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Evaluation of Groundwater Quality in Thrissur Urban Area, Kerala, Southern India

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ABSTRACT

Groundwater quality in the Thrissur urban area, Kerala, southern India is determined by analyzing its physicochemical and microbiological parameters. The results of the analyses show pH < 6.5 in 70% of samples, 24% of samples show high electrical conductivity, and 10% have high potassium. In addition, iron contamination in groundwater in the area is another issue (Fe more than 0.3 mg/l in 30% of samples). The remaining chemical parameters met the standards of WHO (2011). The microbiological findings indicate widespread bacterial contamination with the majority of samples exhibiting total coliform and fecal coliform contamination. The Piper Diagram shows that the concentration of alkaline earth (Ca+Mg) is higher than that of the alkalies (Na+K), and the strong acids (SO_4+Cl) exceed the weak acids (HCO_3+CO_3). Additionally, the diagram indicates several types of water in the study area, with the most common being mixed water, followed by sodium chloride and calcium-magnesium carbonate. Saline water has been observed in certain borewell locations, indicating the ingress of seawater into the aquifers. The conversion from freshwater to saline water in the study area highlights the necessity of monitoring and managing to guarantee the sustainability and quality of water.

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1. INTRODUCTION

In the twentieth century, the global population of cities expanded more than tenfold, while the rural population doubled (WWAP, 2006). The majority of the population growth happened in poor and middle-income countries such as India, China, Indonesia, and Nigeria. Recently, groundwater has become an important part of urban water supply systems (Brindha and Schneider, 2019). More than 2.5 billion people rely on groundwater for drinking (Shaji et al., 2021). This substantial dependence on groundwater will prompt apprehensions regarding the sustainability of groundwater supplies in the future (Shaji, 2013). According to the Composite Water Management Index report, India's water demand is expected to double by 2030, resulting in severe water scarcity and a 6% drop in GDP by 2050 (Datta et al., 2023). By 2050, it is expected that approximately 68% of the world's population will live in cities, with India's urban population alone increasing by 416 million which leads to a huge increase in water demand. In Kerala, groundwater is the primary water supply for residence, industrial, and commercial use (Kumar et al., 2012), particularly in regions where surface water sources are insufficient to meet urban inhabitants' requirements (Chen et al., 2018; Karnieli et al., 1984; Safa et al., 2020). However, it is highly susceptible to pollution and contamination (Hameed et al., 2000). As a result, local government cooperation is critical for effective public water service delivery at the grass-

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roots level (Preetha, 2024). Thrissur, is an urban region and Kerala's third-largest city corporation by size and fourth-largest by population, with a population of over three million people. Thrissur is an important historical city in Kerala and is considered the state's cultural capital. Evaluating the quality and suitability of groundwater for various purposes is crucial in the modern day. Therefore, hydrochemical analysis plays a significant role in establishing if groundwater is appropriate for its intended applications (Mohamed et al., 2022). It not only estimates the difference between the concentration of a parameter and its acceptable limits but also guides the specific utilization of groundwater (Aly et al., 2024). This research aims to investigate groundwater's hydrochemical, biological, and isotopic properties in the Thrissur urban area during the pre-monsoon period of 2024 to determine whether the water is suitable for human consumption. A review of the literature indicates that the urban region of Thrissur has been the subject of very few investigations. A study on the physico-chemical characteristics of groundwater samples from different areas of Thrissur district, Kerala state, India, conducted by Thambi et al. (2015) revealed that most of the physicochemical parameters in the Thrissur urban area exceed the acceptable range but remain below the maximum allowable level of the World Health Organisation's (WHO) drinking water standards. A preliminary assessment of groundwater quality in Thrissur District, Kerala, India, conducted by Kumar et al. (2012) confirmed that the samples gathered from the study area are extremely safe for human consumption.

2. STUDY AREA

Thrissur is rapidly becoming one of Kerala's fastest-developing cities with a population of over three million people. The Thrissur district spans an area of about 3032 square kilometers and is situated (coordinates 10.52°N and 76.21°E) in the middle region of Kerala and extends into the Palakkad plains Fig. 1. The study area covers Thrissur city and some of its surrounding areas in the southern state of Kerala in India. The research area covers about 110 square kilometers and is predominantly urban, except for certain peripheral areas where agricultural practices are observed. With a population exceeding 315,957. The primary soil type in the research region is lateritic soil, which is well-drained. The aquifer system in the research area consists of hard rock and laterite aquifers.

3. GEOLOGICAL AND HYDROGEOLOGICAL SETTING

The Thrissur's aquifer system is divided into hard rock aquifers, laterite aquifers, and sedimentary aquifers. The hard rock and laterite aquifers are Thrissur's primary aquifer system. Laterite is the most common aquifer system in the research region. Because of its high porosity, the laterite aquifer is fully refilled with just a few rainfalls. The lithology of wells revealed that the bottom of the well is represented by hard crystalline rock, followed upward by weathered crystalline rock a laterite horizon, and topsoil on top. The depth of dug wells in the research region varies from 3.60 m to 13.5 m, whereas bore wells range from 35 m to 75 m. The water level in the research area during the pre-monsoon period varied between 1.75 m and 11.63 m below ground level (mbgl). Three distinct rock types are present in the study area: the charnockite group of rock is located in the north, sand and silt are present in the west and northwest parts. The migmatite complex is the predominant type of rock in the area and is present in the middle and south of it (Fig. 2).

4. MATERIALS AND METHODS

In February 2024, 30 well-water samples were taken from the research area during the pre-monsoon season (Fig. 3). The samples were collected directly from the wells using sterile glass bottles having a volume of 1000 ml. The wells were selected at random from the area. The samples were collected and delivered to the lab within 24 hours. They were kept in the chemical laboratory of the Department of Geology at the University of Kerala in appropriate circumstances. The samples are analysed for physical, chemical, and microbiological parameters. The pH was evaluated on-site, while other water quality parameters were tested in the analytical laboratory of the Groundwater Department, Kerala state, Thiruvananthapuram. The analyses adhered to the American Public Health Association (APHA)'s recognized protocols (APHA, 2005). The findings were cross-checked against the World Health Organization's (WHO, 2011) drinking water standards to confirm they met global quality.

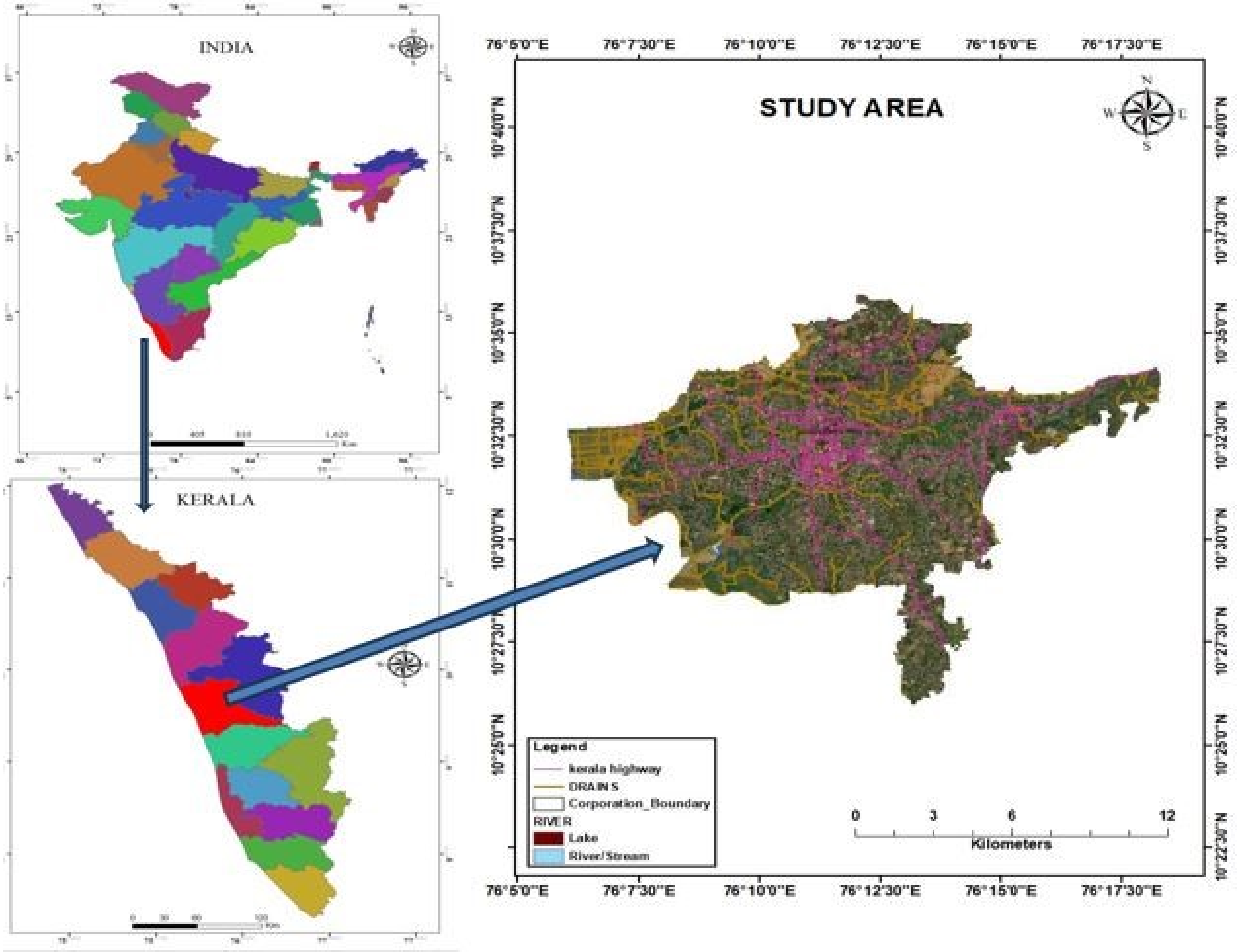

Fig. 1. The study area map.

A variety of parameters were analyzed, including microbiological and physicochemical ones such as total coliform and fecal coliform, as well as turbidity, calcium, nitrate, chloride, total hardness, magnesium, carbonates and bicarbonates, alkalinity, iron, phosphate, sulfate, pH, EC, and TDS. pH and EC were measured using a portable multi-parameter meter (Hounsinou, 2021; Nakhaei et al., 2015), while TDS was measured using a conductivity meter (Hounsinou, 2020). The measurement method for HCO3, alkalinity, and hardness was titration (Sunitha et al., 2014; Hounsinou, 2021). The measurement method for magnesium, calcium, potassium, sodium, chloride, sulfate, and nitrate was chromatography (Hounsinou, 2021). The measurement method for nitrite, iron, phosphate, and fluoride was ionic spectrophotometry (Hounsinou, 2020; Anderson, 1979; Roy et al., 2011). The measurement method for microbiological parameters was incorporated into an agar (Hounsinou, 2021).

5. RESULTS AND DISCUSSION

5.1. General chemical composition of groundwater

The results of physicochemical parameters include pH, EC, TDS, Ca^+, Mg^+, Na^+, K^+, Fe^+, Cl^-, ${SO_4}^-$, ${CO_3}^-$, ${HCO_3}^-$, ${NO_3}^-$, ${NO_2}^-$, F^-, ${PO_4}^-$, total alkalinity, total turbidity, and hardness, are shown in Table 1. The box plot (Fig. 4), displays each parameter's maximum, minimum, and average values. The recommended pH range for drinking water is 6.5–8.5 (WHO, 2011). In the study area, pH levels range from 4 to 7.5, with an average of 5.98. Among the samples, 70% exhibit an acidic trend (below 6.5), while 30% fall within the desired range. Establishing a direct correlation between the pH level of drinking water and human health is challenging (World Health Organization, 2007). The total dissolved solids values (TDS) in the Thrissur urban area range from 22 to 2151 mg/l, with an average of 238 mg/l. According to the WHO (2011) guidelines, the permissible

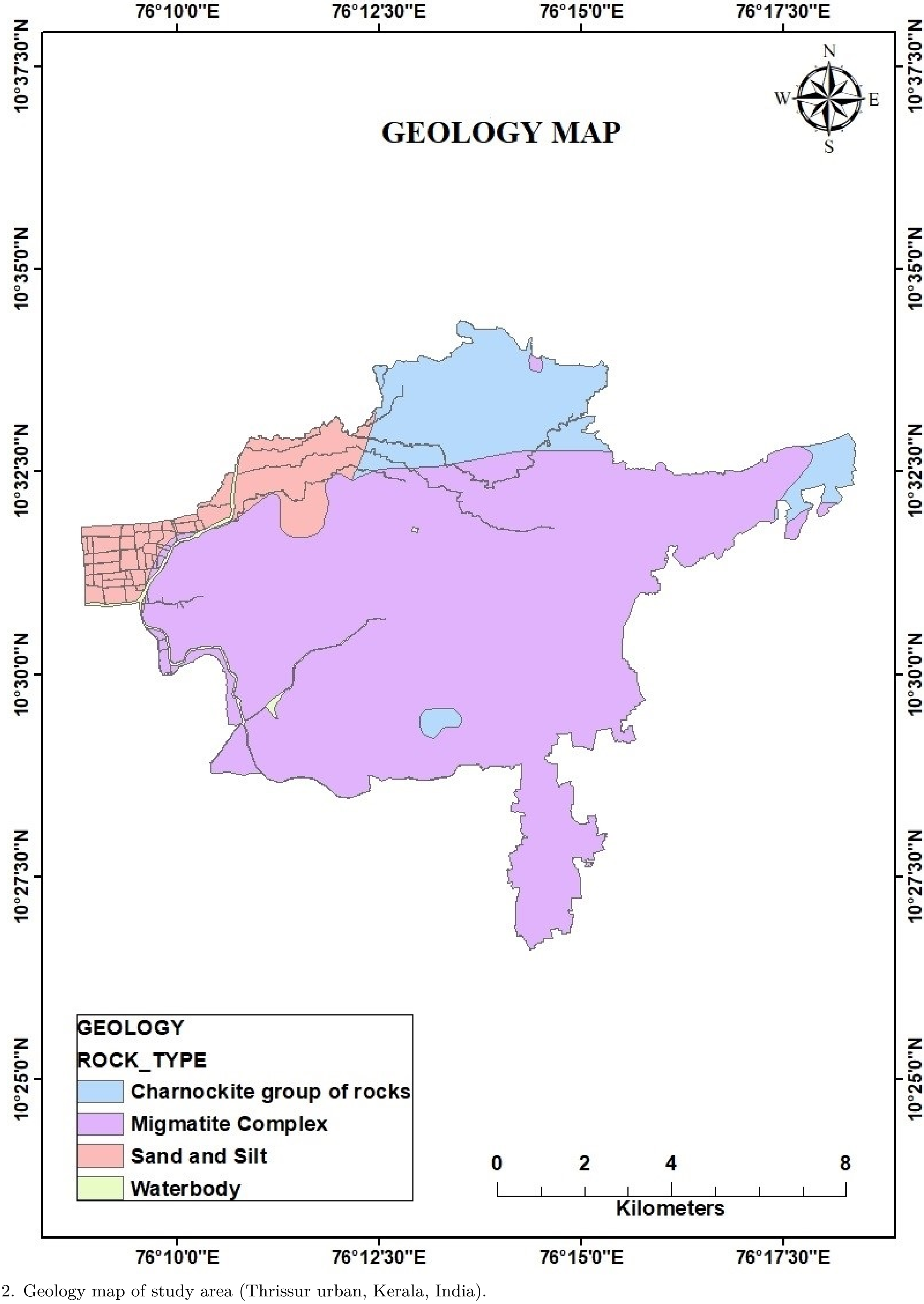

Fig. 2. Geology map of study area (Thrissur urban, Kerala, India).

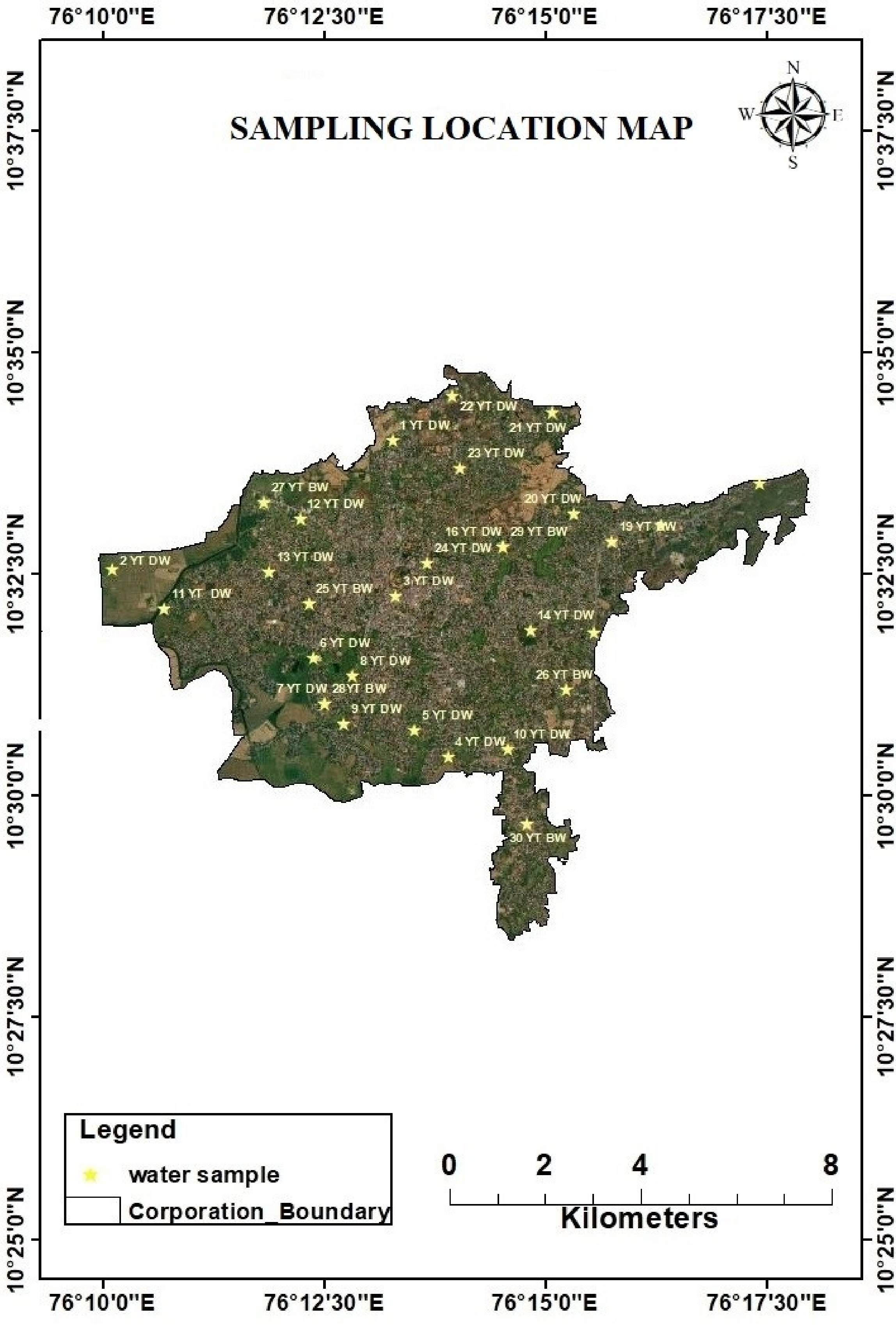

Fig. 3. Sampling location map in Thrissur urban area, Kerala, India.

Table 1. Physico-chemical parameters of the groundwater in Thrissur urban area.

Sl.no	pH	EC	TDS	Turbidity	TH	Ca	Mg	Na	K	TA	HCO_3	SO_4	Cl	$N0_3$	Fe	F	PO_4	NO_2
1	6	124	74	0.19	45	16	1.22	9.1	4.1	20	24	16.78	17.1	0.01	0.07	0.07	2.622	0.415
2	6.6	502	301	0.15	175	44	15.86	33.5	9.2	134	163	29.85	46.55	0.45	0.41	ND	3.273	0.411
3	5.7	304	182	0.2	85	20	8.54	20.1	10.3	8	10	37.65	63.1	6.98	0.05	ND	2.867	0.234
4	5.3	119	71	0.03	30	6	3.66	11.5	2.9	6	7	5.18	22.8	4.51	0.03	0.06	2.832	0.415
5	4.8	148	89	0.13	30	4	4.88	15.5	2.1	0	0	6.44	28.5	5.41	0.02	ND	3.081	0.246
6	7.4	472	283	0.2	200	48	19.52	20.1	9.1	180	220	17.75	31.35	0.15	0.14	0.4	2.51	0.175
7	4.7	288	173	0.03	50	12	4.88	27.9	13.4	0	0	4.5	53.2	10.5	0	0.09	3.417	0.411
8	4.8	256	154	0.16	45	8	6.1	27.6	5.2	0	0	12.47	44.65	9.56	0.02	0.07	0.491	0.225
9	5.6	176	106	0.05	45	8	6.1	15.1	6.3	10	12	1.46	28.5	5.56	0.36	ND	2.675	0.214
10	5.6	203	122	0.05	50	12	4.88	17.4	4.2	8	10	7.63	33.25	7.94	0.05	ND	3.319	0.087
11	5.8	239	143	0.24	55	10	7.32	17.7	10.3	20	24	33.26	33.25	0.26	0.37	0.04	2.942	0.077
12	6.8	885	531	1.55	175	34	21.96	106.9	5.1	128	156	58.42	134.9	0.03	2.28	0.1	2.507	0.231
13	6.2	192	115	0.07	70	16	7.32	11.9	3.6	30	37	22.78	23.75	0.2	0.09	ND	3.907	0.173
14	4.9	221	133	0.29	40	6	6.1	20.2	17.6	4	5	4.28	47.5	7.21	0.02	ND	4.21	0.084
15	5.4	58	35	0.08	25	8	1.22	5.8	0.8	6	7	9.83	11.4	1.8	0.04	ND	2.12	0.409
16	6.3	161	97	0.02	45	12	3.66	15.1	2.6	26	32	15.93	23.75	0.72	0.02	0.08	2.471	0.427
17	6.1	260	156	0.05	75	16	8.54	21.8	3.5	40	49	17.84	34.2	4.81	0.01	ND	2.32	0.429
18	5.5	78	47	0.03	30	4	4.88	7.2	2.2	8	10	4.31	14.25	2.92	0.01	ND	2.16	0.411
19	5.6	104	62	0.01	45	10	4.88	5.3	2.6	14	17	9.18	9.5	4	0	ND	2.16	0.225
20	6.8	215	129	0.02	85	22	7.32	9.7	7.2	56	68	19.78	18.05	0.51	0.07	0.07	2.35	0.082
21	5.4	82	49	0.01	30	8	2.44	8.4	1.5	8	10	4.29	14.25	2.9	0	ND	2.24	0.166
22	4.8	36	22	0.06	15	4	2.44	4.1	0.4	4	5	3.47	7.6	1.08	0	ND	2.15	0.43
23	5.9	173	104	0.11	75	16	8.54	10.5	2.1	30	37	4.66	27.55	2.7	0.2	0.07	3.17	0.062
24	6.5	238	143	0.15	90	26	6.1	11.3	7.4	36	44	20.05	20.9	7.67	0.05	0.07	2.37	0.427
25	5.8	160	96	0.12	50	8	7.32	13.6	3.2	12	15	8.54	17.1	7.25	0.09	0.09	3.19	0.397
26	6.7	161	97	3.29	60	8	9.76	11.6	4.4	66	81	9.32	7.6	0.05	1.24	0.19	3.15	0.19
27	7.5	3585	2151	0.03	180	28	26.84	550.4	16.6	374	456	153.8	627	0.13	1.23	0.22	2.3	0.23
28	6.6	1054	632	0.91	430	94	47.58	33.4	5.3	74	90	47.71	275.5	0.09	0.2	0.2	2.14	0.17
29	7	498	299	0.09	90	22	8.54	78.1	2.4	154	188	35.75	36.1	0.02	0.1	0.28	2.45	0.12
30	7.3	923	554	0.12	260	58	28.06	85.7	4.8	184	224	22.88	157.7	0.03	0.11	ND	2.89	0.35

TDS range for drinking water is 500–1000 mg/l. All samples are within the permitted limit, except sample 27, which has a high TDS level. Water with high quantities of solids can cause laxative or constipation effects (Sasikaran et al., 2012). The electrical conductivity values in the study area range from 36 to 3585 mS/cm, with an average of 397.16 mS/cm. According to the WHO (2011) guidelines for drinking water quality, the desirable limit of electrical conductivity (EC) in water is 400 mS/cm. In the research area, 24% of samples exceed the permitted electrical conductivity limit, while 76% are within the allowed range.

Pure water insulates better than it conducts electric current (Meride and Ayenew, 2016). Turbidity values range between 0.01 and 3.29 NTU. According to WHO (2011), the desired turbidity limit is 5 NTU, and all samples from the research area fall under this limit. The alkalinity in the research area ranges from 0 to 374 mg/l. According to WHO (2011), the desirable limit of alkalinity is 200 mg/l. Alkalinity is not harmful to human beings, but water with less than 200 mg/l is desirable for domestic use. In this study area, all of the samples were within the permissible limit, except sample no. 27, whose concentration exceeded the allowable limit. Total hardness values in the study area range from 15 to 430 mg/l. As per WHO (2011), The permissible limit of total hardness is 200 mg/l. In the research area, all samples are within the permissible limit, except for samples 28 and 30, which exceed the allowable limit. The calcium concentration in the samples ranged from 4 to 94 mg/l. According to WHO (2011), the recommended calcium limit in drinking water is 75 mg/l. In the study area, all samples are within the permissible limit except for sample 28, which exceeds the limit. Magnesium concentrations range from 1.22 to 47.58 mg/l. According to WHO (2011), the permissible limit for Magnesium is 50 mg/l. All samples from the study area fall within acceptable limits. The sodium concentration in samples ranges from 4.1 to 550.4 mg/l. According to WHO (2011), the recommended sodium limit in drinking water is 150 mg/l. All samples are within the permitted limit except for sample no. 27, which exceeds the allowable limit. The potassium concentration in samples ranges from 0.4 to 17.6 mg/l. The World Health Organization (2011) recommends a limit of 12 mg/l of potassium in drinking

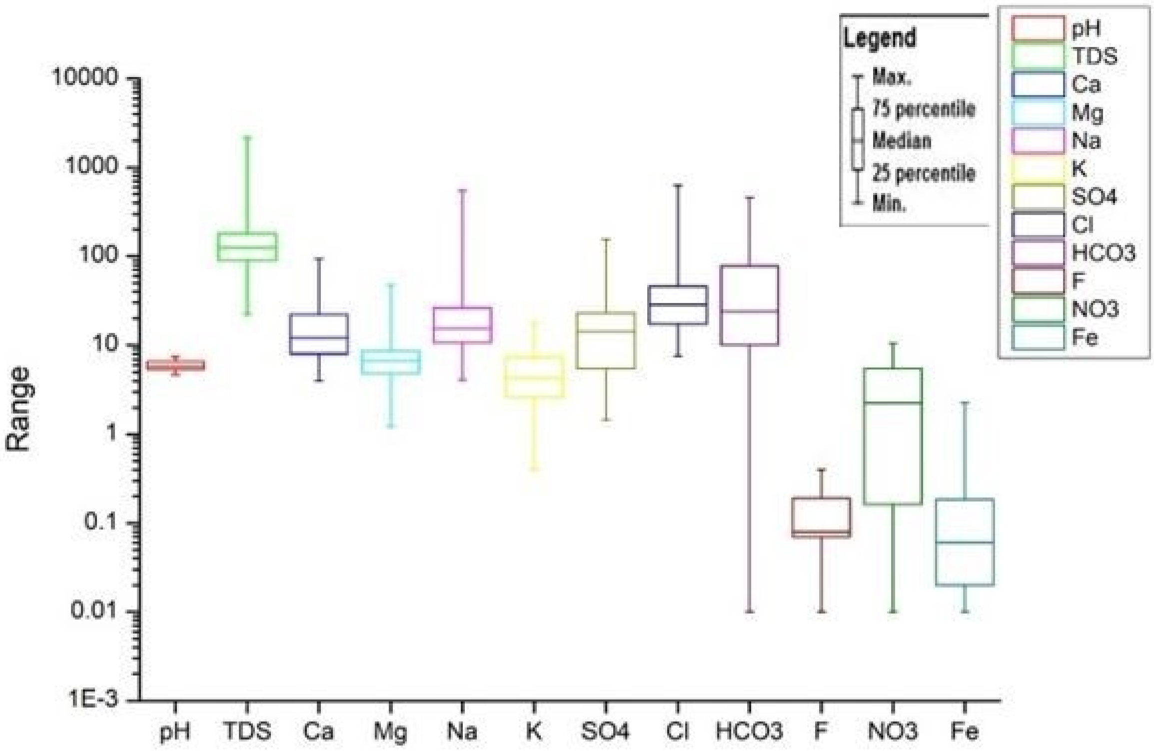

Fig. 4. Box Plot for the study area.

water. In this research area, all samples are within the permissible limit, except samples 7, 14, and 27, which exceed the allowable limit. The chloride values in the samples range from 7.6 to 627 mg/l. Based on WHO (2011), the permissible chloride limit is 200 mg/l. In the study area, all the samples are within the permissible limit, except for sample no. 27, which exceeds the allowable limit. The bicarbonate values in samples ranged from 0 to 450 mg/l. According to WHO (2011), the maximum allowed bicarbonate concentration in drinking water is 300 mg/l. In the study area, all the samples were within the permissible limit, except sample no 27 which has a concentration that exceeds the permissible limit. The minimum and maximum sulfate concentrations range from 1.46 to 153.88 mg/l. According to the WHO (2011) drinking water quality standards, the maximum permissible concentration of sulfate is 200 mg/l. All of the samples from the research area are within permissible limits. Nitrate concentrations in the study area range from 0.03–10.52 mg/l. According to WHO (2011) the maximum permitted value of nitrate for drinking water is 45 mg/l. All samples from the study area are within the permitted limit. The fluoride values in samples range from 0.04 to 0.4 mg/l. According to the WHO (2011) drinking water quality standards, the maximum allowable fluoride concentration is 1.5 mg/l, and all samples from the study area are within the allowed limit. The nitrite values in samples range from 0.06 to 0.43 mg/l, according to the WHO (2011) drinking water standards, the acceptable limit of nitrite is less than 1 mg/l. All of the samples from the research area are within permissible limits. The phosphate levels in the samples ranged from 0.49 to 4.21 mg/l. According to the WHO (2011), the maximum acceptable phosphate level for drinking water is 5 mg/l. In the study area, all of the samples were within the acceptable range. The iron levels in the samples range from 0 to 2.28 mg/l. According to the WHO (2011) the maximum allowable iron concentration in drinking water is 0.3 mg/l. In the study area, 80% of the samples were within the permitted limit, while 20% exceeded it. The groundwater samples in the study area have a Na/Cl ratio ranging from 0.12 to 2.16. The high Na/Cl ratio (more than 0.86) is due to rock-water interaction. Some borewell sample sites, such as 27, 28, and 30, show saline water (Na/Cl < 0.86), indicating the ingress of seawater into the aquifers. The groundwater level during the pre-monsoon period varied from 1.75 to 11.64 meters below ground level (mbgl), with an average of 6.69 mbgl, whereas during the monsoon, it ranged from

1.2 to 9.12 mbgl, averaging 5.16 mbgl. The decline in groundwater levels during the pre-monsoon season results from excessive extraction and insufficient recharge caused by minimal rainfall. Consequently, seawater will infiltrate freshwater aquifers.

5.2. The microbiological analysis of groundwater samples

The microbiological analysis results, which include total coliform and fecal coliform, are shown in Table 2. The WHO's drinking water quality standards state that the permitted limit for coliform bacteria is 10 MPN/100 ml. The total coliform count ranged from 0 to more than 1100 MPN/100 ml over the sampling sites. All samples from the study area exceeded the permissible limit, except for two samples (5, 22) that exhibited the absence of total coliform. Coliform bacteria may enter wells via the direct discharge of feces from mammals, birds, and humans. If we only discover total coliform bacteria in drinking water, it is most likely environmental in origin and unlikely to be caused by feces. Fecal coliform bacteria are a subset of the total coliform bacteria. Both human and animal feces contain it.

The fecal coliform count in samples ranged between 0 and 1100 MPU/100 ml. If 1 fecal coliform per 100 ml of water is found, the water is considered hazardous to drink (USEPA, 1998). 43% of water samples from the research area contain fecal coliforms, while 57% are clear of fecal contamination. Fecal coliform bacteria are strongly associated with fecal pollution of water from warm-blooded animals (Latha and Mohan, 2013). The adverse effects of urbanization in the study area are increased groundwater contamination caused by the infiltration of fecal coliform bacteria into groundwater resources, primarily targeted at open wells (Kumar and Panakkal, 2012). Fecal contamination comes from diverse sources, including sanitation systems, solid waste disposal sites, home wastewater, and rainfall drainage (ARGOSS, 2001). Fecal coliform bacteria are sensitive indicators of bacterial pathogen contamination in natural water. Thrissur urban area shows widespread bacterial contamination due to high human activity, sewer system leaks, and the infiltration of contaminants from road surfaces.

Table 2. The result of the microbiological analysis in the study area.

Sample number	Total coliform (MPN/100 ml)	Faecal coliform (MPN/100 ml)
1	43	23
2	> 1100	7
3	93	NIL
4	240	NIL
5	NIL	NIL
6	> 1100	43
7	460	43
8	240	23
9	43	8
10	> 1100	43
11	210	NIL
12	240	NIL
13	> 1100	1100
14	43	NIL
15	240	NIL
16	93	15
17	> 1100	23
18	23	NIL
19	240	NIL
20	> 1100	93
21	43	NIL
22	NIL	NIL
23	23	NIL
24	> 1100	NIL
25	240	NIL
26	41	7
27	23	NIL
28	210	15
29	23	NIL
30	43	NIL

5.3. Hydrochemical Facies in the Study Area

The Piper diagram is a commonly utilized way of deriving hydrochemical patterns based on ionic data, and better understanding of the hydrogeochemical processes (Yan et al., 2024). Fig. 5 displays the Piper trigram, which highlights the primary cations and anions in the research area. The Piper diagram is based on the principle that cations and anions in natural water are in a state of chemical equilibrium. The distribution of cations in water follows this order: no dominant type > Na^+ > Ca^{2+}, with 67% of samples exhibiting no dominant type, 23% exhibiting sodium and potassium type, and 10% exhibiting calcium type. The distribution of anions in water is Cl^-> no dominant > $HCO_3{}^{-2}$, with 60% of the samples showing chloride type, 23% showing no dominant type, and 17% showing bicarbonate type. The hydrochemical facies in the study area were Ca^{2+}–Mg^{2+}– Cl^-– $SO_4{}^{2-}$, Na^+– K^+– Cl^-– $SO_4{}^{2-}$, and Ca^{2+}– Mg^{2+}– $HCO_3{}^{-2}$, which explains the presence of both permanent and temporary hardness in the groundwater of the research area. In Fig. 5, the diamond shape shows four types of water. 63% of samples are mixed type, the mixed zone, where kinds of groundwater may be defined as neither anion nor cation dominant (Todd and Mays, 2004), while 20% of samples show sodium chloride

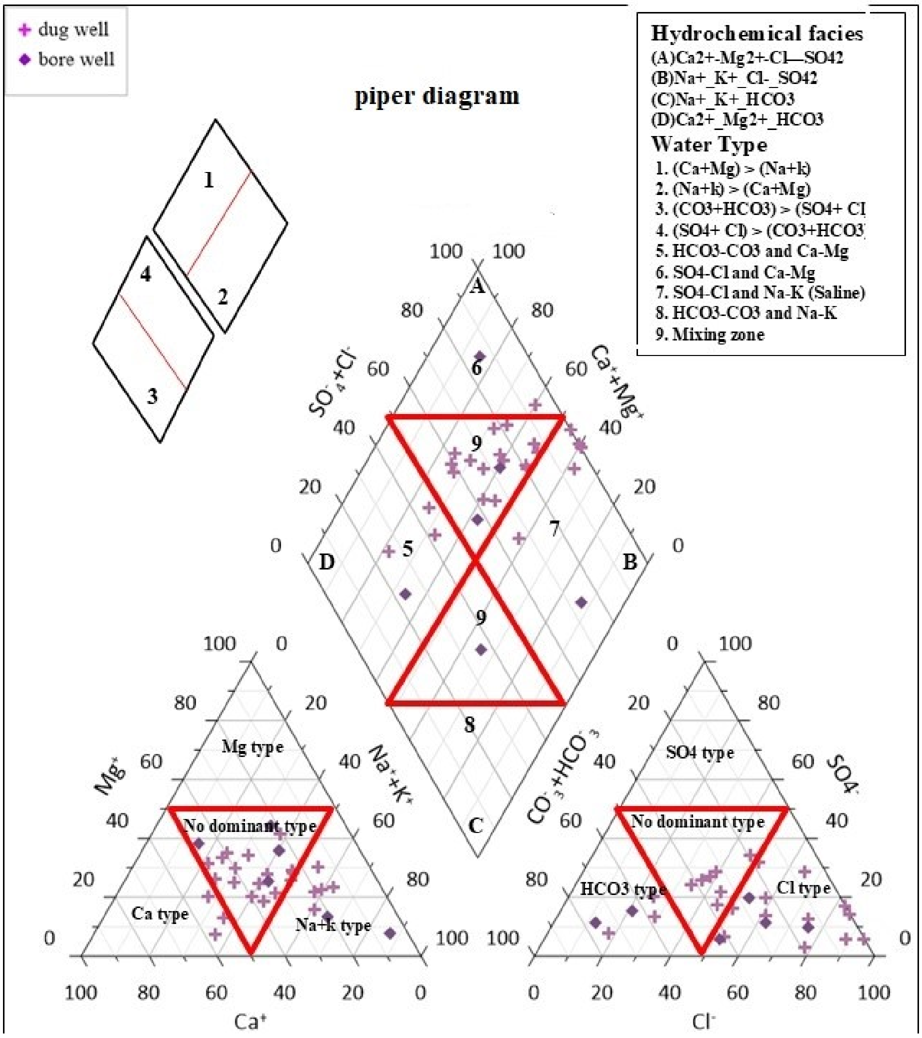

Fig. 5. Groundwater classification of Thrissur urban area based on Piper diagram.

types (saline), where the non-carbonate alkali exceeds 50%. The calcium-magnesium carbonate type covers 13% of samples and is classified as temporary hardness, where the carbonate hardness exceeds 50%, In this zone, reverse/inverse ion exchange controls the chemistry of groundwater (Davis and Dewiest, 1966). The calcium chloride type covers 3% of samples and belongs to the permanent hardness category where non-carbonate hardness exceeds 50%, indicating the presence of groundwater from limestone and dolomite formations or active recharge zones with brief residence times (Ravikumar and Somashekar, 2017). The Piper diagram also shows that 77% of the samples show alkaline earth exceeds alkalies (Ca + Mg >Na + K), while 23% of them show the reverse., and 87% of samples have strong acidic anions exceed weak acidic anions (Cl + SO4 > HCO3), while 13% of them show the contrary. Ravikumar and Somashekar (2017) reported the same tendency, with alkaline earth metals dominating over alkalis and strong acidic anions dominating over weak acidic anions in India's Varahi River basin. The Piper Diagram (Fig. 5) shows the conversion of freshwater (Ca^{2} −HCO) to saline water (Na −Cl) via an intermediate mixed water type (zone 9). This conversion might indicate changes in hydrogeological conditions or the effects of a variety of processes, such as water-rock interactions and anthropogenic activity.

Based on Gibbs's diagram the samples fall within the domain of rock weathering, indicating that water-rock interaction is the primary process controlling the chemistry of water in the study area, as shown in Fig. 6.

6. CONCLUSIONS

The examination of groundwater quality in the research area indicates apprehensions regarding chem-

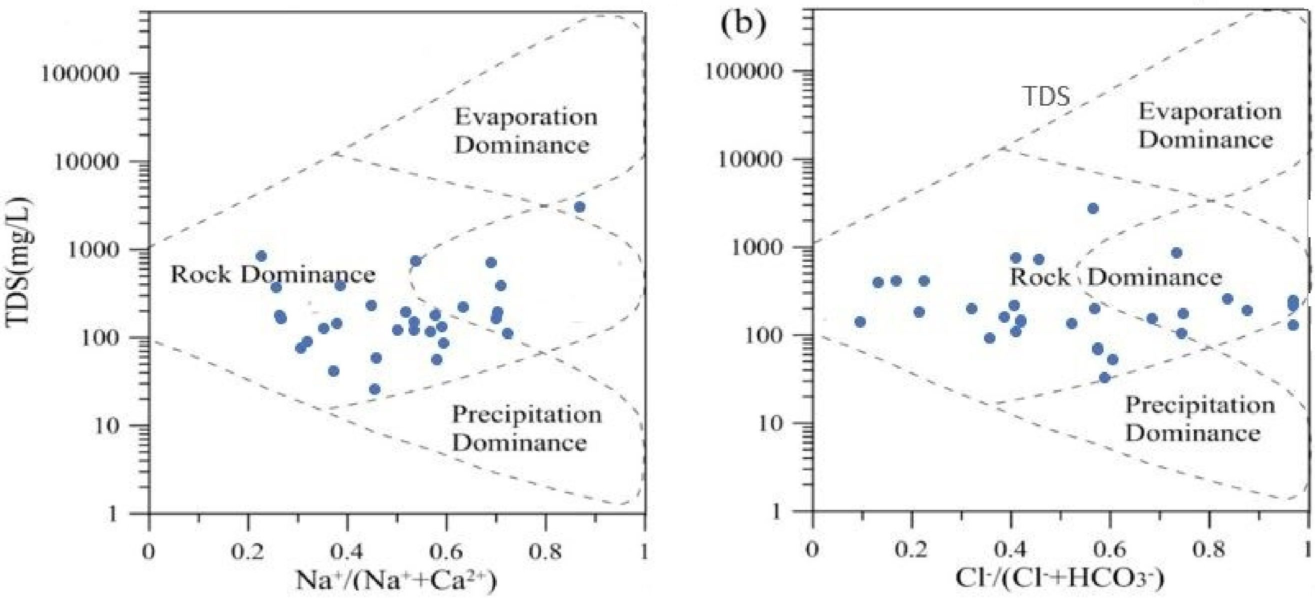

Fig. 6. Gibbs diagram of water chemistry.

ical and microbial aspects. The majority of physico-chemical parameters meet the standards set by WHO, nevertheless, some samples exceed the allowable limits, especially in regards to total dissolved solids (TDS), sodium, potassium, chloride, bicarbonate, and iron. The extensive occurrence of total and fecal coliform bacteria in the samples indicates significant bacterial contamination. The Piper diagram shows that the majority of samples belong to the mixed-type water category, while many of the samples exhibit characteristics of sodium chloride and calcium-magnesium carbonate types. Some borewell sample sites, show saline water indicating the ingress of seawater into the aquifers. The observed groundwater wells suggest a transition from freshwater to saline water, possibly due to the effects of rock weathering, ion exchange mechanisms, and probable human activities. Strategies like establishing a strong groundwater monitoring network, preventing groundwater over-extraction, and land use patterns, and protecting aquifer recharge zones help to protect the groundwater quality and sustainability.

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