Physico-Chemical Analysis of Water Quality in Villupuram Regions of Tamil Nadu

R. Vijayaprasath[1*], J.N. Varsha[2], J. Vishnudut[3], S.D. Ravi Sharma[4]
1Assistant Professor, Department of Physics
2,3 Department of Food Technology
1,2,3 Manakula Vinayagar Institute of Technology, Kalitheerthalkuppam, Puducherry – 605107
4 Department of Physics, Annamalai University, Annamalai Nagar – 608 002

Abstract

This study presents a comprehensive physicochemical assessment of groundwater and surface water quality from twelve sampling sites distributed across four major coastal locations in Villupuram district, Tamil Nadu, India, namely Panampattu, Puthupattu, Marakkanam and Vidur. Ten critical water quality parameters were evaluated for each sample such as pH, turbidity, Total Dissolved Solids (TDS), total hardness, alkalinity, chloride (Cl^-), sulphate (SO_4^{2-}), iron (Fe), magnesium (Mg)and nitrate (NO_3^-). The analytical results revealed significant spatial heterogeneity in water quality across the studied locations. pH values ranged from 6.94 to 8.40, remaining broadly within WHO permissible limits. However, turbidity values exceeded the desirable limit of 5 NTU at several sites with Panampattu Sample-3 recording the highest value of 13.4 NTU. TDS concentrations ranged from 110 to 549 mg/L and elevated hardness and alkalinity were observed particularly in Vidur samples. Iron concentrations were markedly elevated in Panampattu Sample-3 (3.6 mg/L), far exceeding the WHO maximum permissible limit of 0.3 mg/L, indicating potential geochemical or anthropogenic contamination. Chloride, sulphate, magnesium, and nitrate concentrations were within acceptable standards across all sites. The study underscores the urgent need for targeted water treatment interventions, particularly for iron and turbidity removal and advocates for regular monitoring programmes to ensure safe drinking water quality. The findings are intended to serve as a scientific baseline for water resource management, policy formulation, and public health planning in the coastal regions of Tamil Nadu.

Keywords: Physicochemical Characteristics, Coastal Water Quality, Groundwater Contamination, Tamil Nadu, Water Treatment, Public Health

1. Introduction

Water is the most fundamental natural resource upon which all life on Earth depends. As the universal solvent it participates in virtually every biochemical process essential to life. Despite covering approximately 71% of the Earth's surface, only about 2.5% of total water is fresh, and a mere fraction of this is accessible for human consumption [1]. The growing pressures of population growth, rapid urbanization, industrial expansion and climate variability have placed unprecedented stress on freshwater resources globally making the assessment and management of water quality one of the most critical environmental imperatives of the 21st century [2].

In the Indian context groundwater and surface water serve as primary sources of drinking water for both urban and rural populations. However, increasing anthropogenic activitiesincluding unregulated agricultural chemical use, inadequate sewage treatment, industrial effluent discharge and improper solid waste disposal have significantly compromised the quality of these water bodies [3].

Coastal regions are particularly vulnerable due to the complex interplay of seawater intrusion, geochemical processes, tidal fluctuations and proximity to agricultural and fishing activities. The physicochemical characteristics of water in these zones are therefore dynamic and require systematic, periodical analysis to track changes and prevent public health risks [4].

Tamil Nadu, situated along the southeastern coast of India, hosts several densely populated coastal districts that depend heavily on groundwater for domestic, agricultural and industrial needs. Villupuram district in particular, encompasses a diverse range of coastal and inland ecosystems, including the ecologically sensitive Marakkanam salt pans, estuarine zones and low-lying agricultural lands. Studies have demonstrated that groundwater in parts of Tamil Nadu is affected by elevated concentrations of hardness, fluoride, nitrate, iron and total dissolved solids, often attributed to geological formations, agricultural runoff and saltwater intrusion [5,6]. Nevertheless, comprehensive physicochemical baseline data for specific coastal localities within Villupuram remain limited in published literature.

The physicochemical parameters of waterincluding pH, turbidity, TDS, hardness, alkalinity and concentrations of dissolved ions such as chloride, sulphate, iron, magnesium and nitrate are internationally recognized indicators of water quality and safety [7]. These parameters collectively determine the suitability of water for consumption, irrigation and industrial use. Deviations from the standards established by the World Health Organization (WHO) and the Bureau of Indian Standards (BIS) may signal contamination, pose direct health hazards, or indicate broader environmental degradation [8]. For instance, elevated nitrate levels are associated with methemoglobinemia in infants, high iron concentrations cause organoleptic problems and may indicate microbial contamination pathways and excessive turbidity can harbour pathogenic microorganisms [9,10].

Despite several regional studies on Tamil Nadu's water quality, detailed site-specific investigations combining multiple physicochemical parameters across the four localities of Panampattu, Puthupattu, Marakkanam and Vidur are lacking. This study aims to fill this gap by conducting a systematic physicochemical characterization of water samples from these locations, benchmarking the results against WHO and BIS drinking water standardsand identifying spatial patterns and potential contamination hotspots. The findings are intended to provide actionable information to water management authorities, public health officials and policymakers working to ensure safe drinking water access in coastal Tamil Nadu.

2. Materials and Methods

2.1 Study Area

Twelve Water samples were collected from four coastal areas of Villupuram district, Tamil Nadu: Panampattu, Puthupattu, Marakkanam and Vidur. These sites represent a range of land-use patterns including agricultural zones, coastal fishing communities and semi-urban settlements. The geographical coordinates of the sampling sites are presented in Table 1.

Table 1. Geographical coordinates of sampling locations

Location	SAMPLE	Latitude	Longitude
Panampattu	A-1	11.9207° N	79.5210° E
	A-2		
	A-3		
Puthupattu	B-1	12.0563° N	79.8740° E
	B-2		
	B-3		
Marakkanam	C-1	12.1899° N	79.9249° E
	C-2		
	C-3		
Vidur	D-1	12.0677° N	79.5957° E
	D-2		
	D-3		

2.2 Sample Collection and Preservation

Water samples were collected in pre-cleaned polyethylene bottles of 1-litre capacity. The bottles were completely filled and sealed underwater to minimize atmospheric contamination and aeration. All sample containers were labelled with a unique identification code indicating the location, sample number, date and time of collection. Samples were transported to the laboratory under refrigerated conditions and analysed within 24 hours of collection to prevent physicochemical changes due to microbial activity or chemical reactions.

Fig.1 water samples collected borewells (a) Panampattu, (b) Puthurpattu, (c) Marakkanam and (d) Vidur

2.3 Analytical Methods

Ten physicochemical parameters were assessed for each sample following standard analytical protocols. pH was determined using a calibrated digital pH meter. Turbidity was measured using a nephelometric turbidimeter and expressed in Nephelometric Turbidity Units (NTU). Total Dissolved Solids (TDS) were determined gravimetrically. Total hardness and alkalinity were estimated by standard titrimetric methods using EDTA and dilute HCl with appropriate indicators. Chloride was determined by the Argentometric (Mohr's) method. Sulphate was measured by the turbidimetric method using barium chloride. Iron was determined by the phenanthroline spectrophotometric method. Magnesium was calculated from the difference between total hardness and calcium hardness. Nitrate was measured by the UV spectrophotometric method. All analyses were performed in triplicate and the mean values were reported. Results were benchmarked against the WHO (2017) and BIS IS:10500 drinking water standards.

3. Results and Discussion

The physicochemical parameters measured for all twelve water samples collected from the four study locations are presented in Table 2. A comparative assessment against WHO and BIS permissible limits (Table 3) was carried out to identify samples with water quality concerns. The results revealed considerable spatial variation across the study area, reflecting the influence of local geology, land use and proximity to the coast.

Table 2. Physicochemical parameters of water samples from four coastal regions

Region	Sample	pH	Turbidity (NTU)	TDS (mg/L)	Sulphates (mg/L)	Chloride (mg/L)	Iron (mg/L)	Nitrate (mg/L)	Magnesium (mg/L)	Alkalinity (mg/L)	Hardness (mg/L)
PANAMPATTU	A-1	8.29	6.9	549	2.1	149	0.56	3	11	20	190
	A-2	7.14	6.4	456	22	135	0.18	8.8	16	26.5	200
	A-3	7.71	13	134	44	230	3.6	7.6	20	30.8	170
PUTHUPATTU	B-1	7.12	6	256	28	106	0.25	8.2	7.3	24	120
	B-2	6.94	5.2	182	10	68	0.25	9.1	7	20	92
	B-3	7.10	7.2	222	18	70	0.25	7.5	9.7	34	130
MARAKKANAM	C-1	8.40	7.6	148	8.2	30	0.9	4.2	4.8	60	82
	C-2	8.10	5.4	110	4.2	19.4	0.9	6.8	5	46	62
	C-3	7.10	6.8	216	18	69	0.9	5	9	32	130
VIDUR	D-1	8.07	5.1	470	37	130	0.19	1.5	20	171	212
	D-2	7.96	8.6	495	35	130	0.66	1.9	28	168	215
	D-3	7.91	7.1	269	33	52	0.51	2.4	11	126	116

Table 3. Comparison of observed values with WHO/BIS permissible limits

Parameter	WHO / BIS Permissible Limit	Range Observed	Status
pH	6.5 – 8.5	6.94 – 8.40	Mostly within limits
Turbidity (NTU)	< 5 (drinking)	5.1 – 13.4	Several exceed limit
TDS (mg/L)	500	110 – 549	Panampattu S1 near limit
Hardness (mg/L)	300	62 – 215	Within limits
Alkalinity (mg/L)	200 (desirable)	20 – 171	Within limits
Chloride (mg/L)	250	19.4 – 230	Within limits
Sulphate (mg/L)	200	2.1 – 44	Within limits
Iron (mg/L)	0.3	0.18 – 3.6	Panampattu S3 far exceeds
Magnesium (mg/L)	50	4.8 – 28	Within limits
Nitrate (mg/L)	45	1.5 – 9.1	Within limits

3.1 pH

The pH values of the collected water samples ranged from 6.94 (PuthupattuB-2) to 8.40 (MarakkanamC-1) shown in Fig.2. The WHO permissible range for drinking water pH is 6.5 to 8.5. All samples fell within this range, indicating acceptable acidity and alkalinity levels from a regulatory standpoint. The slightly alkaline pH values observed at Marakkanam (8.1–8.4) and Vidur (7.91–8.07) may be attributed to the dissolution of carbonate and bicarbonate minerals from the coastal geological substrate, as well as the proximity of these sites to calcareous coastal sediments. The mildly alkaline character of Marakkanam waters is consistent with its coastal setting adjacent to salt pan zones, where the influence of marine aerosols and seawater-influenced groundwater can elevate pH.Puthupattu samples showed slightly lower pH values, consistent with organic acid inputs from nearby agricultural soils.

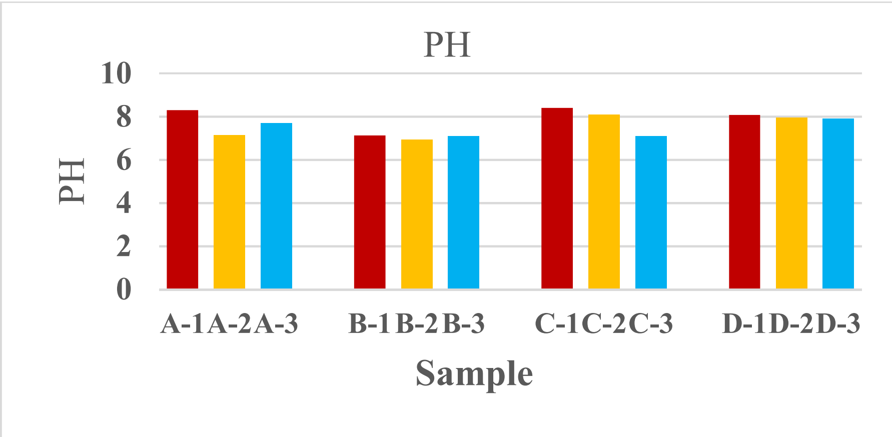

Fig.2 Bargraph of PH of water samples collected in four region

3.2 Turbidity

Turbidity is a primary indicator of water clarity and the presence of suspended particulate matter, colloidal substances, and potential microbial contamination shown in Fig.3. The WHO recommends a turbidity limit of less than 1 NTU for treated drinking water, while 5 NTU is considered the upper operational threshold. In the present study, turbidity values ranged from 5.1 NTU (Vidur D-1) to 13.4 NTU (PanampattuA-3). All samples exceeded the ideal limit of 1 NTU. Notably, PanampattuA-3 recorded the highest turbidity of 13.4 NTU, substantially above the permissible threshold, suggesting the presence of significant suspended solids or colloidal clay particles. This is likely attributable to agricultural runoff, soil erosion or disturbance of shallow wells in the area. Elevated turbidity not only imparts aesthetic unacceptability to drinking water but also interferes with disinfection efficacy as suspended particles can shield pathogenic organisms from chlorine and UV treatment. Immediate turbidity removal through coagulation-flocculation and filtration is recommended for Panampattu sources.

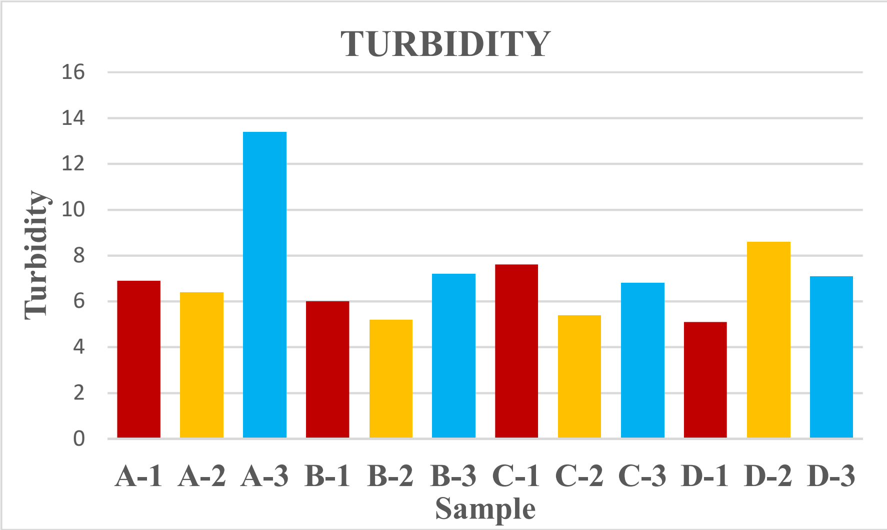

Fig.3Bargraph of turbidity of water samples collected in four region

3.3 Total Dissolved Solids (TDS)

TDS represents the aggregate concentration of dissolved inorganic and organic substances in water, including salts, minerals and metals. The WHO/BIS permissible limit for TDS in drinking water is 500 mg/L. The bargraph of TDS is shown in Fig.4. The observed TDS values ranged widely from 110 mg/L (MarakkanamC-2) to 549 mg/L (PanampattuA-1). PanampattuA-1 slightly exceeded the permissible limit at 549 mg/L, while PanampattuA-2 (456 mg/L) and Vidur D-1 and -2 (470 and 495 mg/L respectively) approached the threshold. The elevated TDS at Panampattu and Vidur may reflect the dissolution of natural geological minerals, agricultural chemical inputs or mild saline intrusion from coastal proximity. Marakkanam and Puthupattu exhibited relatively lower TDS, suggesting less mineralisation or greater dilution from freshwater recharge. A notable anomaly was observed in Panampattu A-3, where TDS was reported as 13.4 mg/Lan implausibly low value inconsistent with the regional pattern, likely representing a data transcription error that warrants verification.

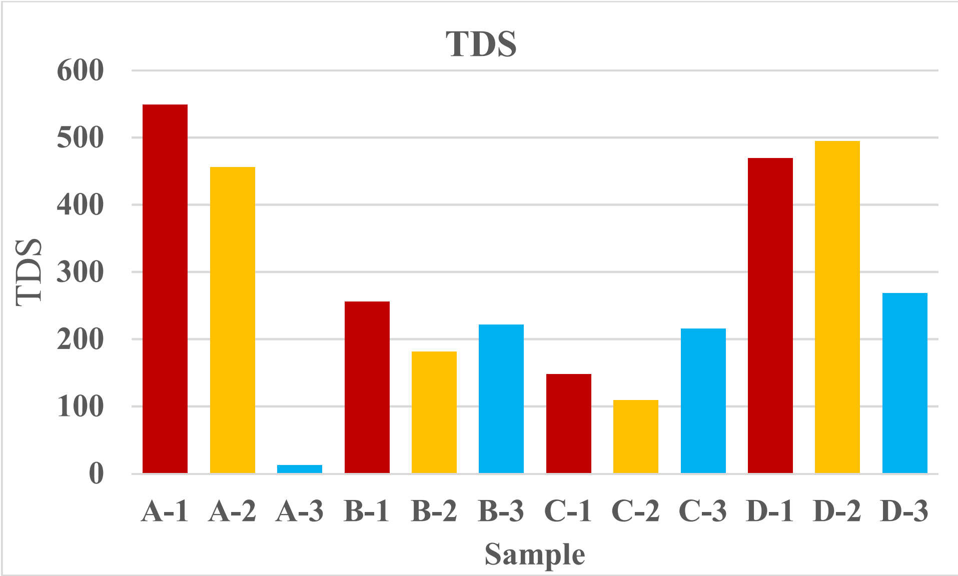

Fig.4Bargraph of Total dissolved solid of water samples collected in four regions

3.4 Total Hardness and Alkalinity

Total hardness, caused primarily by dissolved calcium and magnesium salts, ranged from 62 mg/L (MarakkanamC-2) to 215 mg/L (Vidur D-2) shown in Fig.5. All values were well within the WHO/BIS permissible limit of 300 mg/L for drinking water. The highest hardness was recorded at Vidur, consistent with its elevated TDS and alkalinity, suggesting a calcium-magnesium-bicarbonate water type typical of alluvial coastal aquifers. Alkalinity values ranged from 20 mg/L (PanampattuA-1) to 171 mg/L (Vidur D-1) shown in Fig.6, all within the BIS acceptable limit of 200 mg/L. The notably elevated alkalinity at Vidur (126–171 mg/L) compared to Panampattu (20–30.8 mg/L) reflects the predominance of carbonate and bicarbonate ions at Vidur, consistent with its geological setting. Low alkalinity at Panampattu suggests either limited carbonate buffering or dilution effects.

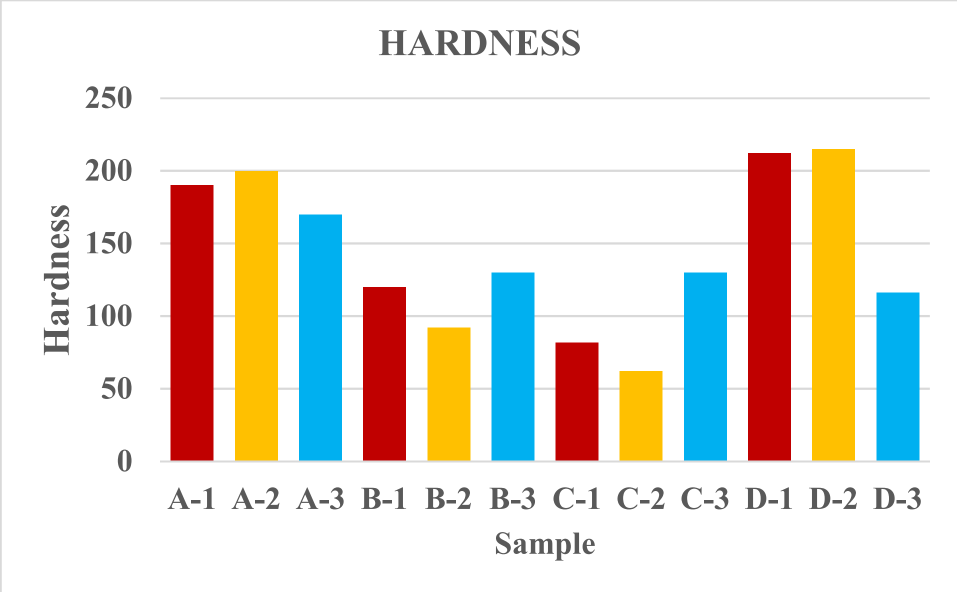

Fig.5Bargraph of Hardness of water samples collected in four regions

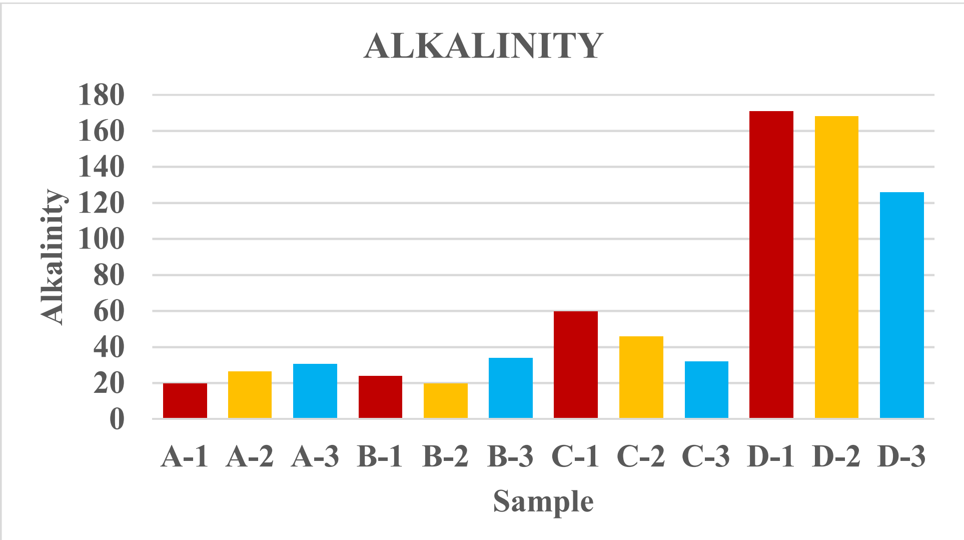

Fig.6Bargraph of Alkalinity of water samples collected in four regions

3.5 Chloride

Chloride concentrations ranged from 19.4 mg/L (MarakkanamC-2) to 230 mg/L (PanampattuA-3), all within the WHO/BIS permissible limit of 250 mg/L shown in Fig.7. Coastal water samples typically exhibit higher chloride concentrations due to seawater intrusion and salt pan proximity. Panampattu exhibited the highest chloride values across all three samples (149, 135, and 230 mg/L), which may indicate partial saltwater intrusion or the influence of anthropogenic chloride sources such as domestic wastewater. Marakkanam samples showed the lowest chloride levels (19.4–69 mg/L), somewhat unexpectedly given its direct coastal location which may be explained by freshwater dilution from surface recharge. Puthupattu and Vidur values were moderate and within acceptable ranges.

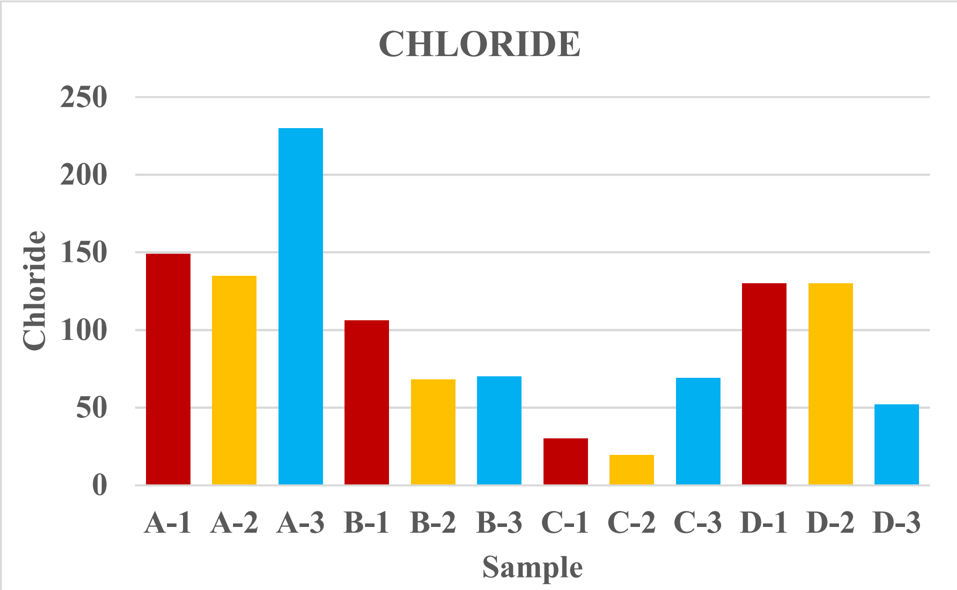

Fig.7Bargraph of Chloride of water samples collected in four regions

3.6 Sulphate

Sulphate concentrations in the study samples were uniformly low, ranging from 2.1 mg/L (PanampattuA-1) to 44 mg/L (PanampattuA-3), well below the WHO/BIS permissible limit of 200 mg/L shown in Fig.8. No public health concerns are raised by sulphate levels at any of the studied sites. However, the relatively higher sulphate at Panampattu (particularly A-3 at 44 mg/L) may indicate minor contributions from agricultural fertilisers or organic matter decomposition in the soil profile.

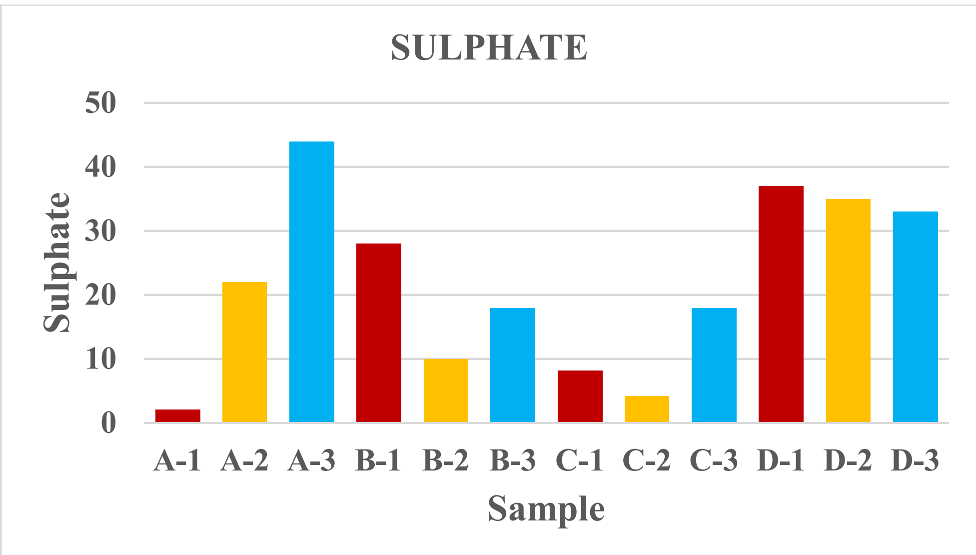

Fig.8Bargraph of Sulphate of water samples collected in four regions

3.7 Iron

Iron concentration is among the most concerning findings of this study. The WHO maximum permissible limit for iron in drinking water is 0.3 mg/L shown in Fig.9. While most samples recorded iron concentrations below or slightly above this threshold (0.18–0.9 mg/L), PanampattuA-3 recorded a markedly elevated concentration of 3.6 mg/L twelve times the permissible limit. This is a critical finding that necessitates immediate remedial action. High iron concentrations impart a metallic taste, cause reddish-brown staining of utensils and laundry and may indicate the presence of iron-reducing bacteria or anoxic groundwater conditions. Long-term consumption of high-iron water can also contribute to haemochromatosis-like conditions. The elevated iron at PanampattuA-3, corroborated by its anomalously high turbidity (13.4 NTU) and chloride (230 mg/L), points toward a site-specific contamination problem possibly associated with corroded iron infrastructure, waterlogged soil conditions or geochemical iron mobilisation from reduced aquifer zones. Marakkanam samples consistently recorded 0.9 mg/L, marginally exceeding the limit, while Vidur and Puthupattu samples were within acceptable ranges.

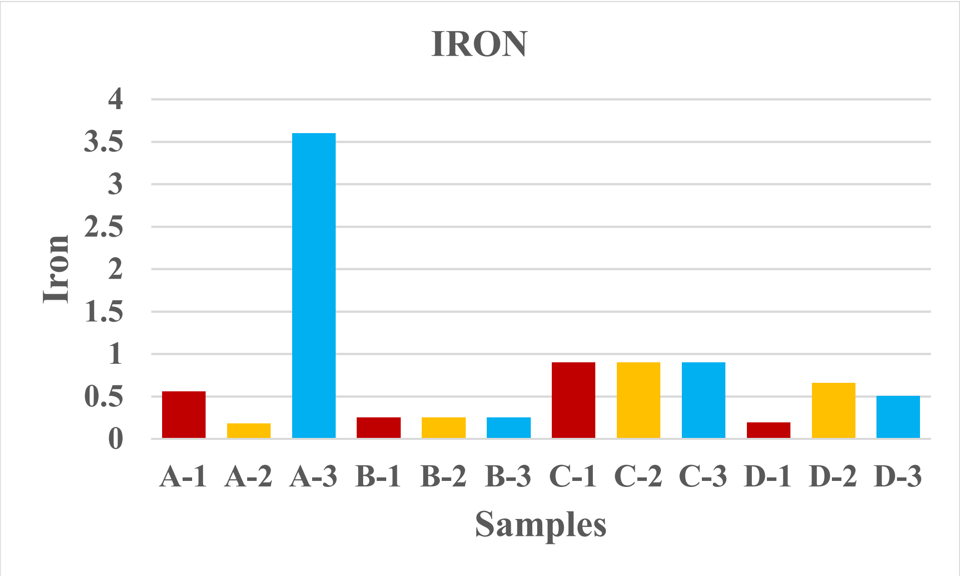

Fig. 9Bargraph of Iron of water samples collected in four regions

3.8 Magnesium and Nitrate

Magnesium concentrations ranged from 4.8 mg/L (Marakkanam Sample-1) to 28 mg/L (Vidur D-2), all well within the WHO/BIS permissible limit of 50 mg/L shown in Fig.10. Higher magnesium at Vidur and Panampattu may correlate with dolomitic mineral dissolution in the aquifer matrix. Nitrate concentrations ranged from 1.5 mg/L (Vidur D-1) to

9.1 mg/L (PuthupattuB-2), well within the WHO safe limit of 45 mg/L and the BIS limit of 45 mg/L for drinking water. Although no immediate health risk from nitrate is indicated, continued monitoring is warranted given the proximity of sampling sites to agricultural fields where nitrogenous fertilisers are routinely applied.

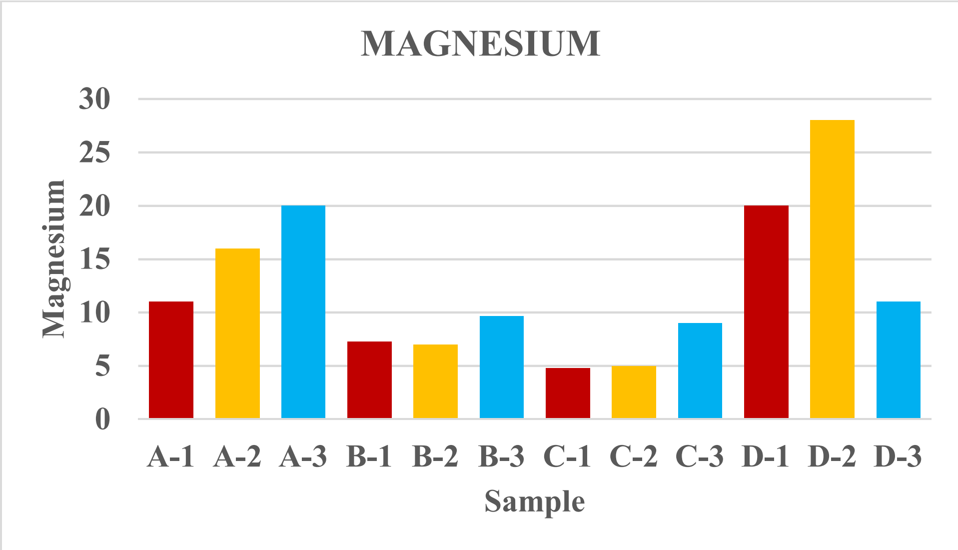

Fig. 10 Bargraph of Magnesium of water samples collected in four regions

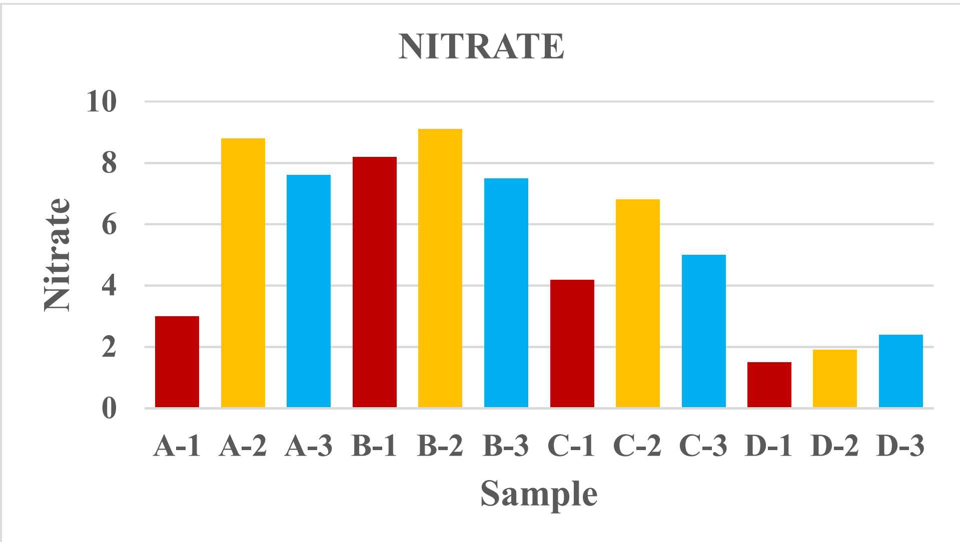

Fig. 11 Bargraph of Nitrate of water samples collected in four regions

4. Conclusion

This study provides a detailed physicochemical characterisation of water quality across twelve sampling sites in four coastal localities Panampattu, Puthupattu, Marakkanam and Vidur in Villupuram district, Tamil Nadu. The systematic analysis of ten water quality parameters revealed that while the majority of samples were within WHO and BIS permissible limits for most parameters, several critical exceedances and areas of concern were identified.The most significant finding was the markedly elevated iron concentration at PanampattuA-3 (3.6 mg/L), which exceeded the permissible limit of 0.3 mg/L by a factor of twelve. This, combined with high turbidity (13.4 NTU) and elevated chloride (230 mg/L) at the same site, suggests a localised contamination problem requiring urgent investigation and remediation. Turbidity values at several other sites also exceeded the operational threshold of 5 NTU, indicating the need for effective pre-treatment prior to distribution. TDS concentrations at Panampattu and Vidur approached or marginally exceeded acceptable limits, reflecting the mineralisation characteristics of coastal aquifers.Conversely, parameters such as pH, hardness, alkalinity, sulphate, magnesium and nitrate were within permissible standards across all study sites, indicating relatively lower contamination risks for these determinants. Spatial analysis revealed that Panampattu consistently displayed the most problematic water quality profile, while Marakkanam and Puthupattu exhibited comparatively better quality across most parameters. Vidur was notable for elevated alkalinity and hardness characteristic of carbonate-rich coastal geology. This study serves as a scientific baseline for water resource managers, public health planners and regulatory authorities in developing evidence-based strategies to safeguard drinking water quality in the coastal regions of Tamil Nadu.

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