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Assessment of agricultural water quality parameters in Tiruppathur district, India

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Abstract

Agricultural water sources are crucial for farming communities and impact both crop health and human consumption. This study examines seasonal variations in the physical, chemical, and bacterial properties of agricultural water sources to understand its effects on public health and agricultural productivity. Water samples were collected from various agricultural wells during different seasons throughout the year. Parameters such as pH, temperature, turbidity, TDS, phosphates, nitrates, and heavy metals were analyzed, along with bacterial content, including *E. coli* and total coliforms. The water quality varied significantly year-round, according to the results, because of factors like rainfall and agricultural runoff. The findings indicated that variables like rainfall and agricultural runoff caused notable annual fluctuations in the quality of the water. Recommendations include improved filtration systems and agricultural practices to ensure safe water for both farming and human use.

Keywords: *E. coli;* Heavy metals; Pphysiochemical; Tannery effluents; Water sources

Introduction

In many parts of the world, tanneries are a major contributor to employment opportunities and economic growth in the leather industry. However, the tannery effluents released into the environment present a significant risk, especially concerning agricultural water sources. Ecological sustainability and public health are at risk when tannery effluents contaminate agricultural water with heavy metals. Agricultural water quality is crucial for crop productivity, environmental sustainability, and public health. In the Tiruppatur district, heavy metal contamination in tannery effluents poses challenges to sustainable practices and human well-being (Xavier *et al.* 2021). Bioremediation, a sustainable approach, uses microorganisms and plants to degrade pollutants, restoring environmental quality and supporting sustainable production systems (Singh *et al.* 2020). This approach is much more important in regions like Tiruppatur, where agriculture is the backbone of the economy. Several physicochemical factors, including pH, conductivity, turbidity, and dissolved oxygen, are important in assessing whether or not water is fit for human consumption. Freshwater, critical for all life, faces heavy metal contamination from human activities, causing harm to ecosystems and health. Toxic metals like lead, mercury, and arsenic can accumulate in the food chain, affecting organisms and humans. Industries and improper waste disposal contribute to metal pollution, necessitating mitigation strategies for environmental conservation. Urbanization and pesticide use also spread metal pollutants, worsening contamination (Karmaker *et al.* 2024). These elements can impact the water's aroma, smell, and looks, as well as how well it supports aquatic life and the health of ecosystems (Patil *et al.* 2012; Saleem *et al.* 2019; Nawab *et al.* 2021). In addition, indicator organisms were detected during heavy metal monitoring. Heavy metals are non-biodegradable, toxic, persistent, and pose ecological risks, accumulating in soil and sediments. These contaminants can enter

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the food chain, causing health issues like cancer, kidney dysfunction, and nerve tissue damage in humans.

Therefore, monitoring and assessing the physico-chemical characteristics of water sources' portability and safety is essential. A small portion of waste water is recycled for the tanning process, while the majority is released into the soil, rivers, and oceans, which contain high concentrations of salt, total solids saturated (TDS), chemical requirement for oxygen (COD), biochemical oxygen demand (BOD), and other pollutants like chromium, sulfate, synthetic tannins, and azo dyes (Singh *et al.* 2013). Released into the environment, tannery wastewater carrying dangerous contaminants profoundly contaminates soil and water, exposing human and other plant and animal health risks. Humans can be affected in several ways, starting with skin and nasal discomfort and progressing to lung cancer (Khan *et al.* 2015; Dhanarani *et al.* 2016). Consequently, it is essential to treat tannery effluents.

In addition to their physical-chemical properties, heavy metals in water sources should be taken seriously due to their potential for toxicity and negative health effects. Lead, arsenic, cadmium, and mercury are examples of heavy metals that can find their way into water sources due to natural processes, industrial operations, agricultural runoff, and inappropriate waste conveyance (WHO, 1996; Ayilara *et al.* 2020; Prabhakar *et al.* 2021). Identifying the forms of heavy metals in soil is crucial for managing their availability and preventing toxicity. Soil organic matter plays a key role in retaining heavy metals in exchangeable forms, affecting their bioavailability. It decomposes to release humic acids, which can bind metals and control their availability. The affinity of heavy metals for it varies, influencing their mobility and retention in soils. Addition of OM can alter heavy metal behavior in soils, affecting their availability to plants over time (Xu *et al*. 2015)

Plants are affected by the toxicity of free metal ions in the soil solution, with only labile metal species being accessible to plants. Numerous health problems, including cancer, kidney damage, and neurological diseases, have been linked to long-term exposure to high amounts of heavy metals in drinking water (Wu *et al.* 2018; Rai *et al.* 2019; Angon *et al*. 2024).

The purpose of this study is to assess the physicochemical and bacteriological characteristics of agricultural water sources like wells,with the seasons. To assess metal contamination risks and remediation feasibility, agriculturists need to identify heavy metals in both available and unavailable forms in the soil (Buccolieri *et al.* 2010). By evaluating these variations, the research seeks to identify possible risks to human and agricultural health as well as provide insights into the dynamics of water quality over different seasons.

Materials and methods

Study area

The study was conducted in the Tirupathur district of Southern India, a region known for its significant leather industry. This district encompasses several key locations where tannery operations are prevalent. The specific areas included in the study are Marapattu, Vadacheri, Kachirapet, Alankuppam, Chinnavarigam, Somalapuram, Solur, Thuttipattu, Devalapuram, and Samanthikuppum. Tirupathur district is strategically positioned, connecting major cities in Tamil Nadu and Andhra Pradesh, and includes two Revenue Divisions, four Taluks, and fifteen Revenue Firkas. The geographical coordinates of Tirupathur are approximately 12.4950° N latitude and 78.5678° E longitude.

Sample collection

Between 2019 and 2022, well water samples were taken at several sites in the Tirupathur district. Marapattu (S1, S2), Varadacheri (S3), Kachirapet (S4, S5, S15, S30), Alankuppam (S6, S7), Chinnavarigam (S8, S9), Somalapuram (S10, S22, S23), Solur (S11, S12, S24, S25), Thuttipattu (S13, S14), Bakkalampalli-Pernampet (S16, S17, S18), V.Kota Road (S19, S20), Periyavarigam (S21), Devalapuram (S26, S27), and Samanthikuppum (S28, S29) were among the sampling locations. Sampling was done to evaluate seasonal differences in water quality throughout both the rainy and dry seasons.

Water was collected in sterile plastic containers, with one liter being provided to each station. After the samples were gathered, the American Public Health Association's (APHA, 2012) standard operating protocols were adhered to to filter them as quickly as possible using the Whatman microfilter paper.

Physicochemical parameters

Each collecting point provided water samples, which were then analyzed for a range of physicochemical properties to assess the water's quality. The criteria included pH and electrical conductivity (EC) to identify the sample's acidity or basicity.

Is a measure of the concentration of ions in the water that reflects its ability to conduct electrical current, calcium (Ca^{2+}), magnesium (Mg^{2+}), chloride (Cl^{-}), total hardness (TH), carbonate (CO_3^{-2}), and bicarbonate (HCO_3), which were estimated following the standard method of APHA. While nitrate (NO^{3-}), phosphate (PO_4^{3-}), nitrite (NO_2), ammonia (NH_3), and silicate (Si_2O_3) were estimated following the method of Strickland and Parsons (1972).

Analysis of heavy metals

Seven different types of metals, including zinc (Zn), lead (Pb), copper (Cu), iron (Fe), nickel (Ni), chromium (Cr), and cadmium (Cd), were analyzed from the water samples. The identification and quantification of metals (As, Se, Hg, Be, Pb, Cd, Co, and V) were performed using an inductively coupled plasma mass spectroscopy (ICP-MS, NexION 2000, PerkinElmer, USA). An atomic absorption spectrophotometer (Shimadzu AAS-7000, Japan) was used to test other metals (Cr, Cu, Zn, and Ni). Certified reference materials (CRM) from Sigma-Aldrich Chemie (GmbH) (Switzerland) were used for the accuracy and precision of data (Karmaker *et al*. 2024). The US Environmental Protection Agency's recommended method, 3050B, was used to digest the water sample (Edokpayi *et al.* 2016). 50 mL of the sample and 3 mL of concentrated HNO_3 were combined in a beaker with a watch glass top. Next to that, the mixture was cooked on a hot plate in a fume hood until it boiled but still had a volume of less than 5 mL. Five milliliters of strong nitric acid were added once the sample had cooled. To finish the digestion process, the contents were cooked on the hot plate once more. Then, fifteen ml of deionized water and ten ml of 1:1 HCl were added. It took an additional fifteen minutes to heat the final solution. After cooling, the contents were filtered through a Whatman No. 1 filter paper. Next, the filtrate was transferred into a 100-mL volumetric flask and filled with deionized water.

The metals were identified quantitatively using VARIAN AA 240 with flame atomic absorption spectrometry. For the tested metals, the solution matrix's instrumental detection limits varied from 0.01 to 0.05 μgL^{-1}.

Bacteriological analysis

The bacteriological investigation included total heterotrophic bacterial and coliform counts. The pour plate method and the serial dilution method (Clesceri *et al.* 1998) were used. Aerobic heterotrophic bacteria were counted and isolated using a nutritional agar (NA, Oxoid Ltd., Basingstoke, UK) medium.

Coliform bacteria were isolated using Sorbitol MacConkey (SMAC) agar (Difco) and SS agar (Diagnostic Pasteur) media. Inoculated Petri dishes were incubated at 37°C for 24 h. A digital colony counter was employed to count the bacterial colony (OSK 10086, DC-3, Japan). After counting, discrete bacterial colonies were isolated immediately. Gram-positive aerobic heterotrophic bacterial isolates were identified using Bergey's Manual for Systematic Bacteriology (Sneath *et al.* 1986). A standard procedure outlined in the Manual for Laboratory Investigations of Acute Enteric Infections was used to identify the enteric bacteria (WHO 1987).

Results and discussion

Seasonal variation of water source quality

The physical and chemical characteristics of groundwater are needed to set standards for quality. The Bureau of Indian Standards (BIS) evaluates diverse techniques for evaluating water quality. A study on groundwater quality in the area indicated it was not suitable for agricultural purposes due to factors such as pH, TDS, EC, alkalinity, and hardness. The research assessed the physico-chemical characteristics of water samples obtained from various agricultural wells, with results detailed in Table I.

pH

The hydrogen ion concentration's acidity, or alkalinity, is indicated by the pH scale. It is particularly crucial for evaluating the water's quality. The pH range of groundwater samples collected during several seasons is 6.7–7.41 to 6.8–7.8. However, the pH values were somewhat higher during the dry season. The pH levels were somewhat alkaline throughout the dry season, ranging from 6.7 to 7.7, which is considered optimal for aquatic species to flourish (Kumar *et al.* 2020). These values fall within the acceptable range set by the BIS (WHO, 2011) of 6.5–8.5. The water is appropriate for agricultural, recreational, and residential use. pH is influenced by factors like industrial waste, mineral content, and organic matter in water sources (Awan *et al.* 2012). Deviations from the ideal pH range can lead to negative effects such as a bitter taste in water, scaling in pipes and appliances, and reduced effectiveness of chlorine disinfection. Despite variations due to factors like mineral reactions with water and temperature, most groundwater samples remain stable within acceptable pH levels throughout different seasons (Koul Nishtha *et al.* 2012).

Temperature

Temperature is a key ecological factor that influences the behavior and distribution of organisms. The heat released during organic matter decomposition and respiration also contributes slightly to the overall temperature. In the monsoon season, temperatures varied from 30°C to 33°C in various locations. The highest temperatures of 41°C and 45°C were recorded during the summer season, with the maximum temperatures occurring in all villages. Summer

Table I. Seasonal variation of physico-chemical parameters of water samples from wells impacted by the tanneries during wet season in the year 2019

S.No	Parameters and Units	Acceptable limit (BIS 10500:2012)	Well water samples collected near tanneries				
			Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
1	Temperature (°C)	-	31	30	32	31	32
2	Appearance		Clear	Clear	Clear	Clear	Clear
3	Colour (pt.co.scale)	5-15	Colourless	Colourless	Colourless	Colourless	Colourless
4	Odour	Agreeable	None	None	None	None	None
5	Turbidity (NTU)	1	3	2	1.5	1.5	2
6	Total dissolved solids (mg/L)	500-2000 (mg/L)	8330	8650	7140	8330	7500
7	Electrical conductivity (micro mho/cm)	-	11900	9500	10200	11800	10000
8	pH	6.5-8.5	7.41	7.44	7.10	7.33	7.25
9	Alkalinity Total as $CaCO_3$ (mg/L)	200-600 (mg/L)	636	532	588	636	576
10	Total Hardness as $CaCO_3$ (mg/L)	200-600 (mg/L)	3800	3500	3700	4100	3600
11	Chromium (mg/L)	0.05 (mg/L)	1.10	0.78	0.59	0.87	1.08
12	Lead (mg/L)	0.01 (mg/L)	0.005	0.002	0.004	0.005	0.003
13	Calcium (mg/L)	75-200 (mg/L)	760	720	760	540	720
14	Magnesium (mg/L)	30-100 (mg/L)	456	408	432	480	432
15	Sodium as Na (mg/L)	200 (mg/L)	282	319	390	296	435
16	Potassium (mg/L)	200 (mg/L)	18	22	29	28	25
17	Iron (mg/L)	0.3-1.0 (mg/L)	0.06	0.09	0.13	0.14	0.10
18	Nickel (mg/L)	0.02 (mg/L)	0.03	0.03	0.02	0.02	0.03
19	Zinc (mg/L)	5.0 (mg/L)	1.14	1.16	0.97	0.98	1.17
20	Copper (mg/L)	0.05 (mg/L)	0.02	0.01	0.01	0.02.	0.02
21	Manganese (mg/L)	0.1-0.3 (mg/L)	0.23	0.21	0.18	0.20	0.16
22	Cadmium (mg/L)	0.003 (mg/L)	0.004	0.003	0.004	0.002	0.004
23	Free Ammonia (mg/L)	0.5 (mg/L)	0.24	0.21	0.25	0.21	0.21
24	Nitrite as NO_2 (mg/L)	_	0.04	0.02	0.02	0.02	0.03
25	Nitrate as NO_3 (mg/L)	45 (mg/L)	98	40	95	93	94
26	Chloride (mg/L)	250-1000 (mg/L)	3000	2000	2100	2800	2100
27	Fluoride (mg/L)	1.0 (mg/L)	0.3	0.6	0.3	0.5	0.4
28	Sulphate as SO_4 (mg/L)	200 - 400(mg/L)	1073	896	1033	1073	977
29	Phosphate as PO_4 (mg/L)	_	0.06	0.09	0.09	0.08	0.06
30	Tidys Test 4Hrs.as O_2 (mg/L)	_	0.2	0.2	0.3	0.2	0.3
31	E. Coli count (cfu/mL)	-	1.73	1.92	1.81	1.98	1.77
32	Faecal streptococci count (cfu/mL)	-	0.77	1.53	0.97	0.93	1.34

Marapattu = (Sample – S1 & S2) , Vadacheri = (Sample – S3), Kachirapet = (Sample –S4, S5)

temperatures were significantly higher ($P<0.05$) compared to the rainy season, but all temperatures observed were within the recommended ambient temperature range by organizations such as WHO and NSDWQ (WHO, 2021; NSDWQ, 2023).

Turbidity

The cloudiness of the water sample signifies a decrease in clarity. It can impede the passage of light rays, affecting the process of photosynthesis. Water turbidity is typically caused by the presence of suspended and colloidal particles like clay, silt, organic and inorganic matter, plankton, and tiny organisms. While turbidity can make water seem more colored, it doesn't alter its true color. The study noted that the turbidity levels in the sample stations were within the acceptable range of 5 NTU. During the wet season in 2017, turbidity readings ranged from 1 to 2 NTU, while in the dry season, they ranged from 2 to 3 NTU. These values were generally below the WHO and NSWDQ (WHO, 2004; NSWDQ, 2007) recommended limits. However, some areas showed slightly higher turbidity levels during the dry season compared to the wet season. It was observed that all well water samples collected in the Ambur taluk area were clear, with no visible color, odor, or turbidity (Tables I - VI).

Electrical conductivity (EC)

The electrical conductivity (EC) of the water is used to calculate its salinity. The EC value typically shows if water has dissolved ions. The ions can change water's taste, make it harder, and indicate pollution levels. Water with high conductivity could be an indicator of severe inorganic pollution. Because ions in high-EC water can cause salinity in agricultural land, it is not advised to utilize it for irrigation or residential use.

Electrical conductivity is a way to measure how water sources can carry an electric current, serving as an indicator of dissolved solids. As the amount of dissolved minerals (ions) in water increases, its electrical conductivity also increases. The recommended limit for EC in drinking water is 1500 μScm^{-1}, with a permissible limit of 3000 μScm^{-1}. In the particular area under study, conductivity levels ranged from 2200 μScm^{-1} to 11900 μScm^{-1}, with the highest values observed in water source like wells, the samples collected from Marapattu, Vadacheri, and Solur villages (Tables III - VIII). The elevated EC levels in the area suggest a high presence of sodium salts in the well water, likely due to salt usage from the leather industry and extensive chemical and fertilizer applications in agriculture. These substances can be retained in the soil or dissolved into water bodies, eventually reaching the wells and leading to the observed high electrical conductivity levels. (Fig. 1).

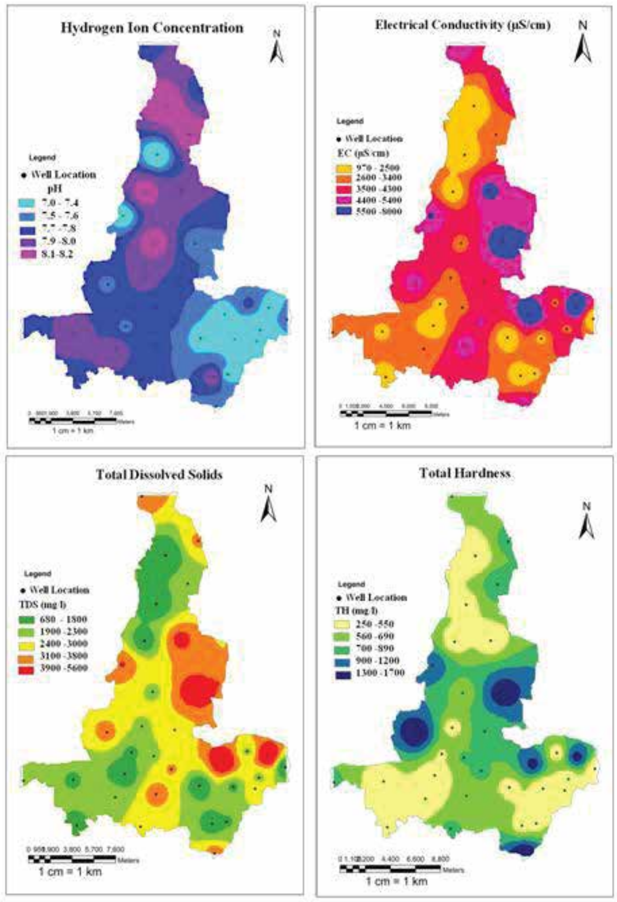

Fig. 1. Spatial variation of pH, EC, TDS and TH in groundwater

Total Alkalinity

The water's alkalinity represents its ability to neutralize strong acids, mainly due to carbonate, bicarbonate, borates, silicates, phosphates, humic and fulvic acid salts, and hydroxide levels resulting from carbon dioxide dissolution. Moreover, industrial discharges like calcium hydroxide and sodium hydroxide from various industries also contribute to water alkalinity. A 200–600 mg/L maximum for total alkalinity in drinking water has been set by the Bureau of Indian Standards (BIS). The research areas' total alkalinity values, expressed as $CaCO_3$, ranged from 324 to 636 mg/L. High alkalinity is a result of elevated bicarbonate (HCO_3) and carbonate (CO_3) levels, while high carbonates lead to the dominance of sodium ions because they produce insoluble minerals from the calcium and magnesium ions. There are instances where the bicarbonates of calcium and magnesium are the exclusive cause of the alkalinity of water.

Total dissolved solids (TDS)

The term "total dissolved solids" (TDS) refers to all kinds of organic and inorganic materials that are dissolved in water and have an impact on the water's appropriateness for use. These materials can be molecular, ionized, or micro-granular (colloidal sol). Elevated levels of total dissolved solids can

Table II. Seasonal variation of physico-chemical parameters of water samples from wells impacted by the tanneries during wet season in the year 2020

S.No	Parameters and Units	Acceptable limit (BIS 10500:2012)	Well water samples collected near tanneries				
			Sample 6	Sample 7	Sample 8	Sample 9	Sample 10
1	Temperature (°C)	-	31	30	32	31	32
2	Appearance		Clear	Clear	Clear	Clear	Clear
3	Colour (pt.co.scale)	5-15	Colourless	Colourless	Colourless	Colourless	Colourless
4	Odour	Agreeable	None	None	None	None	None
5	Turbidity (NTU)	1	1	2	1.5	1.5	2
6	Total dissolved solids (mg/L)	500-2000 (mg/L)	1540	2170	2800	4270	6650
7	Electrical conductivity (micro mho/cm)	-	2200	3100	4000	6100	9500
8	pH	6.5-8.5	6.8	7.50	7.78	7.41	7.10
9	Alkalinity Total as $CaCO_3$ (mg/L)	200-600 (mg/L)	512	388	324	395	580
10	Total Hardness as $CaCO_3$ (mg/L)	200-600 (mg/L)	760	1130	1320	1760	3400
11	Chromium (mg/L)	0.05 (mg/L)	0.769	0.655	0.834	0.990	1.168
12	Lead (mg/L)	0.01 (mg/L)	0.003	0.003	0.002	0.004	0.004
13	Calcium (mg/L)	75-200 (mg/L)	152	228	264	362	680
14	Magnesium (mg/L)	30-100 (mg/L)	101	134	158	213	408
15	Sodium as Na (mg/L)	200 (mg/L)	398	435	452	366	547
16	Potassium (mg/L)	200 (mg/L)	20	18	26	19	22
17	Iron (mg/L)	0.3-1.0 (mg/L)	0.15	0.17	0.09	0.08	0.13
18	Nickel (mg/L)	0.02 (mg/L)	0.05	0.04	0.02	0.02	0.04
19	Zinc (mg/L)	5.0 (mg/L)	1.36	0.99	0.97	0.98	1.17
20	Copper (mg/L)	0.05 (mg/L)	0.03	0.02	0.01	0.03	0.02
21	Manganese (mg/L)	0.1-0.3 (mg/L)	0.14	0.21	0.17	0.22	0.20
22	Cadmium (mg/L)	0.003 (mg/L)	0.001	0.002	0.002	0.001	0.003
23	Free Ammonia (mg/L)	0.5 (mg/L)	0.41	0.33	0.29	0.21	0.21
24	Nitrite as NO_2 (mg/L)	–	0.03	0.02	0.04	0.02	0.03
25	Nitrate as NO_3 (mg/L)	45 (mg/L)	33	40	49	46	49
26	Chloride (mg/L)	250-1000 (mg/L)	355	660	910	1510	2050
27	Fluoride (mg/L)	1.0 (mg/L)	0.4	0.6	0.4	0.5	0.6
28	Sulphate as SO_4 (mg/L)	200 - 400(mg/L)	131	275	389	504	823
29	Phosphate as PO_4 (mg/L)	_	0.03	0.02	0.03	0.05	0.09
30	Tidys Test 4Hrs.as O_2 (mg/L)	_	0.1	0.2	0.1	0.2	0.2
31	E. Coli count (cfu/mL)	-	1.66	1.74	2.10	2.00	1.89
32	Faecal streptococci count (cfu/mL)	-	0.77	1.14	0.82	0.86	1.25

Alankuppam = (Sample- S6, S7), Chinnavarigam = (Sample- S8, S9) Somalapuram = (Sample - S10)

lead to an unpleasant taste. In the research area, the TDS values in groundwater exceed the recommended limit of 500 mg/L, with a maximum permissible limit of 1500 mg/L. TDS levels in the region vary from 1540 mg/L to 8650 mg/L, with well water samples taken from the villages of Marapattu, Vadacheri, Solur, Chinnavarigam, and Periavariagm exhibiting the highest values. High TDS levels during the dry season are likely due to salt dissolution from agricultural runoff, soil contamination leaching, and point sources like industrial and sewage treatment plants.

All well water samples displayed elevated TDS levels, surpassing the permissible limit set by BIS. The high TDS concentration in the groundwater samples is attributed to the leaching of salts from soils as well as the potential percolation of industrial and municipal waste into the groundwater, resulting in a significant rise in dissolved solids.

Total hardness (TH)

The water's hardness is not determined by chemical parameters; nonetheless, it mostly represents the calcium (Ca) and magnesium (Mg), expressed as $CaCO_3$, content of the water. The total hardness in groundwater samples ranged from 760 mg/l to 3400 mg/l, with the highest value observed in well water from Marapattu, Vadacheri, and Solur villages, indicating unsuitability for agricultural use (Tables III–VIII). Total hardness has an admissible limit of 200 mg/l, with a maximum limit of 600 mg/l. All the well water samples had elevated total hardness values surpassing the Bureau of Indian Standards (BIS) allowed limit (Fig. 1). The total hardness (TH) in milligrams per liter (mg/L) was calculated using the formula: TH = 2.497 Ca^{2+} + 4.115 Mg^{2+}.

The elevated total hardness levels could be attributed to the infiltration of textile discharge, leading to direct contamination of groundwater with various pollutants that spread throughout. Excessive water hardness can pose health risks, such as kidney stones and other ailments, to individuals using the water (Ravishankar and Poongothai, 2008). While evaluating if water is suitable for use in homes, businesses, or both, water hardness is a critical factor to consider (Karnath *et al.* 1987). Different agricultural regions showed varied hardness levels, with areas of high hardness often associated with intensive farming practices necessitating more chemical use in the area.

Chloride (Cl^-)

The research area's groundwater samples show that chloride is the most abundant anion, followed by bicarbonate, sulfate, and nitrate. The concentration of chloride in the study area ranges from 355 mg/L to 3000 mg/L, exceeding the BIS permissible limit for drinking water of >250 mg/L to 1000 mg/L. In the research location, the chloride levels in almost all well water samples were greater than the allowable limit. The water's chloride content can be linked to sources like the accumulation of salt, tannery effluents, and high chloride levels in drinking water, affecting water quality and crops. The high chloride levels in groundwater may result from various natural and human activities like brick production, fertilizer use, industrial processes, and waste disposal, contributing to heavy metal concentrations during the winter season (Bundela *et al.* 2012; Ahamad *et al.* 2020).

Sulphate (SO_4^{2-})

The source of sulfate ($SO4^{-2}$) from tanneries includes chemicals like ammonium sulfate, sodium sulfate, and chrome

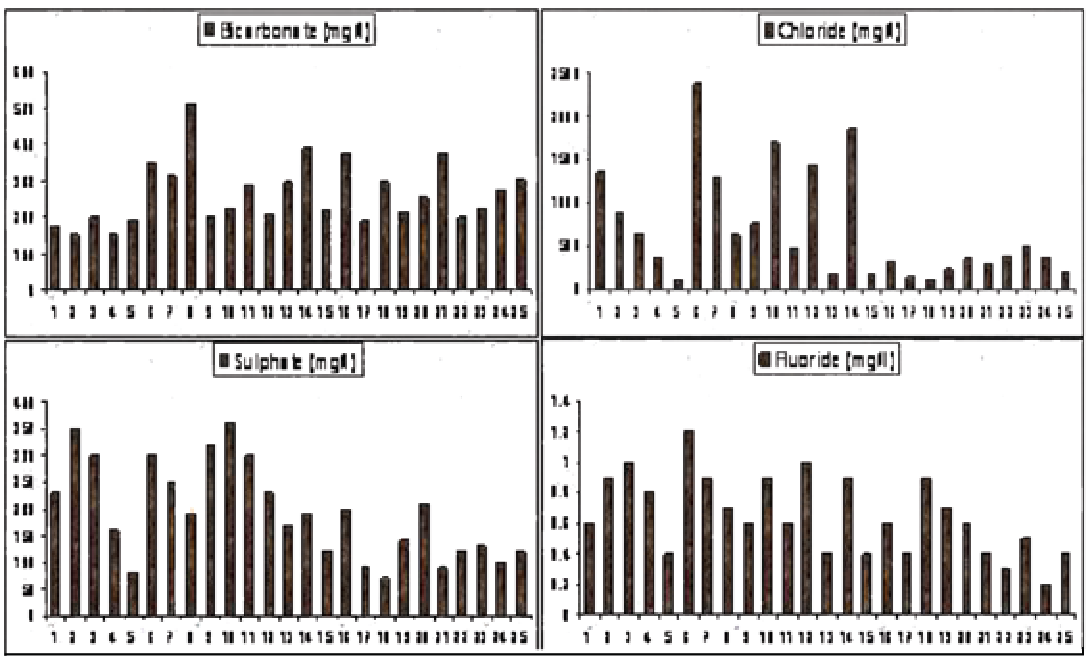

Fig. 2. Variations of HCO_3, Cl , SO_4 and F in groundwater

Table III. Seasonal variation of physico-chemical parameters of water samples from wells impacted by the tanneries during dry season in the year 2021

S.No	Parameters and Units	Acceptable limit (BIS 10500:2012)	Well water samples collected near tanneries				
			Sample 11	Sample 12	Sample 13	Sample 14	Sample 15
1	Temperature (°C)		42	41	40	44	43
2	Appearance	-	Clear	Clear	Clear	Clear	Clear
3	Colour (pt.co.scale)	5-15	Colourless	Colourless	Colourless	Colourless	Colourless
4	Odour	Agreeable	None	None	None	None	None
5	Turbidity (NTU)	1	2.5	2	2.5	3	3
6	Total dissolved solids (mg/L)	500-2000 (mg/L)	1955	2779	3280	7165	6390
7	Electrical conductivity (micro mho/cm)	-	2450	3500	4550	9900	9550
8	pH	6.5-8.5	6.76	6.88	6.55	6.82	6.71
9	Alkalinity Total as $CaCO_3$ (mg/L)	200-600 (mg/L)	655	489	443	628	559
10	Total Hardness as $CaCO_3$ (mg/L)	200-600 (mg/L)	790	1677	1980	3840	3755
11	Chromium (mg/L)	0.05 (mg/L)	1.10	0.99	1.08	1.17	1.36
12	Lead (mg/L)	0.01 (m g/L)	0.004	0.005	0.003	0.004	0.005
13	Calcium (mg/L)	75-200 (mg/L)	167	290	329	755	699
14	Magnesium (mg/L)	30-100 (mg/L)	105	157	163	529	488
15	Sodium as Na (mg/L)	200 (mg/L)	491	542	357	465	549
16	Potassium (mg/L)	200 (mg/L)	27	31	23	29	32
17	Iron (mg/L)	0.3-1.0 (mg/L)	0.29	0.26	0.25	0.28	0.23
18	Nickel (mg/L)	0.02 (mg/L)	0.06	0.04	0.05	0.06	0.04
19	Zinc (mg/L)	5.0 (mg/L)	1.25	1.10	1.36	1.43	1.28
20	Copper (mg/L)	0.05 (mg/L)	0.05	0.04	0.02	0.03	0.04
21	Manganese (mg/L)	0.1-0.3 (mg/L)	0.32	0.30	0.29	0.25	0.27
22	Cadmium (mg/L)	0.003 (mg/L)	0.004	0.003	0.004	0.003	0.005
23	Free Ammonia (mg/L)	0.5 (mg/L)	0.48	0.34	0.35	0.49	0.57
24	Nitrite as NO_2 (mg/L)	_	0.08	0.09	0.07	0.05	0.07
25	Nitrate as NO_3 (mg/L)	45 (mg/L)	47	59	65	48	53
26	Chloride (mg/L)	250-1000 (mg/L)	398	760	983	2755	2400
27	Fluoride (mg/L)	1.0 (mg/L)	0.6	0.7	0.8	0.9	0.5
28	Sulphate as SO_4 (mg/L)	200 - 400(mg/L)	128	207	289	713	695
29	Phosphate as PO_4 (mg/L)	_	0.07	0.04	0.08	0.09	0.04
30	Tidys Test 4Hrs.as O_2 (mg/L)	_	0.2	0.2	0.3	0.2	0.3
31	E. Coli count (cfu/mL)	-	1.53	1.60	1.92	1.87	1.79
32	Faecal streptococci count (cfu/mL)	-	0.68	0.99	0.74	0.53	0.75

Solur = (Sample- S11, S12), Thuttipattu = (Sample- S13, S14), Kachirapet = (Sample - S15)

sulfate commonly used in the tanning process. The release of these chemicals into the groundwater through effluents could result in groundwater contamination. Effluents discharged by factories into open drains also produce a strong odor at times. During the study, the region's sulfate concentrations varied from 131 mg/l to 864 mg/l, with some wells showing concentrations exceeding the permitted limits. The elevated sulfate ion amounts in the groundwater samples surpassed the standard levels set by the BIS (200 mg/l to 400 mg/l) (WHO, 2011). Particularly high sulfate concentrations were recorded in well water samples from Marapattu (1073 mg/l), Periyavarigam (912 mg/l), and Somalapuram (950 mg/l) villages. The presence of sulfate in irrigation water can offer fertility benefits, supporting maximum crop production in the region. In comparison to the summer, the sulfate levels are lower during the rainy season, which may be due to dilution. Elevated sulfate levels contribute to a bitter flavor in the water (Lopez *et al.* 2017).

Fluoride

In the research area, it was observed that the fluoride ion concentration ranged from 0.3 mg/l to 0.9 mg/l, which is below the Bureau of Indian Standards (BIS)-established allowable limit of 1.0 mg/l for drinking water. The concentration of free ammonia in all the villages examined was within the acceptable limit of 1.0 mg/l (BIS 10500:2012). The variations in chloride levels in well water in the study area are depicted in Fig. 2. The presence of minerals containing fluoride may contribute to the elevated fluoride levels in the groundwater samples, emphasizing the importance of addressing high fluoride concentrations in drinking water (Shaji *et al.* 2024; Ramachandramoorthy *et al.* 2009).

Nitrate (NO_3^-)

Nitrate, the oxidized form of nitrogen, is the product of organic nitrogen-containing materials' aerobic breakdown. The presence of nitrate in freshwater bodies is primarily influenced by the activity of nitrifying bacteria and sources like domestic and agricultural runoff. The nitrate levels in the observed area range from 33 to 94 mg/L, with a permissible limit of 45 mg/L. The village of Thutipattu had the highest nitrate concentration at 94 mg/L. While nitrates are usually present in small amounts in surface waters, they can reach higher concentrations in certain groundwater sources. Concentrations exceeding 100 mg/L can be harmful to aquatic life, and excessive levels can lead to methemoglobinemia in infants.Excess nitrate levels in the body can lead to methemoglobinemia or blue baby syndrome, higher infant mortality rates, miscarriages, birth defects, cancer, immune system deterioration, high blood pressure, and other health issues. Infants are more vulnerable to these effects from nitrate exposure through drinking water compared to adults. Moreover, nitrates being present in groundwater and surface water can harm animal health and contribute to water eutrophication, mainly coming from sources like agrochemicals, runoff from farms, septic systems, livestock waste, and industrial activities (Brindha, *et al.* 2017).

Nitrite (NO_2^-)

In the study location, well-water samples usually contain relatively modest amounts of nitrite. The World Health Organization (WHO, 2004) has established a maximum of 3 mg/L as the permissible maximum for nitrate in drinking water. Many factors were investigated in the electrocatalytic reduction of nitrate in continuous flow processes, including cathode material, cell design, beginning nitrate concentration, current density, initial pH, co-existing ions, concentration of chloride ions, and additives. The stability of the cathode material was extensively discussed as a crucial aspect of the technology used for nitrite treatment (Meng *et al.* 2023).

Phosphate (PO_4^{3-})

Phosphorus is commonly found in natural water in the form of phosphates, including orthophosphates, polyphosphates, and organically bound phosphates. It is essential. Plant nutrients are utilized in fertilizers because they are necessary for plant growth and because they are important to animal and plant metabolism. In the research area, phosphate levels in well water samples are typically low.

Ammonia (NH_3)

Ammonia is produced when nitrogen-rich organic materials break down. In our research area, we noticed that free ammonia levels ranged from 0.34 mg/L to 0.57 mg/L. Ammonia is harmful to aquatic organisms, but it can be eliminated through biological oxidation methods, as detailed in Tables III to VIII. As to BIS 10500:2012, all the villages surveyed had free ammonia levels that were within the safe limit of 0.5 mg/l.

Sodium (Na^+)

Among the positively charged ions, sodium (Na^+) was found to be the predominant ion in groundwater, with concentrations exceeding 50 mg/L, rendering the water unfit for hou sehold purposes. The elevated levels of Na^+ and Ca^{2+} in the groundwater were linked to cation exchange processes between minerals and effluent pollution. In the tanning industry, sodium chloride and sodium sulfide are commonly used chemicals during the liming phase. The investigation found that salt concentrations in the region ranged from 282 mg/L to 590 mg/L, exceeding the 200 mg/L allowable limit listed in BIS Tables III to VIII. Such high sodium levels pose health risks such as hypertension, arterial hardening, swelling, and increased osmotic pressure. Irrigation water rich in sodium can alter soil properties, affecting its permeability, texture, and aeration, and subsequently impacting plant

Table IV. Seasonal variation of physico-chemical parameters of water samples from wells impacted by the tanneries during wet season in the year 2022

S.No	Parameters and Units	Acceptable limit (BIS 10500:2012)	Well water samples collected near tanneries				
			Sample 16	Sample 17	Sample 18	Sample 19	Sample 20
1	Temperature (°C)	-	32	33	33	34	33
2	Appearance	-	Clear	Clear	Clear	Clear	Clear
3	Colour (pt.co.scale)	5-15	Colourless	Colourless	Colourless	Colourless	Colourless
4	Odour	Agreeable	None	None	None	None	None
5	Turbidity (NTU)	1	1.5	3	2	2	2.5
6	Total dissolved solids (mg/L)	500-2000 (mg/L)	5950	5810	5320	4060	5040
7	Electrical conductivity (micro mho/cm)	-	8500	8300	7600	5800	7200
8	pH	6.5-8.5	7.50	7.61	7.07	7.37	7.10
9	Alkalinity Total as $CaCO_3$ (mg/L)	200-600 (mg/L)	536	400	536	404	404
10	Total Hardness as $CaCO_3$ (mg/L)	200-600 (mg/L)	3200	2300	1960	1440	1920
11	Chromium (mg/L)	0.05 (mg/L)	0.545	0.597	0.880	0.952	0.938
12	Lead (mg/L)	0.01 (mg/L)	0.001	0.001	0.002	0.003	0.003
13	Calcium (mg/L)	75-200 (mg/L)	640	480	392	288	384
14	Magnesium (mg/L)	30-100 (mg/L)	384	264	235	230	230
15	Sodium as Na (mg/L)	200 (mg/L)	288	474	390	346	438
16	Potassium (mg/L)	200 (mg/L)	19	23	31	35	28
17	Iron (mg/L)	0.3-1.0 (mg/L)	0.12	0.11	0.12	0.14	0.13
18	Nickel (mg/L)	0.02 (mg/L)	0.03	0.02	0.03	0.04	0.03
19	Zinc (mg/L)	5.0 (mg/L)	1.76	1.42	1.37	1.55	1.22
20	Copper (mg/L)	0.05 (mg/L)	0.04	0.05	0.03	0.02	0.03
21	Manganese (mg/L)	0.1-0.3 (mg/L)	0.17	0.19	0.23	0.25	0.12
22	Cadmium (mg/L)	0.003 (mg/L)	0.002	0.003	0.001	0.003	0.002
23	Free Ammonia (mg/L)	0.5 (mg/L)	0.49	0.45	0.34	0.37	0.48
24	Nitrite as NO_2 (mg/L)	_	0.03	0.04	0.06	0.05	0.06
25	Nitrate as NO_3 (mg/L)	45 (mg/L)	48	46	54	48	54
26	Chloride (mg/L)	250-1000 (mg/L)	1700	1750	1660	1550	1690
27	Fluoride (mg/L)	1.0 (mg/L)	0.9	0.4	0.5	0.8	0.7
28	Sulphate as SO_4 (mg/L)	200 - 400(mg/L)	557	856	864	565	578
29	Phosphate as PO_4 (mg/L)	_	0.04	0.02	0.03	0.04	0.03
30	Tidys Test 4Hrs.as O_2 (mg/L)	_	0.3	0.3	0.1	0.2	0.1
31	E. Coli count (cfu/mL)	-	1.88	1.76	2.00	1.91	1.65
32	Faecal streptococci count (cfu/mL)	-	2.10	1.91	0.95	1.33	1.17

Bakkalapalli (Pernambut) = (Samples - S16, S17, S18) , V.Kota road (Pernambut) = (Samples – S19, S20)

growth and seed germination. Excessive sodium content may lead to the displacement of calcium and magnesium in the soil, resulting in soil structure deterioration and reduced permeability.

Seasonal dynamics of heavy metals

Tables I to 6 illustrate the six concentrations of heavy metals (Cr, Pb, Fe, Cu, Mg, Ni, Cd, and Zn) throughout two significant seasons. The seasonal fluctuation of heavy metals in water was controlled by physiochemical characteristics. In the current investigation, the concentration of heavy metals found in well water samples was higher during the dry season than during the wet season. The current study examined the presence of heavy elements such as chromium (Cr), lead (Pb), iron (Fe), copper (Cu), manganese (Mn), nickel (Ni), cadmium (Cd), and zinc (Zn) in well water samples from 30 stations. Tables I through 6 show the amount of heavy metal present in the well water. All the heavy metals present

Table V. Seasonal variation of physico-chemical parameters of water samples from wells impacted by the tanneries during dry season in the year 2019

S.No	Parameters and Units	Acceptable limit (BIS 10500:2012)	Well water samples collected near tanneries				
			Sample 21	Sample 22	Sample 23	Sample 24	Sample 25
1	Temperature (°C)	-	43	42	41	43	42
2	Appearance		Clear	Clear	Clear	Clear	Clear
3	Colour (pt.co.scale)	5-15	Colourless	Colourless	Colourless	Colourless	Colourless
4	Odour	Agreeable	None	None	None	None	None
5	Turbidity NTU	1	1.5	2.5	1	1.5	2
6	Total dissolved solids (mg/L)	500-2000 (mg/L)	6250	6155	5980	5995	6050
7	Electrical conductivity (micro mho/cm)	-	9300	9100	8770	8000	8200
8	pH	6.5-8.5	6.77	6.45	6.90	6.40	6.98
9	Alkalinity Total as $CaCO_3$ (mg/L)	200-600 (mg/L)	720	655	715	690	548
10	Total Hardness as $CaCO_3$ (mg/L)	200-600 (mg/L)	4150	3150	3800	3100	3050
11	Chromium (mg/L)	0.05 (mg/L)	1.19	1.15	1.80	1.50	1.33
12	Lead (mg/L)	0.01 (mg/L)	0.002	0.003	0.002	0.003	0.004
13	Calcium (mg/L)	75-200 (mg/L)	697	518	450	515	589
14	Magnesium (mg/L)	30-100 (mg/L)	410	445	350	365	390
15	Sodium as Na (mg/L)	200 (mg/L)	397	505	435	460	495
16	Potassium (mg/L)	200 (mg/L)	24	30	35	41	37
17	Iron (mg/L)	0.3-1.0 (mg/L)	0.17	0.19	0.13	0.15	0.16
18	Nickel (mg/L)	0.02 (mg/L)	0.05	0.06	0.04	0.05	0.06
19	Zinc (mg/L)	5.0 (mg/L)	1.90	1.97	1.82	1.85	1.76
20	Copper (mg/L)	0.05 (mg/L)	0.06	0.07	0.06	0.05	0.05
21	Manganese (mg/L)	0.1-0.3 (mg/L)	0.31	0.29	0.27	0.30	0.28
22	Cadmium (mg/L)	0.003 (mg/L)	0.004	0.003	0.004	0.004	0.003
23	Free Ammonia (mg/L)	0.5 (mg/L)	0.54	0.51	0.57	0.64	0.53
24	Nitrite as NO_2 (mg/L)	_	0.07	0.06	0.09	0.07	0.08
25	Nitrate as NO_3 (mg/L)	45	54	64	58	62	67
26	Chloride (mg/L)	250-1000 (mg/L)	1950	1900	2100	1960	1990
27	Fluoride (mg/L)	1.0 (mg/L)	0.9	0.7	0.8	0.8	0.7
28	Sulphate as SO_4 (mg/L)	200 – 400 (mg/L)	912	950	580	597	659
29	Phosphate as PO_4 (mg/L)	_	0.07	0.06	0.07	0.06	0.08
30	Tidys Test 4Hrs.as O_2 (mg/L)	_	0.4	0.5	0.3	0.3	0.4
31	E. Coli count (cfu/mL)	-	1.88	1.76	2.00	1.91	1.65
32	Faecal streptococci count (cfu/mL)	-	1.72	1.93	0.95	1.33	1.17

Periyavarigam = (Sample - S21), Somalapuram = (Sample – S22, S23), Solur = (Sample – S24, S25)

Table VI. Seasonal variation of physico-chemical parameters of water samples from wells impacted by the tanneries during wet season in the year 2020

S.No	Parameters and Units	Acceptable limit (BIS 10500:2012)	Well water samples collected near tanneries				
			Sample 26	Sample 27	Sample 28	Sample 29	Sample 30
1	Temperature (°C)	-	32	31	33	32	31
2	Appearance	-	Clear	Clear	Clear	Clear	Clear
3	Colour (pt.co.scale)	5-15	Colourless	Colourless	Colourless	Colourless	Colourless
4	Odour	Agreeable	None	None	None	None	None
5	Turbidity NTU	1	2.5	1.5	3	2	3
6	Total dissolved solids (mg/L)	500-2000 (mg/L)	7490	4760	4270	4830	7500
7	Electrical conductivity (micro mho/cm)	-	10700	6800	6100	6900	10000
8	pH	6.5-8.5	7.27	7.41	7.39	7.30	7.23
9	Alkalinity Total as $CaCO_3$ (mg/L)	200-600 (mg/L)	612	396	320	404	576
10	Total Hardness as $CaCO_3$ (mg/L)	200-600 (mg/L)	4200	2300	2100	2400	3600
11	Chromium (mg/L)	0.05 (mg/L)	0.796	0.583	0.673	0.592	0.735
12	Lead (mg/L)	0.01 (mg/L)	0.002	0.002	0.004	0.004	0.003
13	Calcium (mg/L)	75-200 (mg/L)	840	480	440	480	720
14	Magnesium (mg/L)	30-100 (mg/L)	804	264	240	288	432
15	Sodium as Na (mg/L)	200 (mg/L)	357	250	414	590	518
16	Potassium (mg/L)	200 (mg/L)	20	19	23	35	41
17	Iron (mg/L)	0.3-1.0 (mg/L)	0.12	0.11	0.12	0.11	0.10
18	Nickel (mg/L)	0.02 (mg/L)	0.03	0.02	0.03	0.04	0.02
19	Zinc (mg/L)	5 (mg/L)	1.82	1.54	1.69	1.74	1.48
20	Copper (mg/L)	0.05 (mg/L)	0.02	0.03	0.02	0.03	0.04
21	Manganese (mg/L)	0.1-0.3 (mg/L)	0.29	0.34	0.29	0.15	0.26
22	Cadmium (mg/L)	0.003 (mg/L)	0.002	0.001	0.003	0.002	0.003
23	Free Ammonia (mg/L)	0.5 (mg/L)	0.21	0.17	0.34	0.27	0.51
24	Nitrite as NO_2 (mg/L)	3 (mg/L)	0.04	0.03	0.02	0.04	0.03
25	Nitrate as NO_3 (mg/L)	45 (mg/L)	50	54	44	39	94
26	Chloride (mg/L)	250-1000 (mg/L)	1700	1400	1300	1490	2100
27	Fluoride (mg/L)	1.0 (mg/L)	0.6	0.3	0.4	0.6	0.5
28	Sulphate as SO_4 (mg/L)	200 – 400 (mg/L)	856	726	751	759	977
29	Phosphate as PO_4 (mg/L)	_	0.04	0.15	0.03	0.04	0.06
30	Tidys Test 4Hrs.as O_2 (mg/L)	_	0.3	0.2	0.3	0.1	0.2
31	E. Coli count (cfu/mL)	-	2.00	1.99	1.85	1.73	1.56
32	Faecal streptococci count (cfu/mL)	-	1.57	1.16	0.99	1.16	0.92

Devalapuram = (Sample – S26, S27), Samanthikuppum = (Sample- S28, S29), Kachirapet = (Sample – S30) accepable limits of Bureau Indian Standards (BSI) in most of the stations in all the zones of Tirupattur District. However, in some of the sites in the current study, levels of heavy metals like lead, cadmium, copper, and iron were higher than the WHO guideline, raising concerns for public health.

In the north zone, at stations S1 and S2 (Marapattu), the chromium is 1.10 mg/L and 0.78 mg/L, which exceeds the BIS standard in well water. The chromium in groundwater at stations Vadacheri (S3), Kachirapet (S4 and S5), Alankuppam (S6 and S7), Chinnavarigam (S8 and S9), Somalapuram (S10), Bakkalapalli (Pernambut) (S16, S17, S18), V. Kota Road (Pernambut(S19, S20), Devalapuram (S26, S27), Samanthikuppum (S28 and S29), Kachirapet(S30) was 0.59 mg/L, 0.87; 1.08 mg/L, 0.769 mg/L; 0.655 mg/L, 0.834 mg/L; 0.990 mg/L, 1.168 mg/L, 0.545 mg/L, 0.597 mg/L; 0.880 mg/L, 0.952 mg/L, 0.938 mg/L, 0.796 mg/L, 0.583, 0.673 mg/L, 0.592, 0.735 mg/L, which was the maximum contaminant level as per WHO standard. However, lead (0.002 to 0.004 mg/L), Fe, Cu, Mn, Ni, Cd, and Zn levels the range between (S1 to S5): 0.14 to 0.06 mg/L; 0.02 to 0.01 mg/L; 0.23 to 0.16 mg/L; 0.03 to 0.02 mg/L; 0.004 to 0.003 mg/L; 0.97 to 1.17 wet season 2019, 0.17 to 0.0.08 mg/L; 0.03 to 0.01 mg/L; 0.22 to 0.14 mg/L; 0.05 to 0.02 mg/L; 0.003 to 0.001 mg/L; 1.36 to 0.97 wet season 2020; 0.14 to 0.11 mg/L; 0.05 to 0.02 mg/L; 0.25 to.0.12 mg/L; 0.04 to 0.02 mg/L; 0.003 to 0.001 mg/L; 1.76 to 1.22 mg/L wet season 2021; 0.12 to 0.10 mg/L; 0.04 to 0.02 mg/L; 0.34 to 0.15 mg/L; 0.04 to 0.02 mg/L; 0.003 to 0.001 mg/L; 1.82 to 1.48 wet season 2022, respectively. A phenomenon could explain that during the dry season, Fe, Ni, Zn, Cu, and Mn levels ranged from 0.23 to 0.29 mg/L; 0.04 to 0.06 mg/L; 1.10 to 1.43 mg/L; 0.05 to 0.07; 0.25 to 0.32 mg/L; 0.005 to 0.003 mg/L dry season 2021; 0.19 to 0.13 mg/L; 0.06 to 0.04 mg/L; 1.97 to 1.76 mg/L; 0.07 to 0.05 mg/L; 0.31 to 0.27 mg/L; 0.004 to 0.003 dry season 2019, respectively, were below the detectable level of well water. Wintertime elevations of Fe, Zn, Cu, and Ni can be greatly influenced by farmlands and agricultural operations. The greater concentrations of these heavy metals in the winter have also been linked to anthropogenic activities such as the construction of bricks, electroplating, excavation, fuel production, and industrial emissions. The increased Fe levels may come from natural sources such as the weathering of rocks and minerals, as well as anthropogenic sources like electroplating and industrial emissions (Reddy *et al.* 2012; Ahamad *et al.* 2020; Dogra *et al.* 2023; Vasanthan, *et al.* 2022). Farmlands and agricultural activities can have a significant impact on the wintertime elevations of Fe, Zn, Cu, and Ni.

The wintertime concentrations of these heavy metals have also been connected to human activities such as fuel generation, bricklaying, electroplating, excavation, and industrial emissions. The increased Fe levels may come from natural sources such as the weathering of rocks and minerals, as well as anthropogenic sources like electroplating and industrial emissions (Dogra *et al.* 2023). According to BIS guidelines, the permitted limits for iron in groundwater are 0.3 mg/L and 1.0 mg/L. Iron is frequently collected from groundwater for irrigation and drinking. The investigated metal concentrations in the Tiruppattur district continued to be within acceptable ranges. Permissible levels for copper are 1.5 mg/L and 0.05 mg/L, according to BIS.

Copper enters water systems through corrosion of copper alloy pipes, industrial effluents, and mineral dissolution (Zahir *et al.* 2013; Kannan and Mani, 2015). A vital trace element, zinc is required for many different organisms' physiological and metabolic processes. However, excessive levels of zinc can be harmful to these organisms. The recommended limit for zinc in Indian standards is 5 mg/L, with a permissible limit of 15 mg/L. High lead concentrations in the body can result in severe consequences like death or irreversible harm to the central nervous system, brain, and kidneys. The acceptable limit for cadmium, according to the BIS, is 0.01 mg/L (BIS 1991). It may be attributed to the leaching of solid wastes, agricultural runoff that is let off into the groundwater, and sewage runoff (Dahl *et al.* 2014). Vig *et al.* (2023) calculated pollution indices and the subsequent health risk assessment in the Rupnagar district of Punjab and indicated the necessity for consistent monitoring of groundwater quality within the investigated region. The findings demonstrated that during the dry season, the concentrations of metals were ranked (high to low) as follows: Cr>Cu>Zn>Pb>Cd>Ni>Fe, The concentrations of heavy metals were in the following decreasing order of magnitude during the rainy season: Fe>Cu>Zn>P-b>Cr>Cd> Ni (Fig. 2). Except for iron, which had the highest concentration during the rainy season, heavy metal concentrations were higher during the dry season. Due to increased runoff during the rainy season, which erodes the iron-containing soil particles, the wet season has the highest concentration of Fe. Most metals reach their maximum concentration during the dry season because the river flows more gently and there is less water in the reservoir, leading to higher dissolved metal concentrations in the liquid phase.

In this current research, water samples were collected from different areas of Tirupatur district, specifically from well water sources, and analyzed for the presence of microorganisms. Out of the 30 water samples tested, the microbiological analysis aimed to detect *E. coli* and fecal streptococci using biochemical methods. The total bacterial count in winter well water samples was below 2 cfu/mL, while higher values of 1.56 cfu/mL were observed in spring samples. Fecal streptococci levels varied from 1.57 to 0.92 cfu/mL. The contamination of *E. coli* and fecal streptococci in the study area may be attributed to activities like fishing, where *E. coli* from human and warm-blooded animal feces can persist and remain pathogenic even after passing through sewage treatment plants

Results and discussion

The physical and chemical characteristics of groundwater are essential for establishing quality standards. The Bureau of Indian Standards (BIS) employs various methods to assess water quality. Recent studies of groundwater quality in the area reveal that the water is unsuitable for agricultural use due to high levels of pH, total dissolved solids (TDS), electrical conductivity (EC), alkalinity, and hardness. This research evaluated the physico-chemical characteristics of water samples from multiple agricultural wells, with detailed results presented in Table I.

pH

The pH scale measures the concentration of hydrogen ions, indicating the acidity or alkalinity of water, which is vital for assessing water quality. Groundwater samples collected across different seasons showed pH values ranging from 6.7 to 7.8. Notably, pH levels were slightly higher during the dry season, ranging from 6.7 to 7.7, which is considered mildly alkaline and generally favorable for aquatic life (Kumar *et al.* 2020). These values fall within the acceptable range of 6.5 to 8.5 set by the Bureau of Indian Standards (BIS, 1991) (WHO, 2011), making the water suitable for agricultural, recreational, and residential use. pH can be affected by various factors, including industrial discharge, mineral content, and organic matter present in the water (Awan *et al.* 2012). Deviations from the ideal pH range may result in undesirable effects such as a bitter taste, scaling in pipes and appliances, and reduced chlorine disinfection efficiency. Despite fluctuations due to mineral reactions and temperature changes, groundwater samples generally maintain stable pH levels across different seasons Koul *et al.* 2012).

Temperature

Temperature is a crucial ecological factor that affects the behavior and distribution of organisms. Additionally, the heat generated from organic matter decomposition and respiration slightly influences the overall temperature. During the monsoon season, temperatures ranged from 30°C to 33°C across various locations. In contrast, summer temperatures soared to 41°C and 45°C in all villages. The increase in summer temperatures was statistically significant ($P<0.05$) compared to the monsoon season. However, all recorded temperatures remained within the acceptable ambient temperature ranges set by recent guidelines from the World Health Organization (WHO) and the National Standards for Drinking Water Quality (NSDWQ) (WHO, 2021; NSDWQ, 2023).

Total alkalinity

Total alkalinity measures a water's capacity to neutralize strong acids, largely influenced by carbonate, bicarbonate, borates, silicates, phosphates, humic and fulvic acids, and hydroxides resulting from carbon dioxide dissolution. Industrial discharges, such as those containing calcium hydroxide and sodium hydroxide, also contribute to water alkalinity. The Bureau of Indian Standards (BIS) specifies a maximum allowable total alkalinity of 200–600 mg/L for drinking water. In the research areas, total alkalinity values, expressed as $CaCO_3$, ranged from 324 to 636 mg/L. Elevated alkalinity in these areas is primarily attributed to high levels of bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}). High carbonate concentrations can lead to increased dominance of sodium ions due to the formation of insoluble minerals with calcium and magnesium ions (Singh *et al.* 2020). In some instances, bicarbonates of calcium and magnesium are the primary contributors to the water's alkalinity.

Conclusion

In this study, the majority of the physicochemical wastewater parameters in well water varied with the seasons. All of the observed parameters fell inside the given range. The dry season has higher concentrations of heavy metals than the wet season, except for Cr, which accumulates more during the rainy season.The primary reason for the rising levels of these elements in the research area's groundwater is industrial effluent from the tannery, seafood, fertilizer, copper, and alkali chemical sectors, as well as from shipping and municipal waste water.

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