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Groundwater quality assessment for agricultural purposes at Vellore District of Southern India: A geospatial based study

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A B S T R A C T

Identifying the geographical distribution of contaminants and their severity in polluting water are critical components of water resources management. Untreated industrial effluents cause severe groundwater pollution and health hazards worldwide. Therefore, the present study was carried out in the year (2019–2020) to assess the groundwater quality in the industrial areas of Vellore district, Tamil Nadu, India. Sixty-four groundwater samples were collected from different villages and analyzed. Spatial distribution maps were prepared to evaluate groundwater quality. The results revealed that among the various heavy metals, total Cr (140 mg/L) contamination was higher in the groundwater samples and hazardous for human consumption and irrigation purposes as per the permissible limit of chromium prescribed by WHO (0.05 mg/L). It is observed that the concentration of heavy metals decreases in the following order: Cr > Ni > Pb > Cd. The irrigation quality index was found to be high in Walajah Taluk in the order of Residual Sodium Carbonate<Magnesium Hazard<Permeability Index<Sodium Absorption Ratio. Regular monitoring of pollutants and appropriate remediation must be followed to avoid deterioration of groundwater quality. This study's findings can help to determine the best course of action to safely use groundwater for irrigation purposes in the Vellore District of India.

1. Introduction

Water is the most essential and renewing resource on the planet since it determines the existence of life. Humans require adequate quantities and water quality to survive, thrive, and carry out their various activities. Groundwater is a significant water source for irrigation, drinking, and industrial uses. However, unsafe handling and disposal of hazardous and unprocessed toxic industrial waste and improved conservation of water resources are deteriorating groundwater quality and making the water unfit for drinking and agricultural purposes (Asghari et al., 2018; Mohammadi et al., 2017; Sathya et al., 2021).In addition, discharging untreated industrial effluent into waterbodies is the primary source of groundwater pollution in the industrial belts (Asghari et al., 2018; Karunanidhi et al., 2020b; Mohammadi et al., 2017; Sathya et al., 2021; Venkatesan et al., 2021). Polluted groundwater causes various health disorders

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and economic problems (Abbasnia et al., 2018; Asghari et al., 2018) that must be addressed appropriately (Sinduja et al., 2022a).

Tamil Nadu accounts for around 75% of India's tanning industry, and the majorities are in Ambur, Vaniyambadi, and Ranipet (Ahmed, 2020). Even though various other tanning materials have been investigated to process leather, Cr-based tanning has been shown to be the most durable (Zhu et al., 2019). However, when discharged untreated, they harm the receiving stream's everyday life, and if allowed to percolate into the ground for a long time, they significantly impact the area's groundwater table (Akpan and Bassey, 2020; Egbueri, 2020; Sinduja et al., 2018). A single tannery is expected to contaminate groundwater in a 7–8 km radius (Sadeghi et al., 2022). About 150,000 t of chromium-containing solid waste produced by TCCL has been heaped on open ground in the past two decades (Thangam et al., 2018). The Tamil Nadu Pollution Control Board (TNPCB) discovered Cr pollution in the soils and groundwater in the TCCL region (TNPCB, 2010). These chemicals pollute the groundwater, making it unfit for drinking, irrigation, and other uses when combined with water.

With the ever-increasing demand for potable and agricultural water, the scarcity of accessible surface water, and the unpredictable seasonal rainfall, groundwater is becoming increasingly important (Döring, 2020). Groundwater resources in the many villages of the Vellore district of Tamil Nadu have similar climates and are the most critical water resources for drinking and agriculture (Leonel and Tonetti, 2021). Unfortunately, tanneries discharge vast amounts of chromium, lead, and other metals from the wastewater and sludge from the tanning and leather industries, contaminating the soil and groundwater (Gajalakshmi et al., 2012; Sinduja et al., 2022b). According to the American Public Health Association (Apha, 1995), most heavy metals are hazardous. In addition, their exposure can impair many health issues, even a child's mental development.

Groundwater management for long-term resource sustainability is critical for agricultural purposes (Anand et al., 2021). This study paves the way for baseline data to resolve problems caused by low water quality by using effective management strategies that improve people's living environment. Furthermore, knowledge of assessing groundwater quality through GIS spatial distribution mapping of pollutants and the resulting information on water quality could be helpful for policymakers and farmers when taking remedial measures. The present study aimed to analyze and evaluate spatial variations in drinking water chemical and physical parameters, including different cations, anions, water quality index, sodium adsorption ratio (SAR), and heavy metals speciation, over one year using GIS in the Vellore Vellore district of Tamil Nadu. In addition, the study also attempted to focus on assessing the suitability of groundwater for drinking and agriculture purposes. This study will aid in determining the best course of action for pollution management and increase the public's access to safe drinking water and irrigation purposes in the study region.

2. Materials and methods

2.1. Study area

The research region is in the northern section of the Indian state of Tamil Nadu. The study area is the Vellore district of Tamil Nadu,

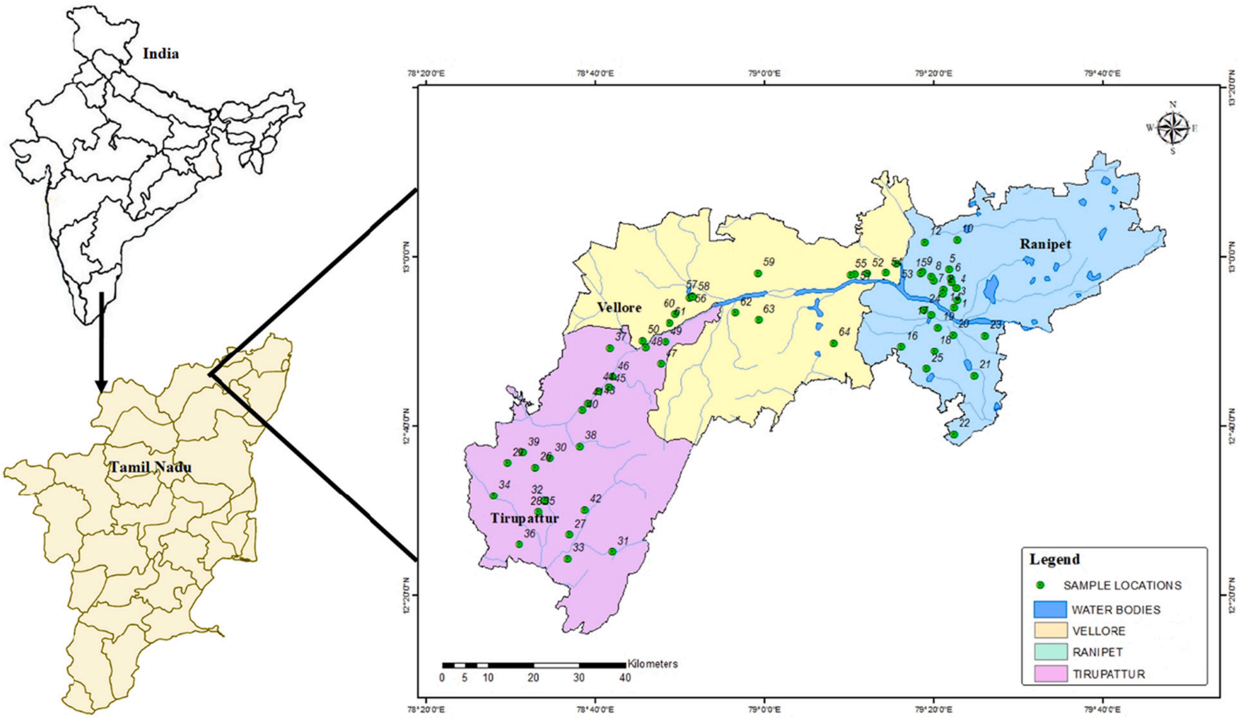

Fig. 1. Spatial distribution map showing the location of groundwater sampling (Study area).

which is between the latitudes 12° 35′ 00″ and 12° 55′ 00″ N and the longitudes 78° 30′ 00″ and 78° 50′ 00″ E. Based on the land degradation maps, six Taluks namely, Walajahpet, Arcot, Tirupattur, Vaniyambadi, Gudiyatham, and Vellorewere selected. The Palar River flows into Tamil Nadu from Karnataka and is the study region's primary water source. Vellore is located at 12.92°N 79.13°E and is 220 m above sea level. The climate of the city is semiarid. It is located 135 km (84 miles) west of Chennai in the Vellore district of the South Indian state of Tamil Nadu. Vellore is located in the Eastern Ghats and the Palar River basin. The topography is nearly plain, with a west-to-east gradient. The temperature ranges from 13C (55 °F) to 39.4 °C (102.9 °F). Like the rest of the state, April to June is the hottest, and December to January is the mildest. Vellore receives 1034.1 mm (40.71) of rainfall every year.

2.2. Sample collectionand elemental (anion/cation) analysis

In this study, 64 groundwater samples were collected over two consecutive years in 2019 and 2020. The water samples were collected from the wells in sterile plastic containers. The study area map indicates the sampling points (Fig. 1). The standard methods used for estimation of the physicochemical and speciation of chromium. Afterward, each parameter's maximum, mean and minimum were determined for each groundwater. The mean was compared with national standards and Indian permissible limits recommended by the World Health Organization (WHO) for drinking water. The temporal variation and spatial distribution of parameter concentrations in underground water resources were studied using ArcGIS software. The water samples were analyzed for pH and EC, as Jackson (1973) described. Analysis of Nitrate, potassium, calcium, magnesium, sodium, and sulfate in the sample was carried out as per the standard methods suggested by the American Public Health Association (Apha, 1995). Heavy metals like cadmium, nickel, and lead were determined using the atomic adsorption spectrometric method. The chromium was determined using the spectrometric method (Diphenyl carbazide) recommended by (USEPA, 1979). Blanks and standards were run at regular intervals to ensure the accuracy of these analytical methods. Except for the pH, all the other analyzed parameters were measured in mg/L. The analytical results were compared with the World Health Organization (World Health Organization, 2017).

2.3. Assessment of Irrigation water quality indices

There is an increasing need to periodically check the kind of water utilized in agriculture. Therefore, this research focuses on the type of water used for irrigation. Significant irrigation water quality factors include numerous specific water characteristics critical for crop production and product quality. For example, salinity indicates the number of salts in groundwater, creating many problems for growing plants. Therefore, the irrigation indices include Sodium Adsorption Ratio (SAR) described by Gupta et al. (2015), Residual Sodium Carbonate (RSC) defined by Eaton (1950), Magnesium Hazard (MH) described by Szabolcs and Darab (1964), Percentage Sodium (%Na) described by Wilcox (1955) and Kelly's index (KI) described by Kelly et al. (1946) and Paliwal and Singh (1967) were calculated by following using Eq. 1, 2, 3, 4, 5 and 6, respectively.

$$SAR = \frac{Na}{\sqrt{(Ca + Mg)/2}} \tag{1}$$

$$RSC = \frac{(HCO3 + Na)}{(Ca + Mg)} \tag{2}$$

$$PI = \frac{\sqrt{(HCO3 + Na)}}{\sqrt{(Na + Mg + Ca)}} \tag{3}$$

$$MH = \frac{(Mg \times 100)}{(Ca + Mg)} \tag{4}$$

$$\%Na = \frac{(Na + K) \times 100}{(Ca + Mg + Na + K)} \tag{5}$$

$$KI = \frac{Na}{(Ca + Mg)} \tag{6}$$

2.4. GIS spatial distribution map preparation

The groundwater quality indicators measured in the research region have been depicted using ArcGIS Version 10.3 Software's spatial distribution maps. This program interpolates data from sample locations with groundwater characteristics and contamination predictions to assign the value and calculate the parameters within the research area's designated boundaries. The major elements that promote groundwater quality in the examined location were classified using spatial distribution. In addition, a level of contamination was highlighted in spatial distribution maps using ArcGIS software (Khan et al., 2019; Nath et al., 2018).

2.5. Statistical analysis

In this study, Pearson correlation co-efficient analysis by r-program was used to relate the correlation between the water quality parameters and calculated (Gomez and Gomez, 1984; Rangaswamy, 2010), and the level of significance and *p*-values and correlation values were calculated using the r-program Version 1.4.1103 were interpreted based on Lew (2019). The high correlation coefficient (near +1 or − 1) means a good relationship between two variables, and its concentration around zero means no relationship between them at a significant level. $*P \leq 0.05$, $**P \leq 0.01$, $***P \leq 0.001$ level means statistically significant with the confidence level. If $P > 0.05$, it has no statistically significant difference. If the values are positive, it signifies a positive relationship between the parameters, and negative values signify a negative or reciprocal relationship. Multivariate statistics such as mean, maximum, minimum, and standard deviation were used to study the groundwater quality characteristics and their interrelationships. SPSS version 22 was used for all multivariate statistical analyses. The dendrogram designates several clusters to identify the values better to compare or understand hierarchical clustering results. In this work, we used a dendrogram and a heat map to determine the best number of clusters for analysis and comparison. The Manhattan distance method was used to estimate the distance value. The distance between two groups is the distance between their two closest members. Various hierarchical or partial clustering techniques can determine the similarity metrics that characterize the proximity of the parameters. With the aid of these scientific tools, various sources (both geogenic and anthropogenic) of contaminants in water may be easily identified. When the sources of water pollution are known, the chances of mitigating associated environmental risks and hazards are enhanced.

3. Results and discussion

3.1. Chemical parameters in groundwater samples

Chemical parameters analyzed in groundwater samples are shown in Table 1. The mean pH of the water is 7.46 ± 0.19. Groundwater samples in the study region showed neutral to slightly alkaline pH values. The spatial distribution of pH in groundwater samples of the study area is given in Fig. 2A. Therefore, the pH level in the study area's groundwater is well within the permissible limits (6.5–8.5) recommended by WHO (2018). The pH decides the acidic or basic condition of water, and if the pH is not within the prescribed limit of 6.5–8.5, it damages the mucous membrane in the eyes, nose, mouth, abdomen, anus, etc. The presence of calcareous aquifers in the study area is a major reason for the elevated pH level.

Electrical Conductivity varies throughout the study area, and a higher variation was found in the Solur and Kannigapuram villages of Vaniyambadi Taluk, as shown in (Fig. 3). Higher EC readings indicate the salt content in groundwater. High salinity and mineral content in groundwater samples produced by geochemical processes such as ion exchange, evaporation, silicate weathering, and solubilization within the studied region can be attributed to higher EC in the analyzed region (Ramesh and Elango, 2012). The geographical distribution of EC reveals a greater concentration in the central and eastern regions of the study area (Fig. 2B). EC is ranged from 600 to 13,800 μS/cm with an average of 3295.31 ± 1.28 μS/cm. In 85.94% of samples, EC was higher than the maximum permitted level (1400 μS/cm). A higher EC may cause gastrointestinal irritation in human beings. Type I is permitted (EC 1500 μS/cm); type II is not permissible (EC 1500–3000 μS/cm), and type III is dangerous (EC >3000 μS/cm) according to the Organization and

Table 1
Groundwater quality of the study area.

Parameters	Minimum	Maximum	Mean ± SE	WHO standards permissible limit	No of samples exceeding WHO limits	% of samples exceeding WHO limits
pH	6.5	8.05	7.46 ± 0.19	6.5–8.5	0	0
EC (μS/Cm)	600	13,800	3295.31 ± 1.28	1400	55	85.94
Sulphate (mg/L)	4.8	2572	160.14 ± 1.25	200–400	2	3.13
Chloride (mg/L)	74.45	3946.59	955.79 ± 2.18	200–600	31	48.44
Nitrate (mg/L)	0.1	9.4	4.93 ± 0.12	50	0	0
Potassium (mg/L)	0	17	5.62 ± 0.08	12	5	7.81
Calcium (mg/L)	38	1071	209.90 ± 0.10	75–200	28	43.75
Magnesium (mg/L)	23	639	112.43 ± 0.35	50–150	24	37.50
Sodium (mg/L)	43	1163	362.56 ± 2.83	200	51	79.69
Cadmium (mg/L)	0	0.95	0.09 ± 0.00	0.50	6	9.36
Chromium (mg/L)	0	140.65	5.26 ± 0.05	1.00	17	26.56
Lead (mg/L)	0	2.28	2.14 ± 0.00	1.00	2	3.13
Nickel (mg/L)	0	19.2	0.05 ± 0.00	2.00	10	15.63

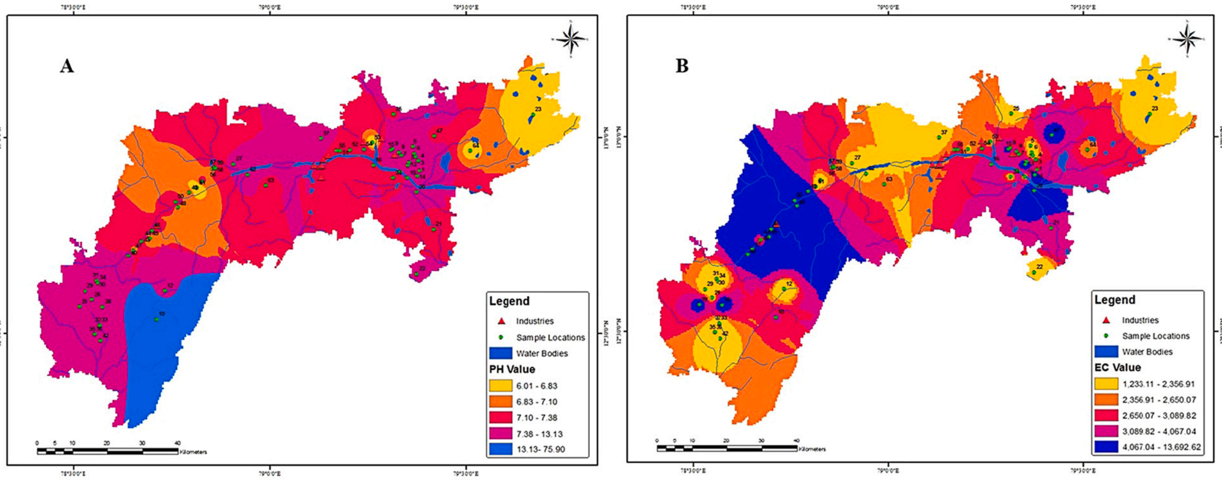

Fig. 2. Spatial distribution of (A) pH and (B) EC.

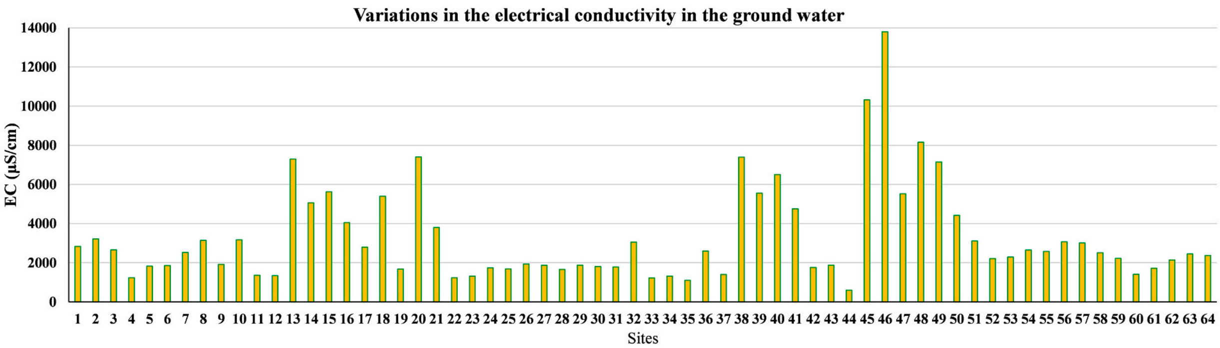

Fig. 3. Groundwater variations of EC.

Zdrowia (2004) categorization. 17.19% of all groundwater samples in the research region are classified as type I (permitted), 39.06% as type II (not permissible), and 43.75% as type III (hazardous) (Table 2).

3.2. Cations in the groundwater samples

The major ions in the groundwater are in the order of (cations and anions) Na^{+}, Ca^{2+}, Mg^{2+}, K^{+}, Cl^{-}, SO_4^{2-}, and NO_3^{-} in the study area. The spatial distribution maps show calcium and magnesium variations of cations in the study (Fig. 4A, B). Calcium, magnesium, chloride, and sulfate ions are naturally present in the groundwater. Groundwater samples had calcium (Ca^{2+}) and magnesium (Mg^{2+}) contents ranging from 38 to 1071 mg/L and 23 to 639 mg/L with an average of 209.90 ± 0.10 and 112.43 ± 0.35, respectively. Out of 64 samples, in 25 samples, the calcium ion level exceeds the permissible limits. The highest content of calcium ions in the study area was recorded in Kannigapuram village in Vaniyambadi Taluk, followed by Pudhupadi in Arcot Taluk. Excessive use of agrochemicals such as fertilizer and insecticides for agricultural production and rock-water interaction are the leading causes of increased calcium ion concentrations in the study region (Deepa and Venkateswaran, 2018). In the study area, 24 villages with magnesium ions concentration ranged above the permissible limits and were unsuitable for irrigation and drinking purpose prescribed by WHO (2018). The Kannigapuram village of Vaniyambadi Taluk has the highest concentration of magnesium ions. Magnesium is the most abundant

Table 2
Groundwater classification for drinking purpose based on Electrical Conductivity.

Observed data		WHO classification	
Number of Samples	Percentage of samples	Electrical Conductivity (µS/cm)	Classification
11	17.19	<1500	Permissible
25	39.06	1500–3000	Not permissible
28	43.75	>3000	Hazardous

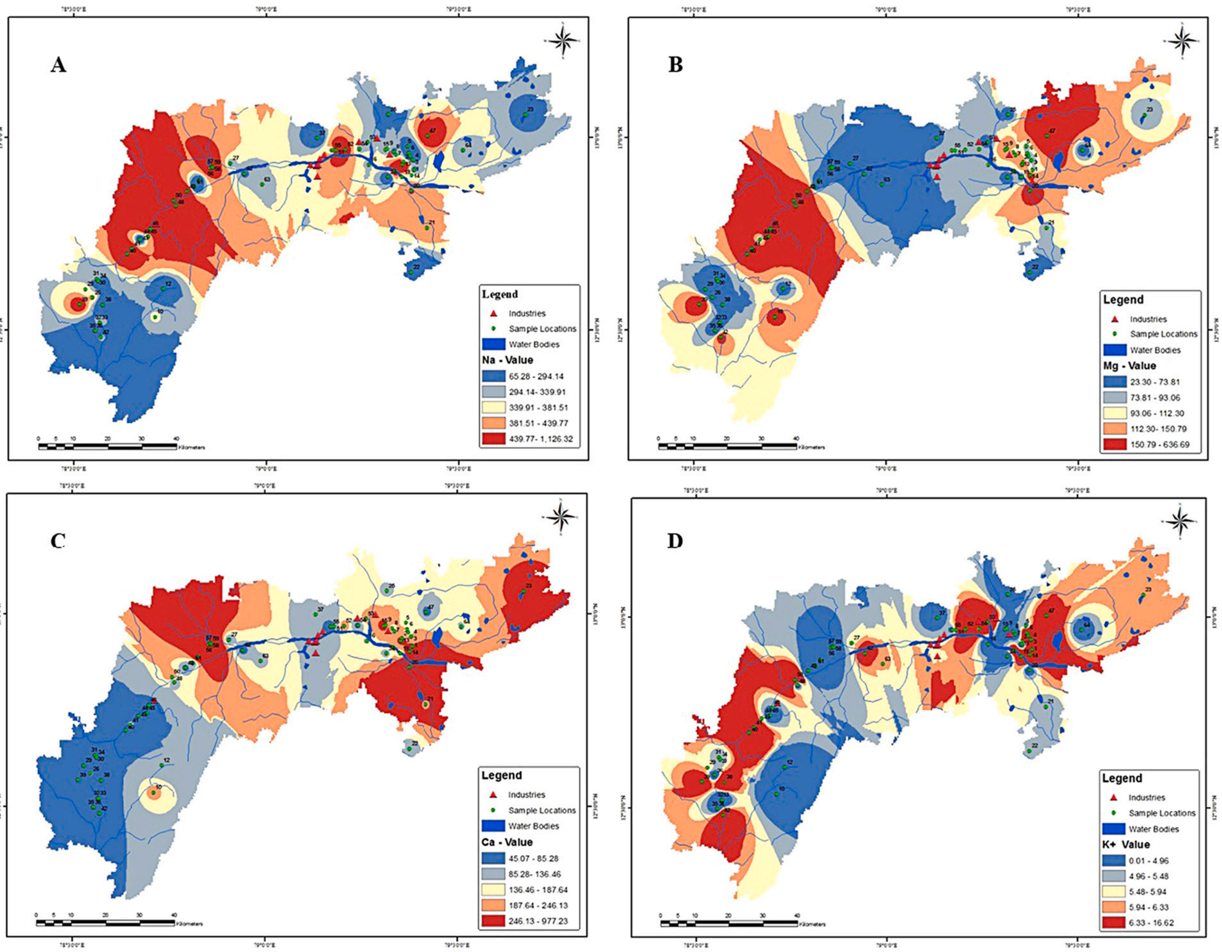

Fig. 4. Spatial distribution of cations (A) Calcium; (B) Magnesium; (C) Sodium; (D) Potassium.

mineral in the earth's crust (Balamurugan et al., 2020). Sodium and potassium in the study area are widely distributed in the spatial distribution map (Fig. 4C, D). In the study area, sodium concentrations in groundwater range from 43 to 1163 mg/L, with an average of 362.56 ± 2.83 mg/L, and potassium concentrations range from 0 to 17 mg/L, with an average of 5.62 ± 0.08 mg/L. The concentration of Na^+ and K^+ in groundwater varies geographically, with relatively high concentrations in the area's southern and central parts. The higher concentration of sodium and potassium is due to the more rock materials in the study area. Rajmohan and Elango (2004) got

Table 3
Groundwater classification based on anions (percentage of samples).

Parameters	Observed data		WHO classification	
	Number of Samples	Percentage of samples	Range	Classification
Chloride	7	10.93	0–142	Very good
	13	20.31	143–249	Good
	8	12.50	250–426	Usable
	6	9.37	427–710	Usable with caution
	30	46.87	>710	Harmful
Nitrate	64	100	0–10	Very good
	0	0	11–30	Good
	0	0	31–50	Usable
	0	0	51–100	Usable with caution
	0	0	>100	Harmful
Sulphate	51	79.68	0–192	Very good
	7	10.93	192–336	Good
	4	6.25	337–575	Usable
	1	1.56	576–960	Usable with caution
	1	1.56	>960	Harmful

similar results in a nearby charnockite and alluvium-rich region. In another study, Amouei et al. (2012) reported that the physico-chemical parameters such as SO_4^{2-}, Cl^-, Na^+, TDS, EC, turbidity, and NO_3^-cross the permissible limit in Rural Areas of Khaf, Iran. They suggested that the focus must be on strengthening the treatment and sanitation of drinking water and its transmission management.

3.3. Anions in the groundwater samples

The anions and nitrate content are within the allowable limits in all 64 samples from the research region. Chloride (Cl^-), the most abundant anion in the research region, has high mobility and solubility. The chloride content in 46% of samples was at harmful levels. An increase in chloride ion concentrations in groundwater is caused by the dissolution of minerals such as khondalite, Charnockite, and peninsular gneiss (Mukherjee and Singh, 2018). It might be due to human activity, such as dumping industrial waste. 12% of groundwater samples are usable, and 20% of samples are good and can be used for all purposes. Regarding the sulfate in the groundwater, 76% of the water samples are very good and safe, 10% of the samples are good, and nearly 6% of the samples are usable; 1% of the samples can be used with caution, and 1% of the samples are harmful as they exceed the permissible limits and cannot be used for the drinking or domestic or irrigational purposes. The percentage variation of the anions is tabulated in Table 3. Chloride (Cl^-) concentration in the water samples ranged from 74.45 mg/L to 3946.59 mg/L with an average of 955.79 ± 2.18 mg/L. Sulfate (SO_4^{2-}) was found in the range of 4.8 mg/L to 2572 mg/L with an average of 160.14 ± 1.25 mg/L, while nitrate (NO_3^-) values ranged from 0.1 mg/L to 9.4 mg/L with an average of 4.93 mg/L. The nitrate concentration ranges from 0.7 to 9.4 mg/L with an average of 4.93 ± 0.12 mg/L in the study area. The chloride, sulfates, and nitrate concentrations vary substantially, with the southern and central sections of the area having the highest concentrations (Fig. 5A, B, C). Because of the higher concentration of major ions in groundwater, about 80% of the sampling locations in the Ambur region are unfit for drinking and agricultural purposes (Kanagaraj and Elango, 2016). Another study conducted by Azhdarpoor et al. (2019)reported that the spatial and temporal variability and extent of contamination of fluoride and nitrate in groundwater resources in the rural area of Iran were obtained higher, which proved to be a severe cause of contamination of drinking water resources.

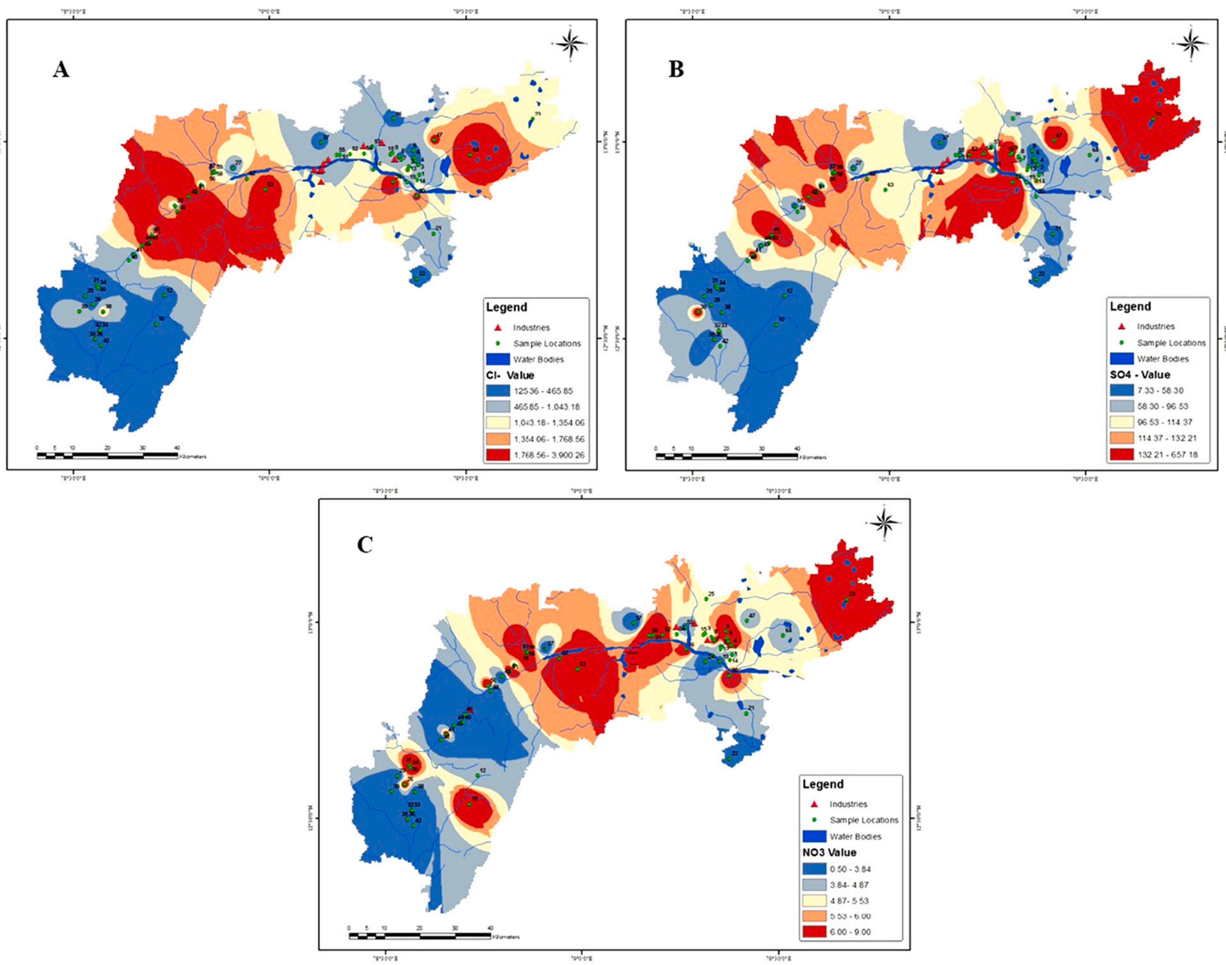

Fig. 5. Spatial distribution of anions (A) Chloride; (B) Sulfate; (C) Nitrate.

3.4. Heavy metals in groundwater samples

Variations in the geographical distribution of cadmium concentrations are illustrated by maps in the research region (Fig. 6A). According to WHO, the maximum allowable level of cadmium in water is 0.003 mg/l. The 9.33% of groundwater samples of the study region were found to exceed the permissible limits. The results corroborate with the findings of Prabhahar et al. (2012) and the studies of severe contamination of cadmium above the permissible limits nearby the regions of Palar and Vaniyambadi mainly due to the problems of municipal sewage, industrial wastes, and anthropogenic activities. Cadmium concentrations in water samples ranged from detectable levels (0.1 mg/L) to 0.95 mg/L, with an average of 0.09 ± 0.00 mg/L. Cadmium is very hazardous and causes nausea, vomiting, breathing problems, cramping, and even loss of consciousness in large concentrations.

Variations in the geographical distribution of lead concentrations are illustrated by maps in the research region (Fig. 6B). The average lead concentration in water samples from the study area is 467.8 mg/L and ranges from DL (0.1 mg/L) to 19.2 mg/L. A higher lead concentration was found in the village TK Thangal 1 of Walajahpet Taluk. Poisoning has been induced by lead salts used in the ceramic industry in the research region. The maximum permissible concentration of Pb is 1.00 mg/L as per WHO (2018). However, nearly 3.1% of the groundwater samples exceed the allowable limit because concerns about long-term toxicity were tabulated, although its concentration rarely exceeds in natural waters. The higher concentration of lead in the study area Ranipet, Vellore district was similar to the previous studies (Saini et al., 2013).

Variations in the geographical distribution of nickel concentrations are illustrated by maps in the research region (Fig. 6C). The nickel concentration ranges from DL (1.0 mg/L) to 0.28 mg/L in the study area with an average of 0.05 ± 0.00 mg/L. Nickel's normal standard threshold value in water is 0.07 mg/L (WHO, 2018), and 15.63% of water samples exceed the permissible limits. They claim that increasing Ni content in water causes a rise in Cu and Pb levels. Nickel was found in higher concentrations in all the samples close to the tannery and fell in the severely contaminated zone, suggesting that they are unfit in the villages of Ambur and Vellore for drinking and agricultural uses.

Variations in the geographical distribution of chromium concentrations are illustrated by maps in the research region (Fig. 6D). The Cr concentration ranges from BDL to 140.65 mg/L in the study area, with an average of 5.26 ± 0.05 mg/L. As shown in Fig. 6D, the geographical distribution findings demonstrate that groundwater samples collected from sites 1, 3, 4, 5, 7, and 8 from Walajahpettaluk in the study regions are severely polluted. The maximum permissible concentration of Cr is 1.00 mg/L as per WHO (2018), and 26.56% of water samples exceed the permissible limits. The reason for an increase in Cr content in the study area i,e, taluks, and villages are surrounded by a huge number of small and large-scale leather and tanning industries, as well as TCCL sites where Cr waste has been deposited on open land for more than two decades across an area of roughly 3.5 ha with a height of around 4 m (TNPCB, 2010). The maximum concentration of Cr was recorded at locations 1 & 8 (TK Thangal 1 and Vanapadi). The high concentration of Cr in groundwater samples from this site is mainly due to the samples from the wells closer to the effluent outlet of the tannery (approx 2 km) at Melpudupettai in Walajapet. Thus, it indicates the extent of Cr pollution in groundwater (Rangasamy et al., 2015). However, the most disturbing fact about this contamination is that these waters are currently used for potable purposes. Therefore, the chromium concentration in some of the village's groundwater was within the permissible limits (BDL to 140.65 mg/L) prescribed for irrigational purposes. Overall, The indiscriminate use of agricultural pesticides and fertilizers is one of the causes of metal contamination in agricultural areas (Sinduja et al., 2022c). Table 1 gives the study area's maximum, minimum, and mean values of chromium concentration. The maximum allowable limit of Cr in the groundwater for agricultural irrigation purposes is 0.5 mg/L (WHO, 2018). Therefore, the potential health risk is anticipated to the chromium concentration above the permissible limit. 26% of the groundwater samples exceed the permissible limit in the study area. Because of long-term wastewater penetration in this location, which has reached deeper depths, some groundwater samples show no change in chromium content. As the surrounding rocks are predominantly

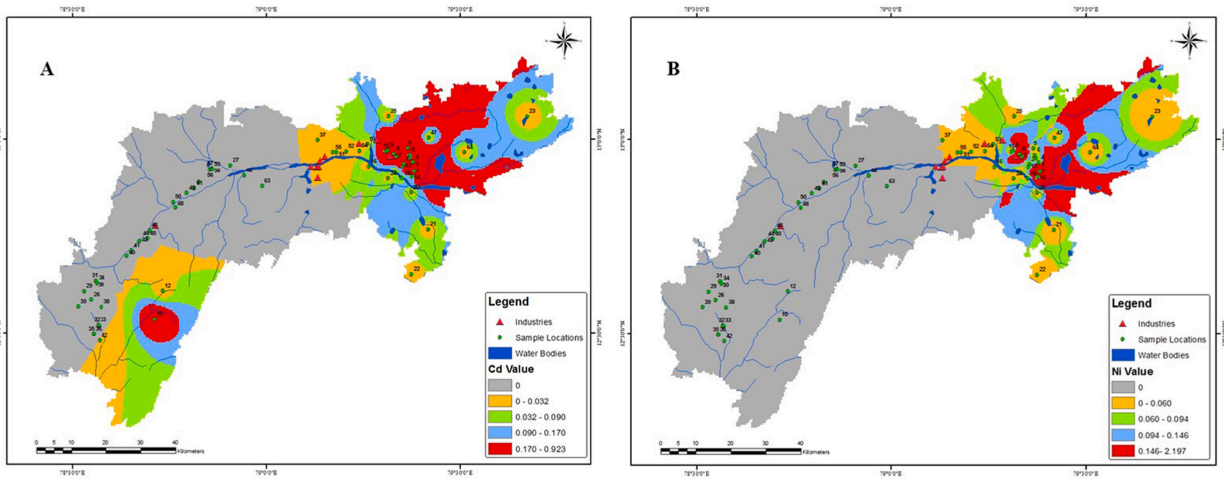

Fig. 6. Spatial distribution of Heavy metals (A) Cadmium; (B) Nickle.

granite, chromium concentration is consistently below 50 mg/kg, and it is impossible to derive such high Cr from rocks (Edmunds and Smedley, 1996; Fendorf, 1995).

As a result, the source of Cr appears to be anthropogenic, as chromium and its derivatives are used in existing tannery businesses. However, high doses of chromium cause liver and kidney damage, and chromate dust is carcinogenic (Mugica et al., 2002). Hence, it is now evident that releasing these heavy metals into the groundwater system is much more dependent on human activities than on natural processes. These findings correlated with the other research and supported the previous observations of the areas of the Vellore district (Rangasamy et al., 2015; Sundar and Chandrasekaran, 2010). Previous studies around 10 years back also reported severe soil and water contamination due to Cr from tannery wastes in Vellore. Moreover, Esmaeilzadeh et al. (2019) study reported that the extent of heavy metals contamination in agricultural soil, particularly concentrations of Pb, Ni, Cu, Zn, and Fe, was higher, which proved to be a severe cause of contamination of soil and water.

3.5. Irrigational quality parameters and indices

The appropriateness of groundwater for agricultural purposes in the study region was determined by calculating Sodium Adsorption Ratio (SAR), Residual Sodium Carbonate (RSC), Permeability Index (PI), Magnesium Hazard (MH), Percentage Sodium (% Na), Kelly's index (KI) for all the 64 groundwater samples.

The sodium and alkaline risks of irrigation water were categorized in terms of SAR, and their relevance for agriculture was assessed. On the other hand, SAR varied significantly according to physiographic, geological, hydrological, and anthropological activities (Karunanidhi et al., 2020a; Mishra et al., 2021; Sakthivel et al., 2018). The aerial depictions of irrigated agriculture regions' purposes based on SAR, RSC, Na (%), MH, and KI are presented in (Table 4). This research might aid farmers ineffectively utilizing groundwater resources for efficient agriculture activities in this location.

3.5.1. Sodium absorption ratio

The quality of the groundwater samples in the study area has been classified based on the sodium absorption ratio calculation (Eq.1). Among the analyzed samples, 51.56% (33 locations) were excellent (Medium salinity and low sodium hazards), indicating good for crop growth yield and other agricultural works. In addition, 40.63% of the total samples (26 locations) were found in a suitable category (medium salinity and medium sodium hazards), indicating good crop growth and medium yield. However, 7.81% of the samples (5 locations) were doubtful for irrigation purposes (very high salinity and medium sodium hazards). The high salinity may have osmotic effects on the plant because of the high salinity. None of the groundwater samples had SAR >26, meaning water is unfit (very high salinity and high sodium hazards) and is hazardous to plant growth and yield.

3.5.2. Residual sodium carbonate

The groundwater samples represent various irrigation water classes based on RSC calculation (Eq.2). The primary factors that impact groundwater quality for agricultural use are carbonate and bicarbonate. The nature of water is greatly influenced by natural earth materials such as calcium and magnesium with carbonate and bicarbonate. The RSC value was used to assess the impacts of carbonate and bicarbonate in groundwater. The RSC is classified into three categories such as A (<1.25- Good), B (1.25–2.5- Doubtful), and C (>2.5 - Unfit). A higher RSC value in water results in a higher sodium ion adsorption concentration. If the RSC value is >2.5 meq/L, the water quality is inappropriate for agriculture. Still, values <1.25 meq/L suggest that water sources are adequate for agriculture, and values between 1.26 and 2.5 meq/L indicate that irrigation usage is doubtful. In the study area, 39.86% of the sample

Table 4
Classification of ground water for agricultural uses.

Parameters	Minimum	Maximum	Mean ± SE	WHO standards permissible limit	No of samples exceeding WHO limits	% of samples exceeding WHO limits
SAR (meq/L)	1.58	25.85	10.64 ± 0.09	0–10- Excellent	33	51.56
				10–18- Good	26	40.63
				18–26- Doubtful	5	7.81
				>26-Unfit	0	0
RSC (meq/L)	97.82	944.09	394.34 ± 9.44	<1.25- Good	0	0
				1.25–2.5- Doubtful	0	0
				>2.5-Unfit	64	100
PI (meq/L)	3.86	28.80	14.06 ± 0.27	>75- Class-I	0	0
				25–75- Class-II	0	0
				<25-Class-III	64	100
MH (meq/L)	59.52	698.13	174.52 ± 1.81	<50- Suitable	0	0
				>50- Unsuitable	64	100
% Na	18.85	84.65	53.91 ± 0.86	<20- Excellent	1	1.56
				20–40- Good	10	15.63
				40–60- Permissible	29	45.31
				60–80- Doubtful	22	34.38
				>80-Unfit	2	3.12
KI (meq/L)	0.23	5.45	1.42 ± 0.00	>1-Unsuitable	27	42.19
				<1-Suitable	37	57.81

(25 locations) was good, 10.10% of the samples (6 locations) were uncertain, and 49.53% of the samples (32 locations) were unfit for irrigation purposes.

3.5.3. Magnesium hazard (MH)

A high concentration of magnesium ions in water has changed soil characteristics, turning it into alkaline earth and reducing agricultural production. Szabolcs and Darab (1964) suggested a magnesium risk value to determine if a groundwater water sample is suitable for agriculture (Eq.3). If the value of Magnesium risk is >50, the water sources are considered hazardous and unsuitable for irrigation. If the value is <50, the water sources are considered appropriate for irrigation. Based on the MH value of 100% (64 locations), if the value of a groundwater sample reaches 50, it is not appropriate for irrigation. Magnesium in the water affects soil quality, is alkaline, and lowers crop yields. The study recommends planting salt-tolerant crops and using crop rotation to enhance profits (Cuevas et al., 2019).

3.5.4. Permeability index (PI)

According to Rawat and Singh (2018), the permeability index (PI) can be categorized into three classes. Class I (PI 75% is appropriate), Class II (PI 25–75% is acceptable), and Class III (PI 25% is unsuitable). Permeability is a fundamental physical characteristic of soils that allows water to flow through them. The long-term application of excessive salt, calcium, magnesium, and bicarbonate water often affects soil permeability. In addition, higher sodium content alters the physical characteristics of soil by lowering permeability and changing the composition of the earth's substance. The permeability index has been computed using (Eq.4), expressed in meq/L. If the PI value is >75, it is considered safe (Class I). It is relatively safe, with a value range of 25-75 meq/L (Class II). A PI value of <25 meq/L indicates that the water is unfit for irrigation. In the study area, 100% of the samples (64 locations) fall under <25 and are unsafe, so it is unsuitable. As a result, it is advised that farmers in this region use gypsum (calcium and sulfate) while ploughing soil for field preparation since it may enhance water infiltration capacity by improving soil structure (Sheoran et al., 2021).

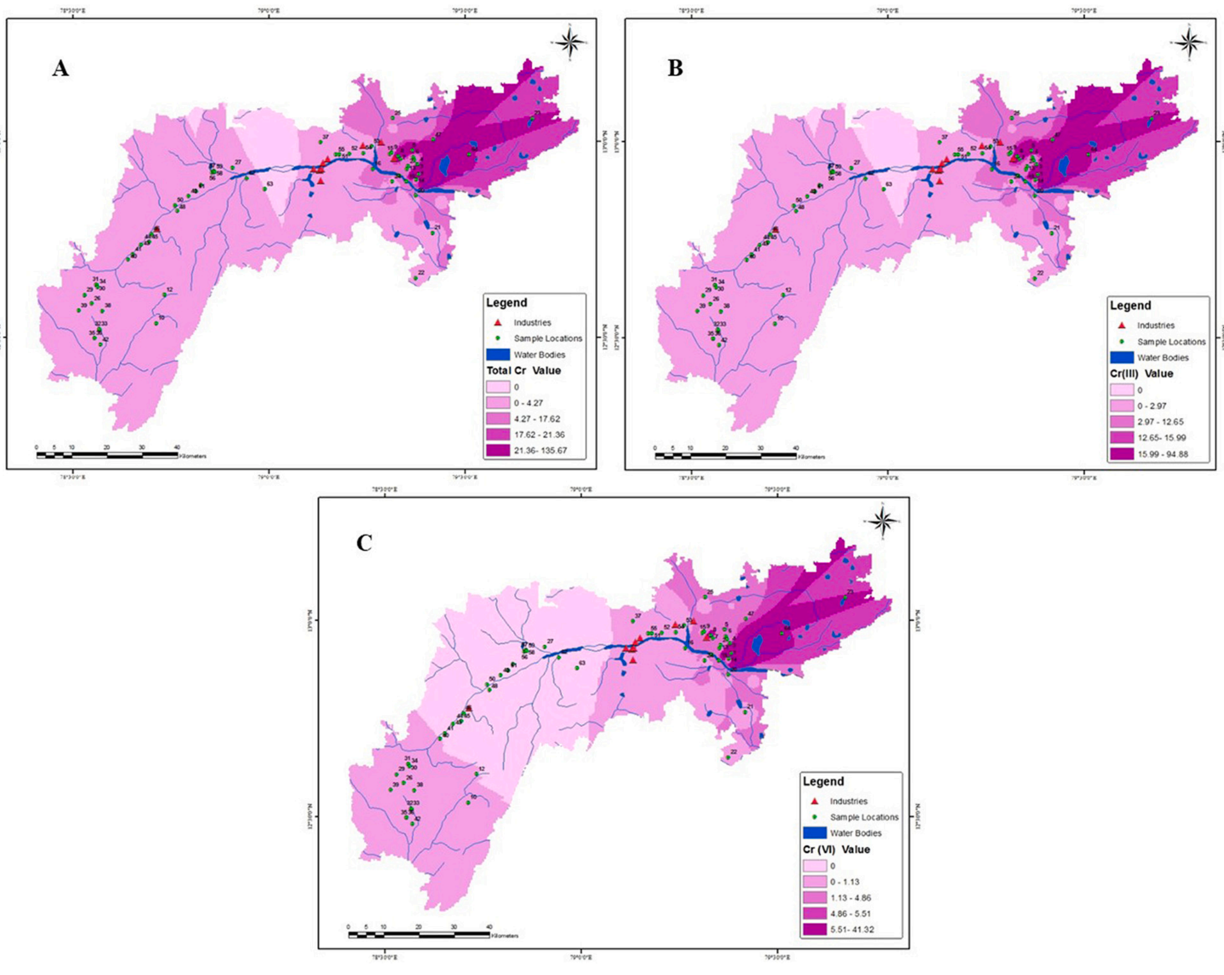

Fig. 7. Spatial distribution maps showing the speciation's of chromium (A) Total Cr; (B) Cr(III); (C) Cr(VI).

3.5.5. Sodium percentage (Na)

Wilcox (1955)classified groundwater into five categories based on sodium content and electrical Conductivity (Eq.5). The percentage of sodium exceeds 60%, and the water is unfit for agricultural use. Na^{+} exceeded the Organization and Zdrowia (2004) standard in some villages of the walajaphet and vaniyambadi regions. Water quality in the research region may be categorized as Excellent (1 location), Good (10 locations), Permissible (29 locations), Doubtful (22 locations), and Unfit (based on Na percent) (2 locations). The majority of the samples fall within the category of good to acceptable. It shows groundwater quality is deteriorating due to the industries' tannery waste disposal. Unsuitable drinking water causes severe health problems like hypertension, congenital diseases, kidney disorders, and nervous disorders in the human body (Rao et al., 2012). Na^{+} is the dominant ion present in the water among the other cations. This is because of the silicate weathering and/or dissolution of soil salts stored by the influences of evaporation and anthropogenic activities (Rao et al., 2012; Subba Rao, 2002), in addition to agricultural activities and poor drainage conditions. Moreover, the solubility of Na salts is generally high. According to GIS data from this study, 50% of the water quality in the study region is excellent. In comparison, the remaining 50% of groundwater samples are unfit for drinking or irrigation.

3.5.6. Kelly's index

Kelly's index was used to categorize irrigation water sources. A comparison of sodium levels against that of calcium and magnesium was considered by Kelly et al. (1946) and Paliwal and Singh (1967) to calculate this parameter (Eq.6). 1.0 l of water Kelly's index show an excessive salt content and therefore is inappropriate for irrigation. Water with Kelly's index of <1.0 alone is considered suitable for agricultural irrigation. Therefore, 27 samples (42.19%) are unsuitable for irrigation purposes in the study area, and 37 samples (57.81%) are suitable.

Based on the irrigational quality index, groundwater samples collected from different villages of the Vellore district is unsuitable for irrigation purpose. Hence, the water quality is inappropriate for agriculture. To remediate the groundwater, many physical and chemical remediation techniques include soil washing, vitrification, encapsulation of contaminated areas by impermeable vertical and horizontal layers, electrokinesis, and permeable barrier systems in groundwater. Furthermore, many carbon-based materials and bioamendments are used to remediate the heavy metal contaminated and polluted sites (G K Dinesh et al., 2022).

3.6. Spatial distribution level in groundwater

The geographical variations in irrigation water quality for all parameters were displayed using GIS. The pH was recorded higher in the Walajah Taluk than in all the Taluks in the Vellore district. Higher pH levels were caused by the calcareous character of the aquifers in the research region, which is a primary cause of the elevated pH levels in the study area.

The distribution of chromium (VI & III) in the study area is shown in Fig. 7B, C. Some part of the northeastern area and Walajapet Taluk groundwater was contaminated with Cr (VI). From the spatial distribution maps, Cr migration in water is governed by its species, primarily Cr^{3+} and Cr^{6+} forms; hence, understanding the Cr species is critical for its distribution in surface and groundwater. Unfortunately, very little to no data are generally available on chromium speciation in drinking water (DEFRA (Department for Environment, Food and Rural Affairs), E.A, 2002; WRC, 2015). Furthermore, the percentage of chromium and its species (Cr III & VI) are given in Fig. 7. The concentration of Cr (VI & III) in the region showed a maximum (42.7 mg/L) and minimum (0.28 mg/L). A higher concentration of hexavalent chromium was found in TK Thangal 1 from the Walajahpet Taluk, the same as the total and trivalent

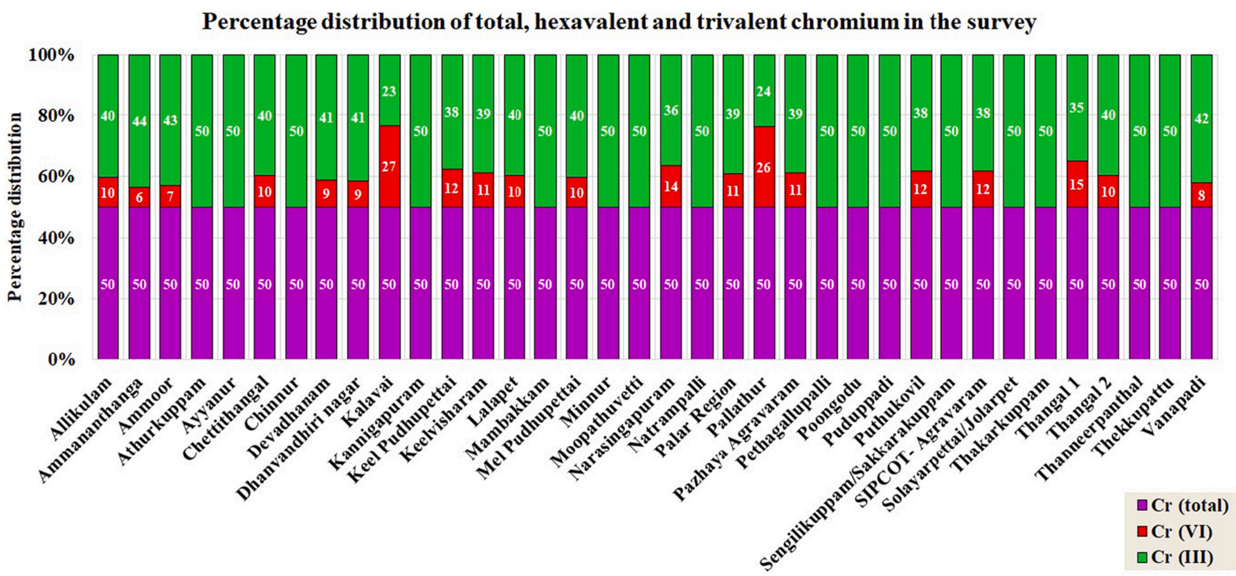

Fig. 8. Chromium distribution percentage in the study area.

chromium in the groundwater. So, all the chromium is bioavailable in the groundwater samples (Fig. 7A, B, C).

Similarly, the trivalent chromium in the groundwater samples showed below detectable levels in most samples. Cr $(OH)^{2+}$ was the dominant species in almost all water samples. Because Cr^{3+} predominates in the water in this area, excess Cr is likely to have come from nearby businesses rather than the TCCL site's deposited Cr waste. Similar to the Cr waste in the TCCL, the concentration of Cr^{3+} in runoff water collected from this location is lower. It is due to the Cr^{6+} solubility nature when compared to Cr^{3+}. However, when this effluent is released into the soil, Cr (III) is oxidized to a hazardous hexavalent form, which seldom stays as chromium owing to variable environmental circumstances (VI) (Govil et al., 2008; Gowd, 2005). Chromium, in its hexavalent form, is both poisonous and carcinogenic. Tanneries' effluent is a major source of chromium since they utilize chromium sulfate, a crucial ingredient in the tanning process. The trivalent chromium concentration in the study area ranges from BDL mg/L to 97.95 mg/L. The maximum level of chromium in drinking water, according to Indian standard standards, is 0.05 mg/L. Only six of the 64 groundwater samples analyzed exceeded the prescribed range. Cr (III) is a trace element necessary for mammals to maintain healthy metabolism of carbohydrates, lipids, and proteins.

On the other hand, Cr (VI) is poisonous to living organisms. Because of its oxidizing potential and the permeability of biological membranes, chromium is water-soluble, highly irritating, and toxic to human body tissue (Anderson, 2003). The distribution percentage of speciation of chromium is given in Fig. 8.

3.7. The geometry of the Pearson correlation matrix

The analyzed parameters were subjected to Pearson's correlation analysis using the SPSS software (v. 22). Pearson's correlation

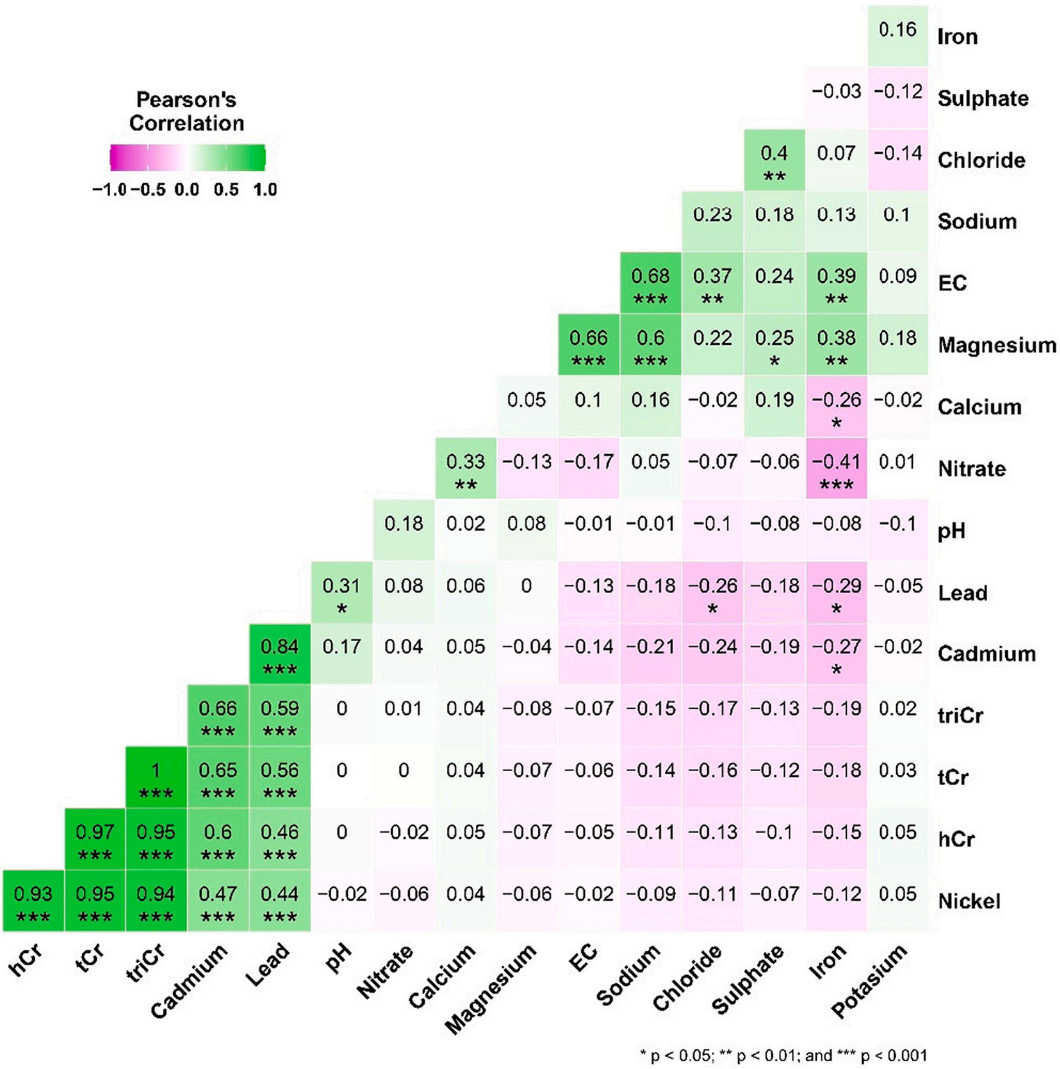

Fig. 9. Pearson correlation Co-efficient between major ions and metals.

analysis and Pearson's correlation coefficient matrixes for specific metals' properties were studied to show their interrelationships of the parameters are presented in Fig. 9. Iron has an excellent statistical significance level (*$P \leq 0.05$) with calcium and lead. Cadmium has a high level of statistical significance (**$P \leq 0.01$) with EC and magnesium and has a firm level of statistical significance (***$P \leq 0.001$) with Nitrate significant correlation exhibited between Iron and Calcium, EC, and Lead and EC, Nitrate. Magnesium shows good correlations with respective correlation coefficients. Sulfate has a good level of statistical significance (*$P \leq 0.05$) with magnesium and has a strong level of statistical significance (**$P \leq 0.01$) with chloride. Sulfate has a good level of statistical significance (*$P \leq 0.05$) with lead and has a strong level of statistical significance (**$P \leq 0.01$) with EC. The positive correlations between physicochemical variables imply that these metal species are involved in geochemical and biochemical processes that affect the water chemistry in the research region (Subba Rao et al., 2020). Sodium has a very high level of statistical significance (***$P \leq 0.001$) with EC and magnesium. EC has a very strong level of statistical significance (***$P \leq 0.001$) with magnesium. On the other hand, sodium has very low correlations with magnesium, suggesting it may come from a different source than the other trace elements (Kanagaraj and Elango, 2016). Calcium has a Strong level of statistical significance (**$P \leq 0.01$) with nitrate. pH has a good level of statistical significance

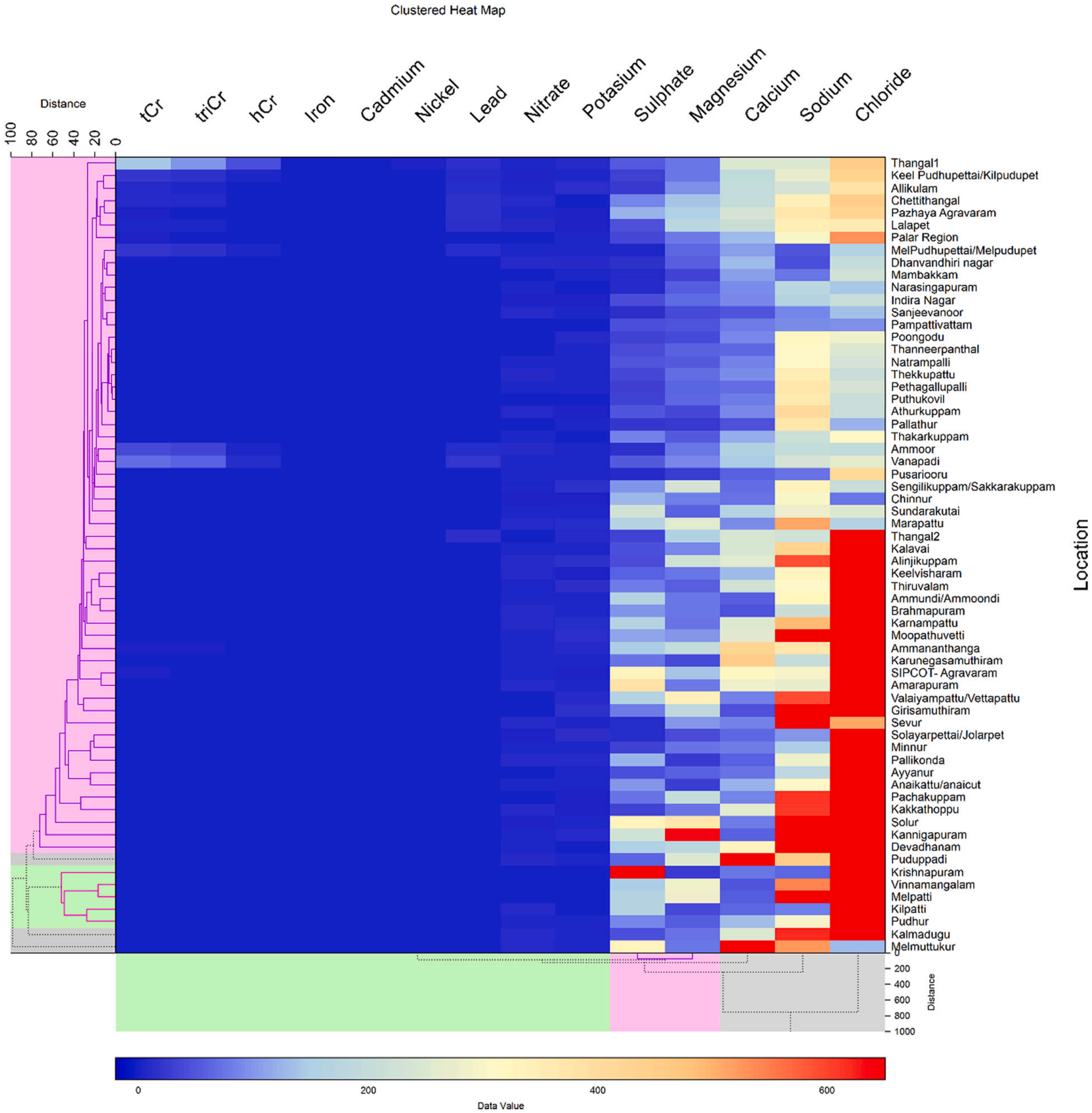

Fig. 10. Cluster analysis between major ions and metals in the study area.

(*$P \leq 0.05$) with lead. Lead has a very strong level of statistical significance (*$P \leq 0.001$) with nickel, hexavalent chromium, trivalent chromium, total chromium, and cadmium. Cadmium has a very strong level of statistical significance (*$P \leq 0.001$) with nickel, hexavalent chromium, trivalent chromium, and total chromium. Trivalent chromium has a very strong level of statistical significance (*$P \leq 0.001$) with nickel, hexavalent chromium, and total chromium. Total chromium has a very strong level of statistical significance (*$P \leq 0.001$) with nickel and hexavalent chromium. Hexavalent chromium has a very strong level of statistical significance (*$P \leq 0.001$) with nickel. These metal associations show that the groundwater has assimilated different pollutants from chemical industry operations and municipal sewage/landfill leachate systems (Akhtar et al., 2020; Tariq et al., 2010). The other parameters mentioned above are statistically non-significant. Iron has a moderate negative correlation with nitrate (−0.41). EC has a relatively high positive correlation with magnesium (0.66) and sodium (0.68). Sodium hasa high positive correlation with magnesium (0.60), and lead has a moderate positive correlation with nickel (0.44), hexavalent chromium (0.46), and total chromium (0.56) trivalent chromium (0.59), and a high positive correlation with cadmium (0.84). Cadmium has a moderate positive correlation with nickel (0.47) and a moderately high positive correlation with hexavalent chromium (0.60), total chromium (0.65), and trivalent chromium (0.66). The lack of connection between these heavy metals demonstrates that a single mechanism does not regulate the metals. Nickel and trivalent chromium have a strong positive relationship (0.94), hexavalent chromium (0.95), and a perfect positive correlation with total chromium (1.0). Total chromium has a very high positive correlation with nickel (0.95) and hexavalent chromium (0.97). Hexavalent Cr, Ni, and Cr have a strong positive relationship (0.93). The parameters mentioned above have a negligible weak or no correlation in Pearson's correlation analysis.

In Pearson's correlation analysis, all three chromium species, nickel, lead, and cadmium, have high statistical significance levels and moderate to high positive correlation values. Significant correlations between the metals Mn, Cu, Pb, and Cd showed that they might have come from a similar source, preferably from the industrial activity in the study area(Selvam and Venkatramanan, 2015). The statistically significant level is $p < 0.01$. The correlation matrix shows that pH and Cd and pH and Pb may share the same potential for contamination sources. Metals positively correlate with other physical parameters, and chromium positively correlates with EC and pH. All the parameters positively correlate with lead, nickel, and chromium heavy metals. The high concentration of these ions suggests that chemical weathering and chloride salt leaching are the most common processes (Esmaeili and Moore, 2012).

3.8. *Cluster analysis*

In this study, we have used the single linkage clustering method to find the nearest parameter based on distance value (Fig. 10). From the cluster analysis, among the water quality parameters, total chromium, hexavalent chromium, trivalent chromium, nitrate, iron, potassium, cadmium, nickel, and lead are based on the linkages clustered into a single cluster. Likewise, sulphate and magnesium are clustered in another cluster. On the other hand, chloride, Calcium, and Sodium are unclustered. Clusters occurred with a distance of 0.10 to 756.97, and the Cophenetic Correlation was 0.99.

Among the villages of Vellore district, based on the linkages distances, Thangal1, Thangal 2, Keel Pudhupettai, MelPudhupettai, Ammoor, Allikulam, Chettithangal, Vanapadi, PazhayaAgravaram, Lalapet, Narasingapuram, Ammananthanga, SIPCOT- Agravaram, Keelvisharam, Palar Region Moopathuvetti, Poongodu, Kalavai, Mambakkam, Amarapuram, Thakarkuppam, Natrampalli, Thekku-pattu, Pethagallupalli, Puthukovil, Chinnur, Sanjeevanoor, Pampattivattam, Pusariooru, Indira Nagar, Vettapattu, Girisamuthiram, Marapattu, Sengilikuppam, Ayyanur, Solur, Kannigapuram, Pachakuppam, Alinjikuppam, Sevur, Karnampattu, Thiruvalam, Ammoondi, Brahmapuram, Kakkathoppu, Sundarakutai, Karunegasamuthiram, PallikondaAnaikattu clustered into a single cluster. Likewise, Krishnapuram, Vinnamangalam, Melpatti, Kilpatti, and Pudhur are clustered in another cluster. Puduppadi, Kalmadugu, and Melmuttukur are unclustered. This finding suggests that these two clusters of metals do not have the same origin. By observing the second axis, it can be stated that magnesium, sulphate, and calcium probably have the same origin and that chloride is negatively correlated to nitrate and potassium. Due to this tannery industry, this region is considered to be the most polluted region (Sinduja et al., 2022a). The metals exclusively contribute to this axis, probably originating from the tannery industries of the Vellore district. These metals are found in phosphate fertilizers, where some of them, like lead and cadmium, are usually studied (Jiao et al., 2012). Clusters were occurring with a distance of 30.94 to 98.51, and Cophenetic Correlation was 0.85.

Results also showed that tannery effluents are rarely treated and are frequently improperly discharged onto land and into water bodies, and thereby reducing water quality. To prevent the improper discharge of untreated wastewater into open drains and to implement appropriate remediation technologies for decontaminating chromium from drinking and irrigational water as well as affected areas, it is crucial to develop strategies to improve the functional efficiency of effluent treatment plants (Sinduja et al., 2022a, 2022b). Such remediation technologies would support agriculture and also assist in reducing harmful effects in the environmental.

4. Conclusion

Groundwater is the primary source of water for domestic and agricultural use in the Vellore district, Tamilnadu. To assess groundwater usability for agricultural purposes, 64 samples were collected and tested for chromium (Cr) concentrations. Each parameter's concentration was compared to WHO guidelines to determine if the groundwater was safe for human consumption and irrigation. Groundwater samples in this research location had pH values ranging from neutral to slightly alkaline EC values of 17.19% of the groundwater samples. EC values of 17.19% of the total groundwater samples come under permitted levels, 39.06% under not permissible levels, and 43.75% under dangerous levels. In the research region, $Na^{+}$and Cl^{-} concentration in groundwater samples is >200 mg/L, bringing the majority of the groundwater samples in the study area into the non-safe category for drinking and agricultural purposes. Most groundwater samples include alkaline metals (Na^{2+}, K^{+}) than alkaline earth metals (Ca^{2+}, Mg^{2+}). The excessive salt in irrigation water may impair plant osmotic activity and reduce the soil's nutrition absorption. As a result, farmers in this region are advised to use gypsum (calcium sulfate) during soil ploughing to enhance water infiltration capacity by improving soil structure. The results indicated that most groundwater samples are unsuitable for irrigation crops. The general trend of the current research area's water quality index showed higher WQI values suggesting poor water quality. The main requirements for better water quality management for sustainable development in the research region include public awareness campaigns on the impact of poor water quality on human health and agricultural areas and rainwater conservation measures. The contaminated groundwater resources should be adequately treated before consumption. This would help to ensure the sustainability of public health now and in the future. Regular groundwater quality monitoring is also encouraged in this area.

Ethics approval and consent to participate

Not applicable.

Consent for publishing

Not applicable.

Availability of data and materials

The authors confirm that the data supporting the findings of this study are available within the article.

Code availability

Not applicable.

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Work contribution

M. Sinduja: Formal analysis, Investigation, Data Curation, Writing - Original Draft, Visualization, Software analysis, Conceptualization, Editing; **V. Sathya**: Conceptualization, Methodology, Validation, Review & Editing, Project administration, Funding acquisition, Supervision; **G K Dinesh**: Writing - Review & editing, Software analysis, Data analysis and visualization, language editing; **M. Maheswari**: Supervision, Review & editing; **P. Kalpana**: Resources, Lab accommodation, Review & editing; **Shiv Prasad**: Manuscript technical corrections & Suggestion, English language editing.

Author statement

None.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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