluation of groundwater pollution through groundwater pollution index in kodavanar watershed, a part of Amaravathi basin, Tamil Nadu

Thilagaraj Periasamy, Masilamani Palanisamy*, Killivalavan Jothiramalingam and K. Kumaraswamy, Tamil Nadu

Abstract

The groundwater quantity and its pollution need monitoring for conservation and management to attain a sustainable future. Kodavanar watershed in Tamil Nadu suffering from widespread water scarcity has been selected for the current study to estimate the extent of groundwater pollution. Anthropogenic activities like over-exploitation of groundwater and release of untreated tannery effluents are found to dominate the basin responsible in large measure for groundwater pollution. The estimation of the pollution level is based on a total of 42 groundwater samples that were collected from open wells and bore wells for the pre-monsoon season of July 2022. The groundwater samples were analysed for major cations and anions by using American Public Health Association standard procedures. The Groundwater Pollution Index (GPI) was computed to analyse the distribution of pollution levels. The physicochemical parameters utilised for calculating the GPI include parameters such as pH, Bicarbonate (HCO_3), Electric Conductivity (EC), Potassium (K), Total Dissolved Solids (TDS), Calcium (Ca), Sodium (Na), Chloride (Cl), Fluoride (F), Nitrate (NO_3), Magnesium (Mg) and Sulphate (SO_4). The measurement shows that about 15 percent of the Kodavanar watershed suffers from medium and high levels of ground pollution which is to be critically monitored for the improvement and management of the groundwater in the watershed.

Keywords: *Groundwater, Kodavanar watershed, Groundwater Pollution Index, groundwater quality.*

Introduction

In recent years there has been increasing dependence on groundwater resources in India for irrigation, domestic, and industrial requirements. The natural quality of groundwater depends upon lithological units and the chemical composition of the rocks as well as hydrological factors. Groundwater is subject to contamination due to both geogenic and non-geogenic factors. In recent

decades, the contamination of groundwater has occurred due to the exponential increase in population, industrial growth and urban expansion. Nevertheless, the infiltration of untreated effluents and improper sewage and solid waste disposal can deteriorate the groundwater quality around the region. Intensive agricultural activities that involve the excessive use of chemical fertilizers also

pollute groundwater sources (Killivalavan *et al.*, 2023). These activities can modify the existing quality of groundwater. However, groundwater is an inevitable part of human life, and the consumption of poor quality can directly affect human health and lead to many illnesses. Thus, there is an urgent need to assess the groundwater quality and identify the distributional pattern of pollution in order to conserve groundwater resources for a sustainable future. Groundwater chemistry changes are governed by geochemical processes that take place within the aquifer consequent upon their chemical reactions. Through validation of physiochemical parameters which regulate the primary sources of ions in groundwater that require prior management can be done by the proper time interval monitoring.

The geochemical classification and the hydrochemical characteristics of the groundwater can be identified by utilising Geographical Information System (GIS) and statistical methods. As far as GIS has been efficiently utilized to map the groundwater quality classification. The Groundwater Pollution Index (GPI) is calculated to measure the intensity of groundwater pollution. GPI is used to identify and quantify the influence of cations and anions on the quality of groundwater and this index has been generally employed to evaluate the pollution intensity of groundwater quality by researchers (Al-Aizari *et al.*, 2023; Kumar *et al.*, 2020; Kamaraj *et al.*, 2021). This method also detects the intensity of pollution in the groundwater samples to infer their spatial association.

The present study analyses the spatial pattern in groundwater quality in the Kodavanar watershed in Tamil Nadu, India for

the area experiences water scarcity and people frequently rely on groundwater resources for domestic and drinking purposes. The aim of this study is to evaluate the pollution intensity of groundwater in the watershed. To achieve this, the main objectives are to collect groundwater samples from the watershed and identify the concentration of major cations and anions; determine the dynamics of hydrochemical facies by preparing suitable diagrams; and evaluate the groundwater pollution intensity by calculating the GPI. The polluted regions were identified for the management of the groundwater resources of the Kodavanar watershed for sustainable development.

Study area

Kodavanar watershed, a part of the Amaravathi basin is selected to evaluate levels of groundwater pollution which has been facing groundwater quality and quantity-related issues in recent decades. The geographical extent of the watershed is about 2,254 km² most of which is included in the Dindigul District and a small portion in the Karur District (Fig. 1). The watershed extends between 10° 11' 37" to 10° 27' 30" North latitude and 77° 37' 46" to 78° 01' 10" East longitude. The main course of the Kodavanar River in the watershed originates from the Pandrimalai and Sirumalai hills of Dindigul District and is notably a north-flowing river in Tamil Nadu. The watershed is mostly plain with elevation ranging between 120m to 360m from MSL and in the hilly terrain the maximum elevation goes up to 1,350 m. The land use/land cover of the Kodavanar watershed is dominated by agriculture and barren lands. The geomorphological features are complex and consist of 13 classes of which charnockite and hornblende biotic gneiss are the major types.

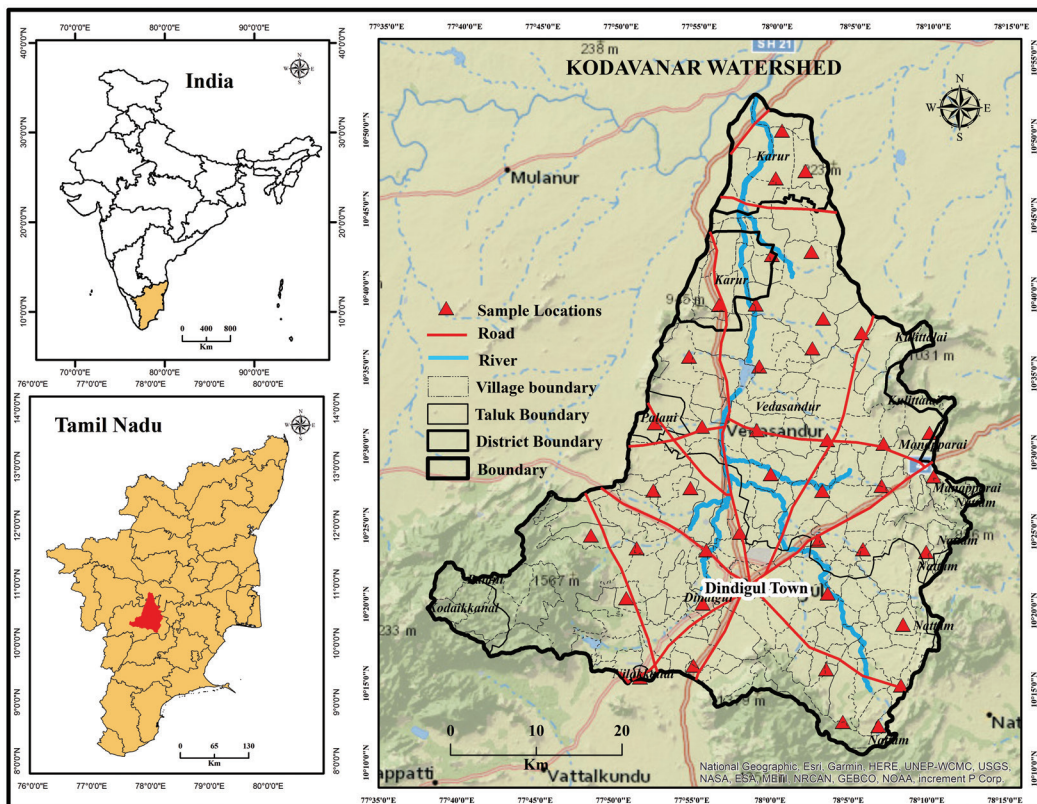


Fig. 1: Location of Kodavanan watershed

Methods

Considering the physical and anthropogenic setting of the watershed, sampling points were established based on geology, geomorphology, and land use, using a 6 km spatial grid. The groundwater samples were collected from the bore wells/dug wells and stored under 4°C temperature to avoid any contamination. Further, the samples were examined for EC, TDS, pH, major anions (NO_3 , HCO_3 , Cl , SO_4 , F), and cations (Na , Ca , K , Mg) based on standard procedures of the American Public Health Association (1995). Piper trilinear and United States Salinity Laboratory (USSL) diagrams have been prepared using Aquachem 4.0 software

to examine the dominant cations, anions, and salinity-sodium hazards in the study area. This software is helpful in creating graphical representations of the water quality data. All the maps of the quality parameters were prepared by using the interpolation technique of IDW (Inverse Distance Weighting) in Arc GIS 10.2 environment based on WHO 2004 limits.

Groundwater Pollution Index

The GPI was developed by Subba Rao in 2012 and since then has been profitably used by researchers across the world to quantify pollution levels by integrating individual chemical parameters. Calculation of the GPI involves the following steps:

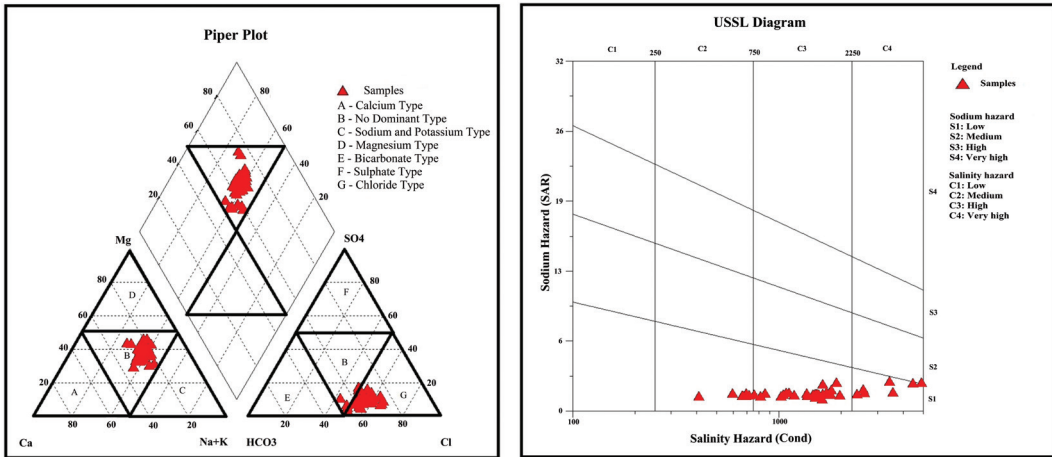


Fig. 2: Piper plot & USSL diagram

Relative Weight (RW) is fixed to individual parameters, ranging from 1 to 5, based on their level of concentration. The Weight of the Parameter (WP) is the proportion between the RW of each parameter with the sum of all relative weights ($\sum RW$). That is represented in Equation 1.

$$WP = \frac{RW}{\sum RW} \dots\dots\dots (1)$$

The Status of Concentration (SOC) is the ratio between the actual concentration (C) of the parameter and its respective drinking water quality standard (DWQS) (Eq. 2).

$$SOC = \frac{C}{DWQS} \dots\dots\dots (2)$$

The overall quality of groundwater (OQG) is assessed using the given equation 3.

$$OQG = WP \times SOC \dots\dots\dots (3)$$

Finally, the GPI has been calculated by summing the values of OQG (Eq. 4).

$$GPI = \sum OQG \dots\dots\dots (4)$$

The GPI has been categorised as very high pollution (GPI >2.5), high pollution

(GPI 2.0 - 2.5), moderate pollution (GPI 1.5 - 2.0), low pollution (GPI 1.0 - 1.5), and insignificant pollution (GPI <1.0).

Results and discussion

Piper Plot

The plot helps to understand the facies of the groundwater as well as the presence and distribution of major anions and cations in the groundwater samples. Results from the piper plot show that there is no dominant cation present in the samples (Fig. 2). On the other hand, chloride anion is dominant in the groundwater samples.

USSL Diagram

The USSL diagram helps in getting an insight into the sodium and salinity hazards present in the groundwater samples. The USSL diagram for the groundwater samples of Kodavanan illustrates low sodium hazard prevalence in the samples (Fig. 2). However, the salinity hazard is high to very high and is higher in the study area compared to the sodium hazard. This is due to the lower concentration of sodium, calcium, and magnesium, which

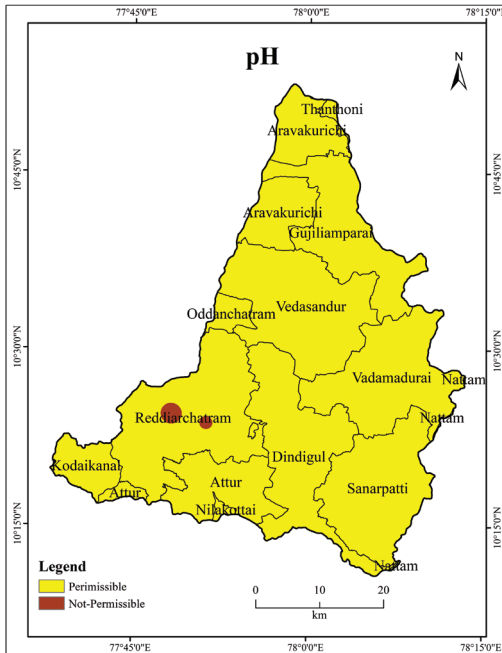


Fig. 3: Spatial distribution of (a) pH

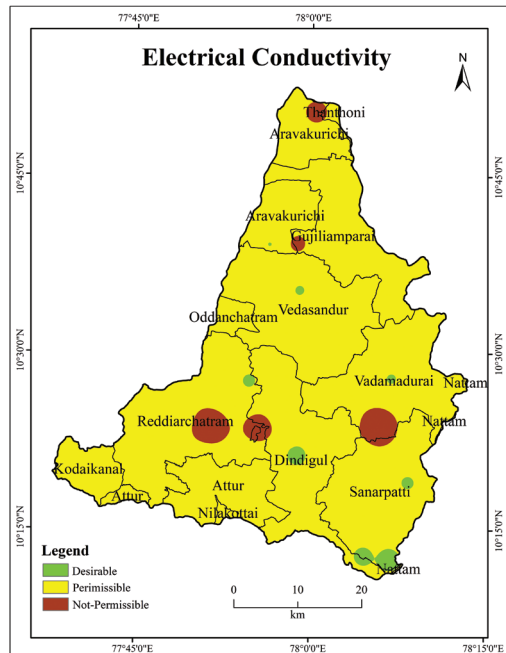


Fig. 3: Spatial distribution of (b) Electrical Conductivity

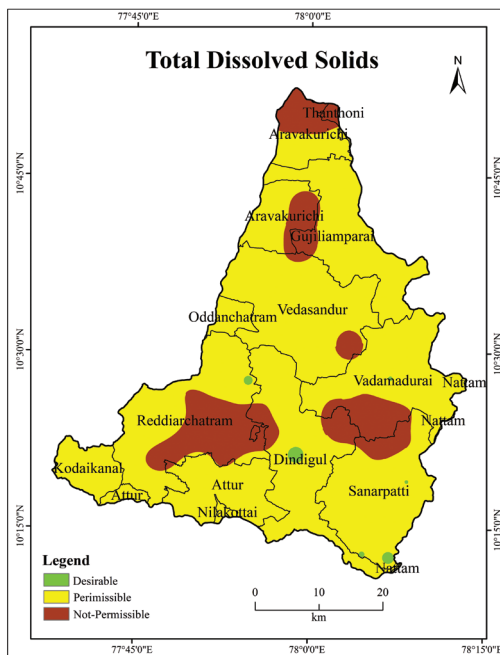


Fig. 3: Spatial distribution of (c) Total Dissolved Solids

results in a low Sodium Adsorption Ratio (SAR), i.e., sodium hazard.

Hydrogen Ion Concentration (pH)

The pH of the groundwater sample is referred to as the production or consumption of hydrogen ions that are the result of the interrelated chemical reactions taking place within them. The result of pH in the study area shows that it is under the permissible limit whereas some parts, especially in the southwest crosses the permissible limit (Fig. 3). This could be due to local irrigation practices or improper sewage disposal.

Electrical Conductivity (EC)

The EC values are directly corresponding to the concentration of total ions present in the groundwater sample which is influenced by the change in temperature, type of parent

rocks and concentration of ion. It generally indicates the capability of the groundwater samples to conduct the electric current where the higher EC value is due to higher salt content (Fig. 3). The highest EC values are found in the middle and eastern portions of Reddiarchatram block and in the southern portion of the Vadamadurai block. The dominant portion of the watershed came under the permissible class.

Total Dissolved Solids (TDS)

The EC and TDS are directly proportional to each other, where the results of both EC and TDS of the Kodavanar watershed have almost similar spatial distribution; the not-permissible limits of TDS and EC were found in the blocks of Reddiarchatram, Vadamadurai, Gujiliamparai, Aravakurichi and Thanthoni, where TDS is observed with a dispersed spatial distribution compared to EC. The limit of TDS below 500 mg/l is desirable for drinking purposes as per both WHO and Bureau of Indian Standards (BIS) standards. The value of TDS in the study area varies between 290 and 3,820 mg/l (Fig. 3). Higher TDS values of the groundwater are observed either in the fringe areas of Dindigul town or along the main river course due to discharge of domestic and industrial wastes in the river.

Calcium (Ca)

There is no major issue concerning calcium as most of the portion of Kodavanar fell under the desirable limit. The maximum and minimum values of the calcium in the watershed vary between 38.5 and 99.2 mg/l (Fig. 4). The desirable limit of calcium is about 75 mg/l.

Magnesium (Mg)

The importance of magnesium presence in groundwater is that it determines the hardness

of the water. While the limit of magnesium is about 50 mg/l and is desirable, none of the samples has magnesium concentration more than the permissible value. The entire Kodavanar watershed is free from any magnesium-related issues.

Sodium (Na)

The concentration of sodium is within the permissible limit throughout the watershed and the value is below 200 mg/l. Hence, there is no issue associated with the sodium distribution in the study area.

Potassium (K)

Potassium is a major issue in the Kodavanar watershed as the value exceeds the permissible limit in all the sample locations. As per WHO standards, the desirable limit of potassium is about 12 mg/l. However, the minimum value of potassium from the groundwater samples is about 36 mg/l (Fig. 4). This is primarily due to the overuse of potassium-based fertilizers in agriculture within the watershed, as there is no geological source for an increase in the concentration of potassium.

Bicarbonate (HCO₃)

Bicarbonate values usually correspond to the carbonate equilibrium of the groundwater samples. However, the occurrence of carbonate is the combined product of pH, dissolved carbon-di-oxide, temperature and other dissolved solids. The result of bicarbonate reveals that dominant samples fell under the non-permissible class in the Kodavanar watershed and it is mainly due to the mixing of rainwater with carbonated rocks (Fig. 5).

Sulphate (SO₄)

Sulphate is one of the significant anions which need to be considered while analysing

Major Cations

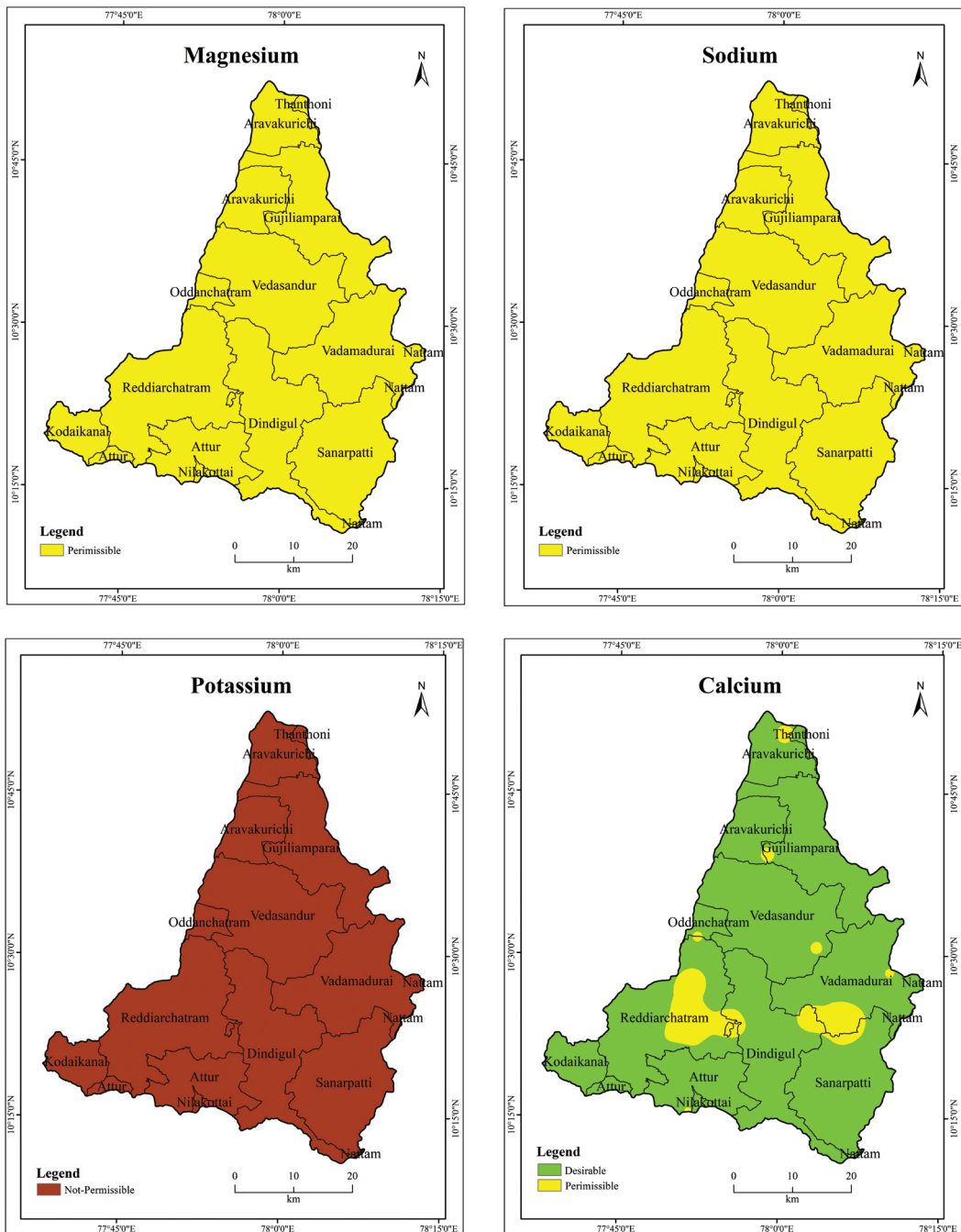


Fig. 4: Spatial distribution of (a) Magnesium, (b) Sodium, (c) Potassium, (d) Calcium

Major Anions

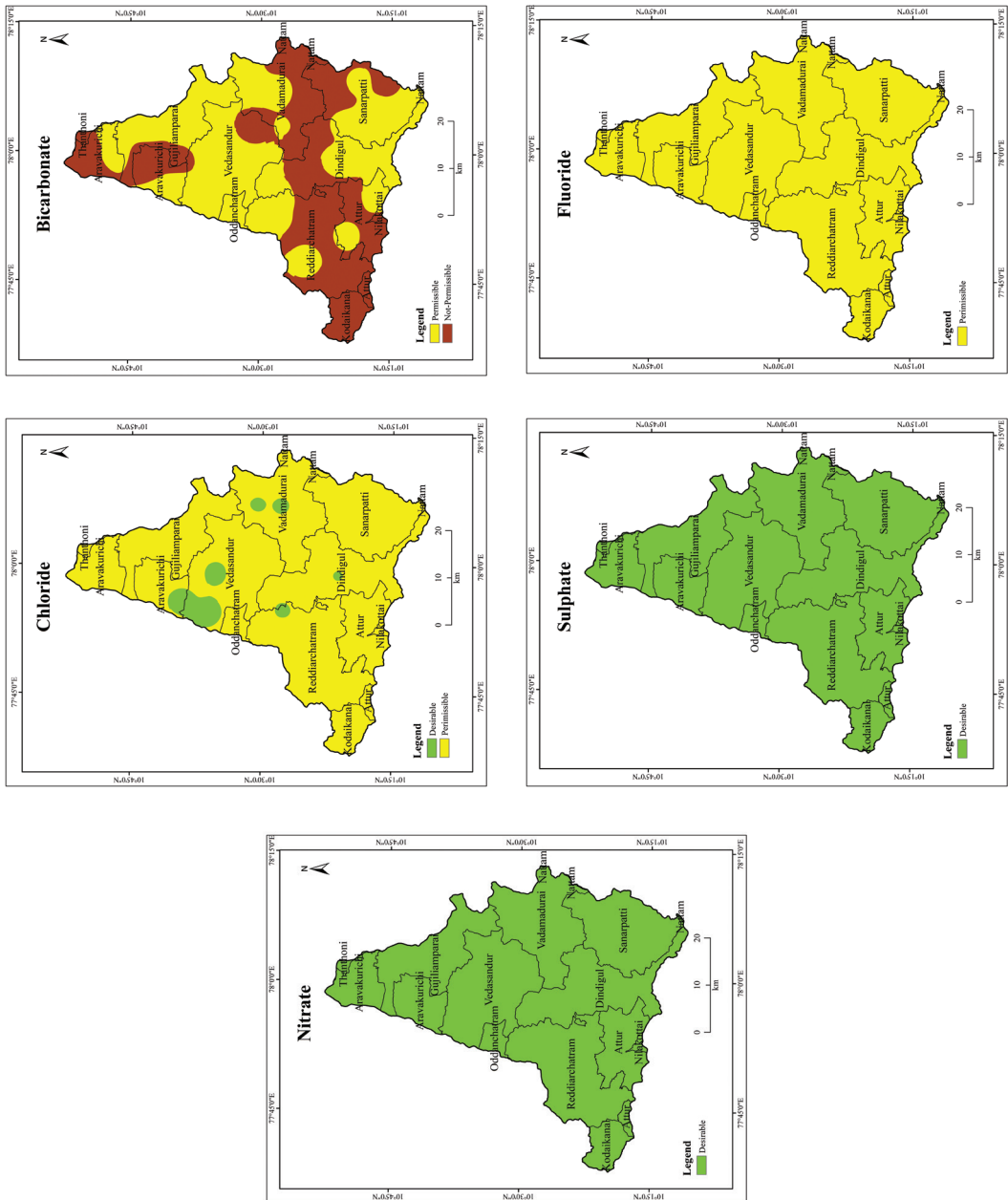


Fig. 5: Spatial distribution of (a) Bicarbonate, (b) Fluoride, (c) Chloride, (d) Sulphate, (e) Nitrate

Table 1: Distribution of GPI

GPI	No. of Samples	Percentage of Samples
Insignificant Pollution	20	47.62
Low Pollution	16	38.10
Moderate Pollution	3	7.14
High Pollution	3	7.14
Total	42	100

the water quality and pollution in the groundwater samples as it directly affects the human organs if exceeds 250 mg/l as per WHO standard. In the case of the Bureau of Indian Standards (BIS) standard, the desirable limit is 200 mg/l. Fortunately, the highest sulphate concentration in the Kodavanan watershed is only 95 mg/l and the entire watershed falls within the desirable limit.

Chloride (Cl)

Weathering of sedimentary rock, soil leaching, as well as domestic and municipal effluents are the main sources of chloride ions. The desirable limit of chloride is about 200 mg/l as per WHO and BIS standards. The results of chloride analysis in the Kodavanan watershed illustrate that a dominant portion of the study area falls within the permissible limit, extending across every block in the watershed (Fig. 5). A minor portion, including the Dindigul, Reddiarchatram, Vadamadurai, Vedasandur, and Aravakurichi blocks, falls under the desirable limit.

Fluoride (F)

The groundwater contains a geogenic form of fluoride. The minimum and maximum value of fluoride ranges between 0.35 and 0.94 mg/l. Thus the entire study area falls under the permissible limit.

Nitrate (NO₃)

Nitrate ion is a naturally occurring ion in groundwater and it plays a crucial role in the nitrogen cycle. If present in excess of the permissible level of 45 mg/l, the increased concentration of nitrate ions would pose serious health risks to people, which is also mentioned in the earlier study by Kumar *et al.* (2014). The highest quantity of nitrate is observed around 0.92 mg/l, while the lowest amount is 0.35 mg/l showing that the entire Kodavanan falls below the ideal nitrate limit (Fig. 5).

Groundwater Pollution Index (GPI)

It is a compound index, which includes the major physico-chemical parameters of pH, TDS, EC, F, NO₃, SO₄, Mg, K, Cl, HCO₃, Na and Ca are weighted in accordance with their influence on groundwater pollution within the scale of 1 to 5. The indexes are classified into four broad classes: high pollution (>2), moderate pollution (1.5 - 2), low pollution (1 - 1.5) and insignificant pollution (<1).

Figure 6 shows that the high pollution zone is located in the southern part of Vadamadurai block and the central part of Reddiarchatram block of the watershed, accounting for about 7 percent of the total samples (Table 1). Moderate pollution is noted in three samples and is distributed

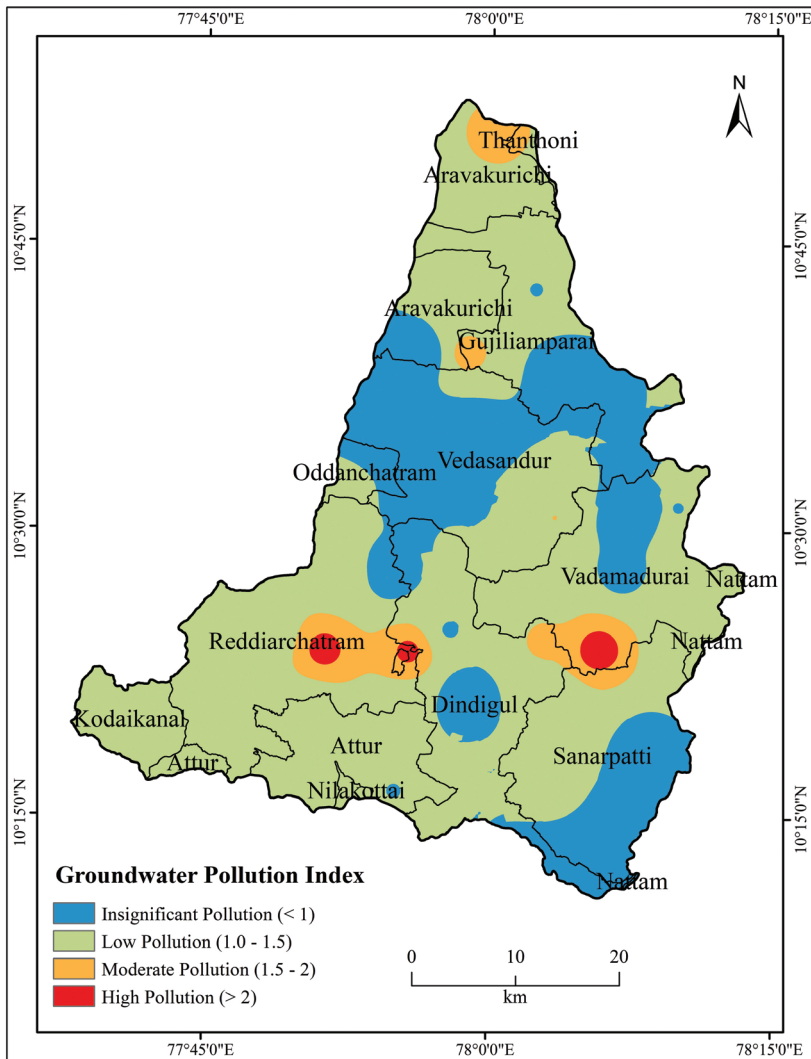


Fig. 6: Kodavanan watershed: Spatial variation in the level of groundwater pollution

around the high-pollution areas where some portions of moderate pollution are observed in the northernmost part of the watershed. It is significant that the moderate and high pollution zones are concentrated in the urban fringes of the Dindigul core region. This pollution could be due to partial or untreated disposal of effluents from tannery industries, and improper disposal of solid wastes and sewage, as no sources of geogenic

contamination (geology & geomorphology) were observed in the Kodavanan watershed. The low pollution areas are found in sixteen samples (38.1%), covering significant parts of the Attur, Kodaikanal, and Nilakottai blocks. Further, insignificant pollution is observed in twenty samples (47.62%), which is the dominant class in the Vadamadurai, Vedesandur, Oddanchatram, Gujiliamparai, and Sanarpatti blocks. The regions identified

as having moderate to high groundwater pollution need to be critically monitored, while the regions with insignificant to low pollution should be conserved.

Conclusion

The study aimed to evaluate the status of groundwater pollution in the Kodavanan watershed through a Piper plot, USSL diagram and groundwater pollution index. The major anion present in the study area was Chloride and there was no dominant anion identified from the piper plot and the USSL diagram revealed that salinity hazard is higher in most parts of the study area compared with sodium hazard. The GPI is a compound index of pH, TDS, EC, F, NO₃, SO₄, Cl, K, Mg, Ca, HCO₃, and Na which are weighted in accordance with their influence to pollute groundwater. High and medium pollution zones are associated with the urban fringes of the Dindigul core region most likely due to the presence of the tannery industry, besides sewage and solid waste disposals since no source of geogenic contamination (related to geology and geomorphology) was observed in the watershed.

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Competing interest

The corresponding author declares that they have no conflict of interest.

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Thilagaraj Periasamy
ICSSR Doctoral Fellow,
Department of Geography,
School of Earth Sciences,
Bharathidasan University,
Tiruchirappalli, Tamil Nadu

Masilamani Palanisamy*
Assistant Professor,
Department of Geography,
School of Earth Sciences,
Bharathidasan University,
Tiruchirappalli, Tamil Nadu

Killivalavan Jothiramalingam
ICSSR Doctoral Fellow,
Department of Geography,
School of Earth Sciences,
Bharathidasan University,
Tiruchirappalli, Tamil Nadu

K. Kumaraswamy
Emeritus Professor,
Department of Geography,
School of Earth Sciences,
Bharathidasan University,
Tiruchirappalli, Tamil Nadu

* Author for correspondence
E-mail: masilamani@bdu.ac.in