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ORIGINAL ARTICLE

Assessment of groundwater quality using GIS in Thane Municipal Corporation, Maharashtra, India

Sitaram Shinde[1] · Pandurang P. Choudhari[1] · Bhushan Popatkar[2] · Namit Choudhari[1]

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Abstract

In this paper, the groundwater quality of the Thane Municipal Corporation (TMC) area of Maharashtra state, India was assessed for drinking and industrial purposes as per the standards recommended by WHO (2017) and BIS (2012)). In the February 2019, using Random sampling method 25 water samples were collected from different parts of the TMC area. Using these ground water samples various parameters were analysed such as Power of Hydrogen (pH), Electrical Conductivity (EC), Total Hardness (TH), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Potassium (K^+), Chloride (Cl) and Lithium (Li). The pH and EC were determined by Digital pH meter and conductometer respectively. The Cl^- was assessed by non-instrumental experiment (Mohr's method) and the rest of the parameters were analysed by ELICO CL378 flame photometer. With the help of Geographical Information System (GIS), spatial distributions of groundwater quality parameters were mapped. The results indicated that, the ionic dominance for cations and anions were $Cl^- > Ca^{2+} > Mg^{2+} > K^+ > Li^+$. TH and EC showed higher concentrations near the Thane creek and artificial rills compare to forest and construction zones. This infers that anthropogenic activities have greater influence than the natural process (water–rock interaction). Overall study reveals that water quality is good for industrial use in the zone surrounding to Thane creek but unsuitable for drinking. However, 86% of the samples in the study area showed good to excellent water quality for drinking purposes.

Keywords WHO · BIS · TMC · Ground water quality · GIS · Conductometer · Flame photometer

Introduction

Water is essential among all the natural sources available on the earth and hence it is considered as life. Without water, life on planet earth is not possible (Singh and Hussain 2016). Hydrogen and oxygen are the main elements of water (Hem 1985). Due to a steady rise in population and urbanization, the demand for water has consistently increased which has put enormous stress on the available water resources across the globe (Choudhari 2013; Choudhari and Kurlakar 2012; Dev and Bali 2018). Furthermore, improper management of water, land use/land cover, changing climate, rise in sea levels, saltwater intrusion, uneven rainfall patterns, and droughts have led to water scarcity, especially, in developing countries (Singh et al. 2009, 2010, 2014; Srivastava et al. 2013; Thakur et al. 2015; Gautam et al. 2015, 2018; Jacintha et al. 2017). This has ultimately affected the availability and quality of clean drinking water (Gautam et al. 2016; Gajbhiye et al. 2015; Rawat et al. 2017, 2018; Pande et al. 2019). UNESCO (2019) reported that water adulteration has caused 80% of the diseases and deaths in developing countries.

In India, monsoon is one of the most important seasons because agriculture, industrial and domestic activities are highly dependent on it. In the TMC (Thane Municipal Corporation) region, Vaitarna, Modak Sagar and Tansa dams fulfill water demand of TMC for drinking and industrial purposes. However, due to the increasing population and migration in Thane city, the demand for water is consistently increasing and thus, freshwater resources are not adequate

✉ Pandurang P. Choudhari
choudharipp79@gmail.com

Sitaram Shinde
sitaramkshinde26@gmail.com

Bhushan Popatkar
bpopatkar@gmail.com

Namit Choudhari
namit70@gmail.com

[1] Department of Geography, University of Mumbai, Mumbai, Maharashtra, India

[2] Department of Chemistry, University of Mumbai, Mumbai, Maharashtra, India

to fulfill the drinking water for the need of the whole city. Moreover, due to the irregularity of monsoon rains, droughts and improper water management, Thane city is facing water scarcity problem for last few years. In this circumstances, groundwater is the only substitute for surface water. A steady rise in population will increase the demand for fresh water in the coming decades (Subramani et al. 2012). Hence, it is of utmost importance to check the suitability of groundwater of the TMC region for drinking and industrial purposes.

Most studies on groundwater quality have carried out by various researchers from India and across the globe using Remote Sensing and GIS techniques (Vennila et al. 2008; Magesh et al. 2013; Singh et al. 2015, 2017; Thakur et al. 2017; Rawat and Singh 2018; Pande et al. 2019; Shomar et al. 2010). Hussain et al. (2010) reported that groundwater quality is highly dependent on the geological formation of the underlying strata. Moreover, interactions between water and rocks/minerals with varied chemical composition affect the quality of groundwater (Singh et al. 2013a,b; Nemčić-Jurec et al. 2019; Rawat et al. 2019; Zaidi et al. 2015). The release of chemicals in water and nearby streams from various construction activities degrade groundwater quality (Gautam et al. 2013; Ram et al. 2013; Singh et al. 2012; Miller and Hutchins 2017). Human activities such as improper disposal of industrial waste and mining are the major factors for the presence of metals in groundwater (Kolpin et al. 1998; Gautam et al. 2018; Musa et al. 2013). Heavy metals such as lead, mercury, copper and nickel were reported across the globe (Maliqi et al. 2020; Gautam et al. 2015; Wu 1980) and in India too (Annapoorna and Janardhana 2015). Nagarajan et al. (2010) reported the dominance of sodium and chloride from the groundwater samples of the industrial area in Thanjavur city of Tamil Nadu, India. Anthropogenic activities have led to arsenic and fluoride adulteration in groundwater samples across several regions in India (Thakur et al. 2013; Singh et al. 2013b; CGWB 2010). High nitrate concentration was found in construction and industrial zones in the lower Varuna River basin of Varanasi district (Raju et al. 2009).

In this paper, the focus of the study is to assess the groundwater suitability for drinking and industrial purposes in the TMC region. It is important to find out whether groundwater can be used for drinking and industrial purposes during water scarcity time in TMC region so that government/decision-makers can take proper initiatives for water management and formulate the policies accordingly. The suitability of drinking water has been evaluated as per the standards of the World Health Organization (WHO) and the Bureau of Indian Standards (BIS).

Study area

The study area is the TMC region of Thane district as represented in Fig. 1. Thane city is the headquarters of the district, which lies between 18°25′ to 20°12′ north latitudes and 72°27′ to 73° 29′ east.

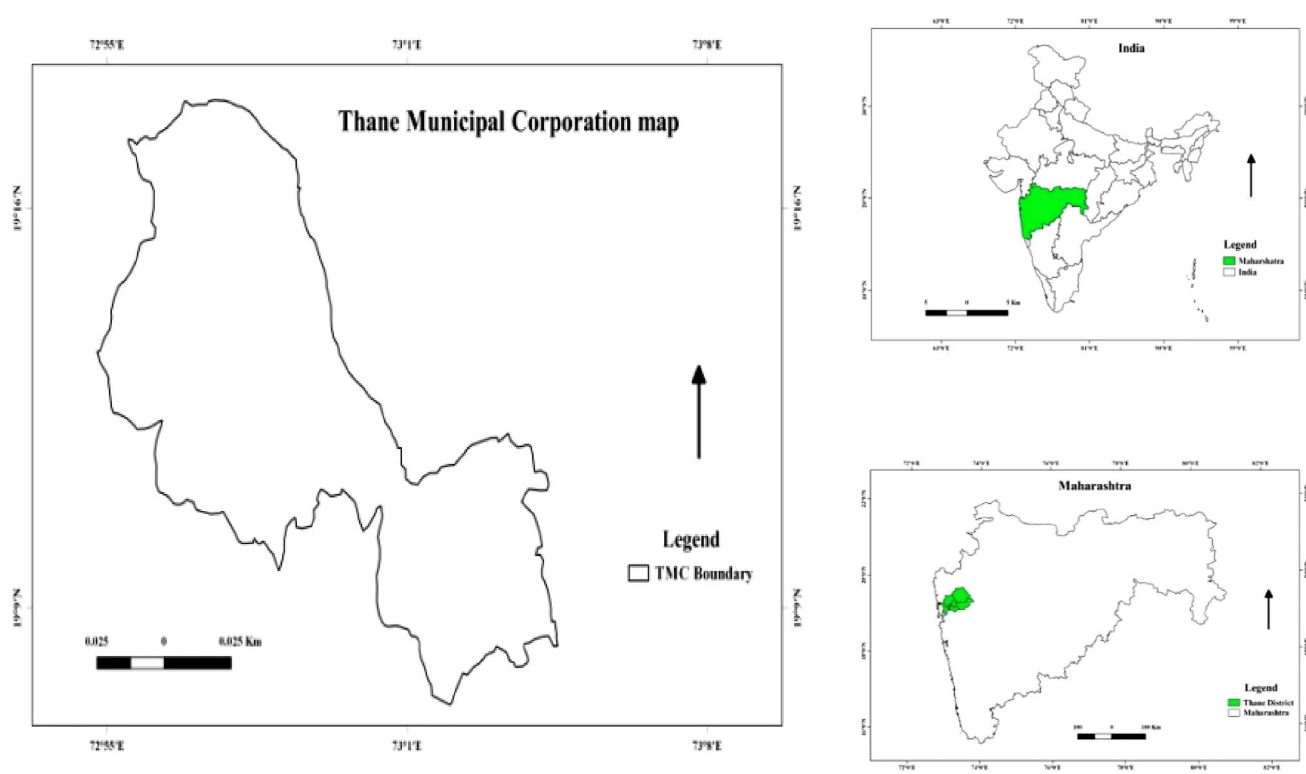

Fig. 1 Study area map

Table 1 Zone wise division of areas in TMC region

Zones	Name of areas
Residential	Uthalsar, Tembi Masjid, Rutu Park, Vasant Vihar, Mumbra, B Cabin, Naupada, Dongripada, Vartak Nagar and Amrut Nagar
Industrial	Samta Nagar, Jyotiba Temple, Kolshet and Nitin Company
Construction	Mumbra Colony, Tetavli Kausa, Chitalsar, Owala and Hiranandani Estate
Forest	Yeoor and Bendipada
Surrounding Thane creek	S.D.Vithavkar, Gaimukh, Vitawa and Kharegaon

Longitudes covering an area of 147 sq. km. It has situated on the eastern side of the Western Ghats and the nearby the Arabian Sea. Geomorphologically, this area represents an uneven topography with high hills and steep valleys. The average annual rainfall of Thane is 2300 mm and has a tropical climate (Am) with a mean yearly temperature of 27 °C. There are various surface water bodies like lakes and wells apart from Thane creek. For study, purposes study area divided into various zones as described in Table 1.

Data source and methodology

Total 25 ground water samples collected through Well, Hand pumps and Bore wells in the TMC region of Thane district, Maharashtra, India (Table 2). These entire Well, Hand pumps and Bore wells are located in residential, industrial, construction, forest and Thane creek zone. The geographical location of each sample was determined with the help of Global Positioning System (GPS). Before collecting the water samples, water was pumped out for about 5 min to remove stagnant groundwater. Samples were randomly collected in pre-cleaned polypropylene bottles rinsed with hydrochloric acid as per the procedures described by the American Public Health Association (APHA 1998) to ensure good data quality. On the same day after collecting water samples, they were stored in the laboratory at 4 °C temperature level and were analysed for various physicochemical parameters (Fig. 2) like the power of hydrogen (pH), electrical conductivity (EC), total hardness (TH), calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+), chloride (Cl^-) and lithium (Li^+) were assessed.

The pH and EC measurements carried out by Equiptronix EQ 610 Digital pH meter and Equiptronix EQ 660B conductometer respectively. The TH was estimated by complex metric titration (EDTA method). Parameters Ca^{2+}, Mg^{2+}, K^+ and Li^+ ions were determined by the ELICO CL378 flame photometer, whereas Cl^- was quantified by a non-instrumental experiment (Mohr's method). The analytical precision for the total measurements of ions was crosschecked by repeating all the measurements and calculating the ionic balance errors. These ionic balance errors were within ± 5%.

Results and discussion

Water samples analyzed for various physicochemical properties and analytical results of groundwater parameters have presented in Table 3 along with sample locations. Figures (3, 4, 5, 6, 7, 8, 9, 10) shows the spatial distribution of various parameters. These maps were prepared

Table 2 Groundwater sampling locations with latitude and longitude in the TMC area, Thane

Sample no.	Sample location	Latitude	Longitude	Type of source
1	Uthalsar	19.2083	72.9734	Borewell
2	Tembi Masjid	19.1911	72.9750	Well
3	Bendipada	19.2369	72.9429	Hand pump
4	Yeoor	19.2201	72.9419	Hand pump
5	Rutu Park	19.2161	72.9803	Well
6	Vasant Vihar	19.2285	72.9665	Borewell
7	Samta Nagar	19.2132	72.9870	Borewell
8	Jyotiba Temple	19.2385	72.9809	Well
9	Chitalsar	19.2304	72.9837	Well
10	Dongripada	19.2556	72.9706	Borewell
11	Gaimukh	19.2812	72.9438	Borewell
12	Kolshet	19.2434	72.9965	Borewell
13	Mumbra	19.1840	73.0198	Well
14	B Cabin	19.1805	72.9790	Borewell
15	Naupada	19.1989	72.9606	Hand pump
16	Nitin Company	19.1881	72.9607	Borewell
17	Vartak Nagar	19.2164	72.9612	Hand pump
18	Owala	19.2731	72.9581	Borewell
19	Hiranandani Estate	19.2479	72.9802	Borewell
20	S.D Vithavkar	19.1893	73.0003	Hand pump
21	Vitawa	19.1852	72.9887	Hand pump
22	Kharegaon	19.2039	73.0068	Hand pump
23	Mumbra Colony	19.1843	73.0460	Borewell
24	Amrut Nagar	19.1715	73.0296	Borewell
25	Tetavli Kausa	19.1612	73.0245	Borewell

Source: Compiled by author

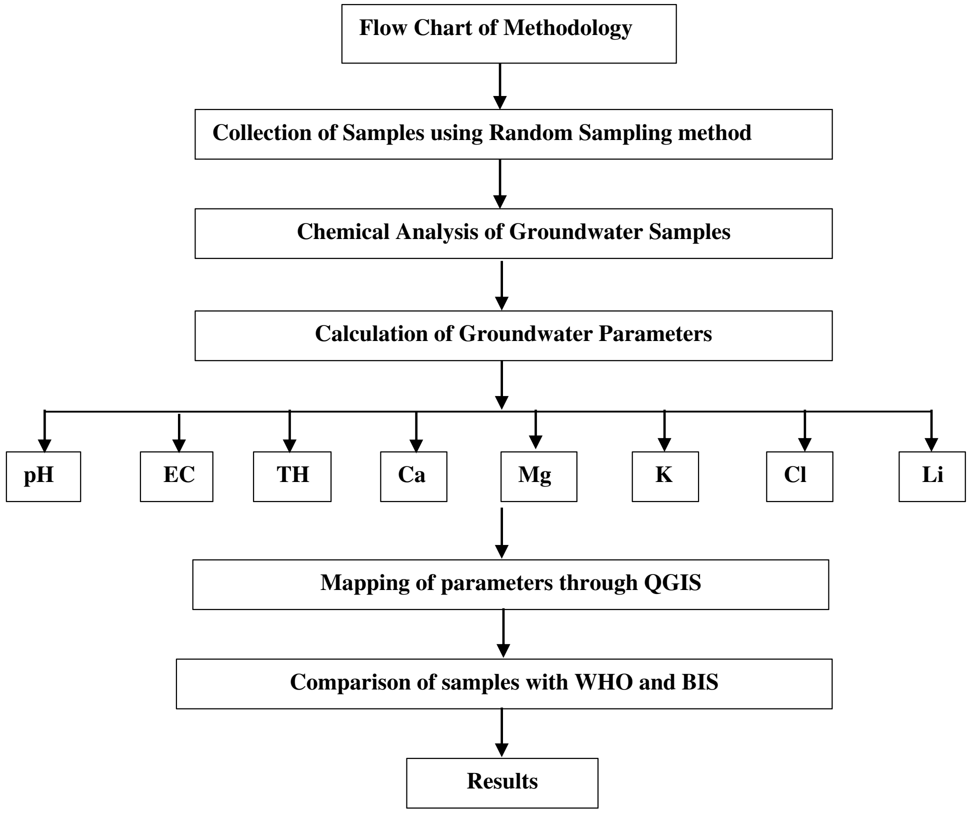

Fig. 2 Flow chart of methodology

using IDW interpolation (inverse distance weighted) method in QGIS software, which shows significant variation.

Power of hydrogen (pH)

The pH is the negative logarithmic of hydrogen ion concentration and normally expressed in moles per liter at a given temperature. It is a measure to find out the acidity of the solution, which contains hydrogen ion. The values of the physical parameters of the groundwater in the TMC region shown that pH ranged from 6.37 to 8.58 with a mean of 6.8 (Fig. 3), which indicated the neutral nature of water as per the USDA (2017) described in Table 4. The lowest pH (6.37) found at Chitalsar and the highest pH (8.58) recorded at Rutu Park (Table 3). Water samples collected from the industrial zone and surrounding Thane creek were neutral in nature. This indicates that the presence of industries or intrusion of saline water in freshwater aquifer did not affect the pH much in these areas. Only the sample of Hiranandani Estate (close to Thane creek) was slightly alkaline (7.64) due to ongoing construction activities that might contain alkaline materials (OH^- ions) (Tables 5, 6, 7, 8). Water samples at Chitalsar (6.37) and Bendipada (6.41) showed a slightly acidic nature. This could be due to the nature of soils and rocks. Sarath Prasanth et al. (2012) concluded that anthropogenic activities like construction, sewage disposal and brackish water intrusion into the sandy aquifers are the major factors responsible for the slightly acidic nature of groundwater. Rutu Park shown highest pH (8.58). This is due to anthropogenic causes, such as domestic effluents from houses besides artificial rills and high EC due to the presence of Cl^- ions (Table 9).

Electrical conductivity (EC)

Electrical conductivity is the quantity of electric current passed in a specific quantity of water; it depends on water temperature, dissolved mineral content and types of ions present. The average EC content was 712.96 mg/l with a range from 103 to 1747 mg/l (Fig. 4). Enrichment of salt in groundwater is the major factor behind high EC (Nagarajan et al. 2010). The highest EC observed in the zone surrounding the Thane creek (Fig. 11). In addition, high EC found at Tetavli Kausa, Mumbra Colony, and Kharegaon with 1747, 1732, and 1277 µS/cm respectively (Table 2). This may be due to the presence of total dissolved solids (TDS) like Ca^{2+}, Mg^{2+}, K^+, Cl^-, Li^+ ions in underground water. High EC in the zone surrounding Thane creek might be due to ongoing construction activities at the banks of the creek and the release of the sewage waste from nearby slums. Rutu Park also showed high EC (1152 mg/l) because of highly alkaline groundwater. This highly alkaline nature is due to effluents from household wastes that directly enter

Table 3 Physicochemical characteristics of different samples of groundwater in TMC

Sample no.	Sample location	pH	EC µS/cm	TH mg/l	Ca^{2+} mg/l	Mg^{2+} mg/l	K^+ mg/l	Cl^- mg/l	Li^+ mg/l
1	Uthalsar	6.64	610	212	172	40	4.5	58.44	0.0
2	Tembi Masjid	6.55	524	208	128	80	8.0	87.66	0.0
3	Bendipada	6.41	653	256	148	108	2.8	175.32	0.0
4	Yeoor	6.98	523	200	168	32	0.2	116.88	0.0
5	Rutu Park	8.58	1152	32	12	20	5.0	204.54	0.1
6	Vasant Vihar	7.03	103	48	32	16	0.6	58.44	0.0
7	Samta Nagar	6.58	825	324	208	116	0.3	175.32	0.2
8	Jyotiba Temple	6.56	852	336	208	128	0.6	116.88	0.2
9	Chitalsar	6.37	860	372	248	124	0.7	146.1	0.2
10	Dongripada	6.73	549	232	140	92	0.2	58.44	0.2
11	Gaimukh	6.43	225	60	60	00	0.3	58.44	0.2
12	Kolshet	6.91	800	116	64	52	3.6	116.88	0.3
13	Mumbra	6.71	836	284	176	108	2.3	146.1	0.3
14	B Cabin	6.70	424	148	84	64	0.2	58.44	0.3
15	Naupada	6.69	489	189	100	89	0.2	58.44	0.4
16	Nitin Company	6.56	486	212	212	00	0.3	58.44	0.4
17	Vartak Nagar	6.53	628	240	68	172	2.0	116.88	0.4
18	Owala	6.73	146	74	40	36	0.9	58.44	0.3
19	Hiranandani Estate	7.64	602	256	164	92	0.2	116.88	0.3
20	S.D Vithavkar	6.91	513	184	140	44	0.3	87.66	0.3
21	Vitawa	6.94	767	132	68	64	7.4	116.88	0.3
22	Kharegaon	6.95	1277	284	112	172	1.8	175.32	0.0
23	Mumbra Colony	6.70	1732	304	136	168	11.9	467.52	0.0
24	Amrut Nagar	6.56	501	240	140	100	0.2	146.1	0.0
25	Tetavli Kausa	6.76	1747	548	260	288	6.1	350.64	0.0

into artificial rills. Furthermore, the effects of saline intrusion in a freshwater aquifer (in the zone surrounding Thane creek), variation in groundwater level/presence of clay and shales also contributes to high EC. Apart from this, factors like temperature, evaporation, ion exchange and topographic conditions may surge EC (Toth 1999). EC showed the highest variance amongst other parameters (Table 8). This indicates that there is variation in their sources. The effect of pH may also increase the EC value but it has found that the pH

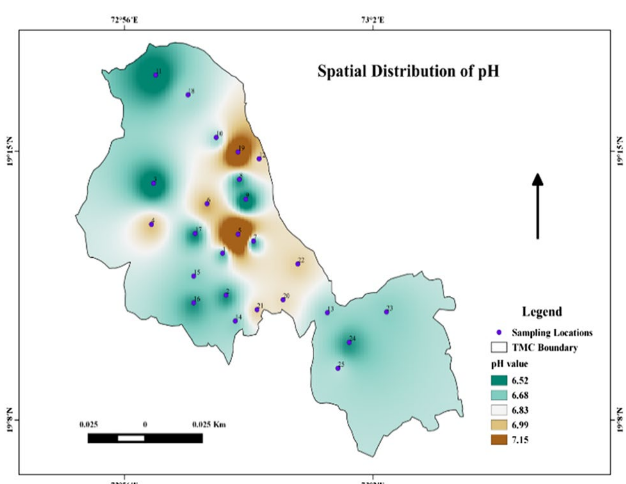

Fig. 3 Spatial distribution of pH

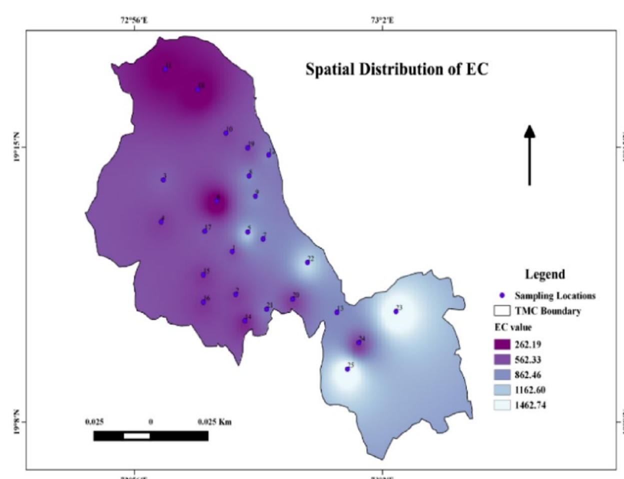

Fig. 4 Spatial distribution of EC

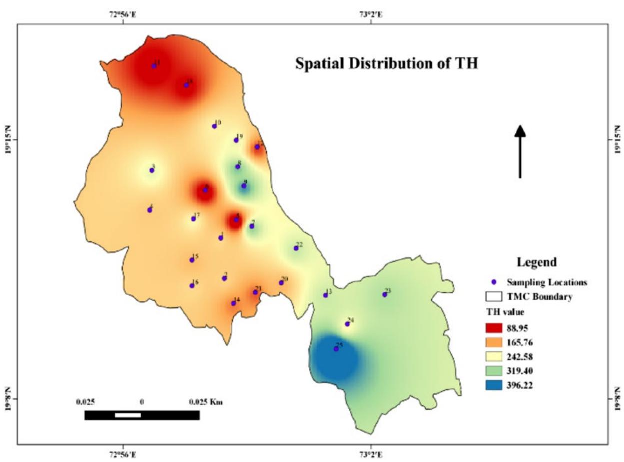

Fig. 5 Spatial distribution of TH

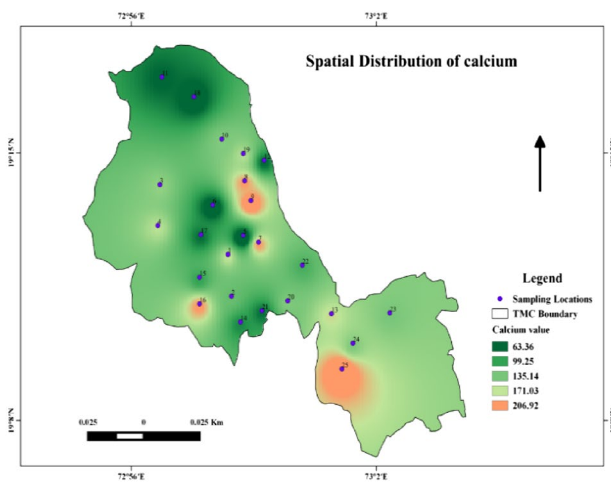

Fig. 6 Spatial distribution of Ca

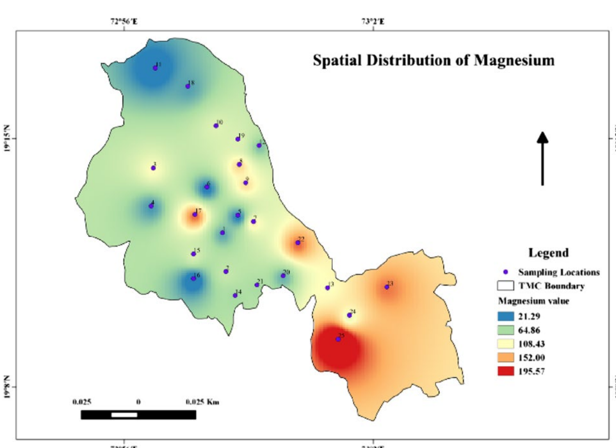

Fig. 7 Spatial distribution of Mg

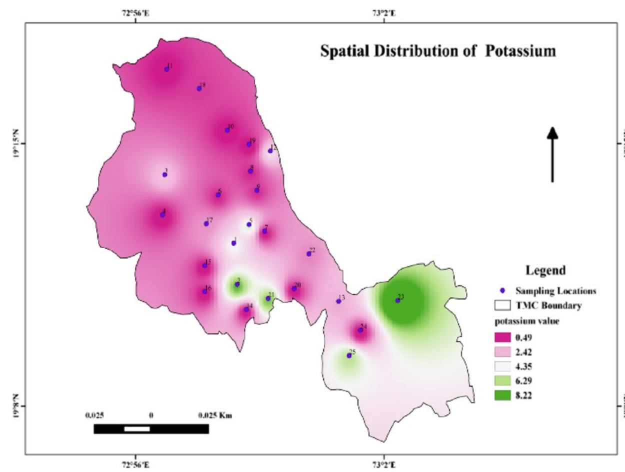

Fig. 8 Spatial distribution of K

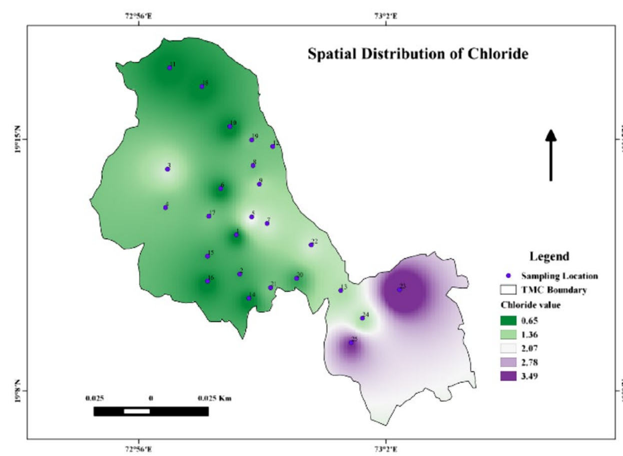

Fig. 9 Spatial distribution of Cl

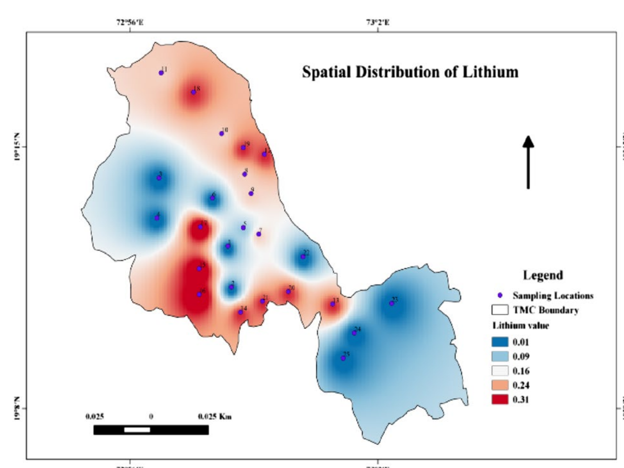

Fig. 10 Spatial distribution of Li

Table 4 Comparison of pH based on United States Department of Agriculture (USDA 2017)

Sr. no.	Denomination	pH range	Sample no.	Percentage of samples
1	Ultra-acidic	< 3.5	–	0
2	Extremely acidic	3.5–4.4	–	0
3	Very strongly acidic	4.5–5.0	–	0
4	Strongly acidic	5.1–5.5	–	0
5	Moderately acidic	5.6–6.0	–	0
6	Slightly acidic	6.1–6.5	2, 3, 7–9, 11, 16, 17, 24	36
7	Neutral	6.6–7.3	1, 4, 6, 10, 12–15, 18, 20–23, 25	56
8	Slightly alkaline	7.4–7.8	–	0
9	Moderately alkaline	7.9–8.4	–	0
10	Strongly alkaline	8.5–9.0	1	4
11	Very strongly alkaline	> 9.0	–	0

Table 5 Classification of groundwater samples based on electrical conductivity (EC) as per Richards (1954)

Sr. no.	EC range (uS/cm)	Water class	Sample no.	Percentage of samples
1	< 250	Excellent	6, 11, 18	12
2	250–750	Good	1–4, 10, 14–17, 19–20, 24	48
3	750–2000	Acceptable	5, 7–9, 12–13, 21–23, 25	40
4	2000–3000	Doubtful	0	0
5	> 3000	Undesirable	0	0

Table 6 Classification of groundwater samples based on total hardness (TH) as per Sawyer and McCarty (1967)

Sr. no.	Class	TH range	Sample no.	Percentage of samples
1	< 75	Soft	5, 6, 11	12
2	75–150	Moderately hard	12, 14, 18, 21	16
3	150–300	Hard	1–4, 10, 13, 15–17, 19, 20, 22, 24	52
4	> 300	Very hard	7–9, 23, 25	20

in these samples was quite low. Thus, it is concluded that pH did not affect the EC. The classification of EC is represented below in (Table 5) as per Richards (1954).

Total hardness (TH)

The total amount of calcium and magnesium ions concentration in groundwater describes as its total hardness. The TH for the tested samples ranged from 32 to 548 mg/l (Fig. 5) with a mean of 219.64 mg/l. Groundwater samples of Tetavli

Table 7 Comparison of water quality parameters with drinking standards of WHO (2017) and BIS (2012))

	WHO (2017)				BIS (2012))			
	Desirable limit (DL)	Samples above DL (%)	Permissible limit (PL)	Samples above PL (%)	Desirable limit (DL)	Samples above DL (%)	Permissible limit (PL)	Samples above PL (%)
pH	6.5	88	8.5	4	6.5	88	8.5	4
EC	–	–	–	–	–	–	–	–
TH	100	84	500	4	200	60	600	0
Ca^{2+}	–	–	–	–	75	72	200	20
Mg^{2+}	–	–	–	–	30	84	100	36
K^{+}	–	–	–	–	–	–	–	–
Cl^{-}	–	–	250	8	250	8	1000	0
Li^{+}	–	–	–	–	–	–	–	–

Table 8 Statistics of physicochemical parameters

Parameters	Minimum value	Maximum value	Mean	Standard deviation	Variance
Ph	6.37	8.58	6.81	0.45	0.20
EC	103	1747	712.96	409.86	167,958.22
TH	32	548	219.64	113.95	12,984.60
Ca	12	260	131.52	67.30	4529.29
Mg	0	288	88.20	65.52	4292.87
K	0.2	11.90	2.42	3.10	9.61
Cl	58.44	467.52	133.24	95.83	9183.39
Li	0	0.4	0.18	0.15	0.02

Table 9 Pearson's correlation matrix of physicochemical parameters

	pH	EC	TH	Ca^{2+}	Mg^{2+}	K^+	Cl^-	Li^+
pH	1.00							
EC	0.18	1.00						
TH	− 0.36	0.63	1.00					
Ca^{2+}	− 0.40	0.36	0.86	1.00				
Mg^{2+}	− 0.22	0.70	0.85	0.47	1.00			
K^+	0.11	0.62	0.14	− 0.06	0.31	1.00		
Cl^-	0.11	0.89	0.54	0.27	0.67	0.66	1.00	
Li^+	− 0.05	0.33	− 0.20	− 0.13	− 0.21	− 0.38	− 0.43	1.00

Kausa, Samta Nagar, Jyotiba Temple, Chitalsar and Mumbra Colony showed very hard TH as per the classification of Sawyer and McCarthy (1967) represented in Table 6.

This is due to the high amount of TDS and slightly high pH. TH showed a strong positive correlation with Ca^{2+} and Mg^{2+} ions (Table 9). It has found that Rutu Park (32) and Vasant Vihar (48) showed a very less TH due to less TDS. It was surprising that Gaimukh and Owala showed soft TH range despite located close to the Thane creek. This is due to less TDS content in groundwater samples, which might be due to slight intrusion of saline water from Thane creek into the freshwater aquifer. Compared to other zones, TH showed higher concentration in the zone surrounding Thane creek (Fig. 11) due to the presence of a high concentration of Ca^{2+} and Mg^{2+} ions. However, Th was low in construction and industrial zones.

Calcium (Ca^{2+})

Calcium is an important constituent in determining the hardness of underground water. The Ca^{2+} concentration ranged between 12 and 260 mg/l in different sites for individual samples (Fig. 6) with an average of 131.52 mg/l. As shown in Table 3, high calcium level recorded at Tetavli Kausa (260 mg/l), Chitalsar (248 mg/l), Samta Nagar and Jyotiba Temple (208 mg/l for both). Water samples of Owala (40 mg/l), Gaimukh (60 mg/l), Kolshet (64 mg/l) showed lesser Ca^{2+} ions as compared to other areas. This may be due to low TH despite close to Thane creek. Thus, it can inferred that there is a slight intrusion of saline water from Thane creek into the freshwater aquifer. High Ca^{2+} ions at Hiranandani Estate (164 mg/l) and Kharegaon (112 mg/l) might be due to constant construction activities including the use of cement containing Calcium Oxide (CaO) and Calcium Sulfate ($CaSO_4$). Construction activities are going on at Owala and Gaimukh too, but it is not intense as compared to Kharegaon and Hiranandani Estate. This is why these areas have lesser Ca^{2+} ions than Kharegaon and Hiranandani Estate. In terms of Ca^{2+} ions, subsurface water showed excellent water quality for drinking purpose in all the zones of the study area.

Magnesium (Mg^{2+})

Magnesium is an important constituent of basalt and its water dissolving capacity is five times more than that of calcium (Satyanarayana et al. 2017). The hardness of the water depends on the presence of Mg^{2+} and Ca^{+2} ions and these occur as bicarbonates in the form of sulfate and chloride (Magesh et al. 2013). Figure 7 displays that Mg^{2+} ions fluctuate from 0 to 288 mg/l with a mean of 88.2 mg/l.

Mg^{2+} ions are completely absent at Nitin Company and Gaimukh area in a zone surrounding Thane Creek (Table 3). This absence of Mg^{2+} ions in groundwater might be due to the lesser amount of TH and Ca^{+2} than other ions. This is mainly due to deficiency of saltwater intrusion from Thane Creek into a freshwater aquifer. In addition, the water table at Nitin Company and Gaimukh might be at higher levels due to which it could have been hindered the saltwater intrusion.

Mg^{2+} ions were higher at Tetavli Kausa (288 mg/l) and Kharegaon (172 mg/l) than other areas due to ongoing construction activities. The cement, which uses during construction activities, contains Magnesium Oxide (MgO) due to which Mg^{2+} ions increases. Moreover, high Mg^{2+} content in the zone surrounding Thane creek is due to household sewage/domestic effluents from people living in slums at the banks of the creek. The presence of Mg^{2+} in groundwater is due to minerals and pollution from various uses of chemical fertilizers or domestic effluents in industries and agricultural activities (Mohamed et al. 2003). In terms of Mg^{2+} ions, groundwater showed unsuitable water quality for drinking in the zone near Thane creek. Following is the formula used to calculation of Magnesium hardness.

$$\text{Magnesium hardness} = \text{Total hardness as } CaCO_3(\text{mg/l}) - \text{Calcium hardness as } CaCO_3(\text{mg/l}).$$

Potassium (K^+)

"Potassium is mainly found in rocks/soils and occur naturally in local groundwater or from manmade sources" (Devic et al. 2013). Various minerals like microcline, hornblende, muscovite, silicate, orthoclase, and biotite in igneous and metamorphic rocks are the major sources of K^+ ions in groundwater (Sayyed and Bhosale 2011).

Figure 8 displays that the K^+ ions in the samples range from 0.2 to 11.9 mg/l with an average value of 2.42 mg/l. Apart from Mumbra Colony, the mean value of K^+ content was below the WHO (2017) recommended limit of 10–12 mg/l. The lowest K^+ ions (0.2 mg/l) were found at Yeoor, Dongripada, B Cabin, Naupada, Hiranandani Estate, and Amrut Nagar, whereas, the highest K^+ content (11.9 mg/l) in groundwater was recorded at Mumbra Colony. K^+ ions occur naturally in groundwater or can arise from construction sites and household wastes (Lundy et al. 2011). Compared to other ions, K^+ showed lesser concentration in all the zones of the study area (Fig. 11).

Chloride (Cl^-)

Chloride is an anion having negatively charged species and its presence affects the quality of groundwater. As shown in Fig. 9, Cl^- content in the samples fluctuated from 58.44 to 467.52 mg/l with an average value of 133.24 mg/l which is below the recommended limit of WHO (2017) and BIS (2012). The lowest Cl^- ions (58.44 mg/l) observed in north-western and central parts of the TMC (Fig. 9) which includes Uthalsar, Vasant Vihar, B Cabin, Naupada, Owala, Nitin Company, Dongripada KMC and Gaimukh Hills (Table 3). This may be due to a natural process such as the passage of water through the aquifer. The highest concentration of Cl^- was recorded at Mumbra Colony (467.52 mg/l) followed

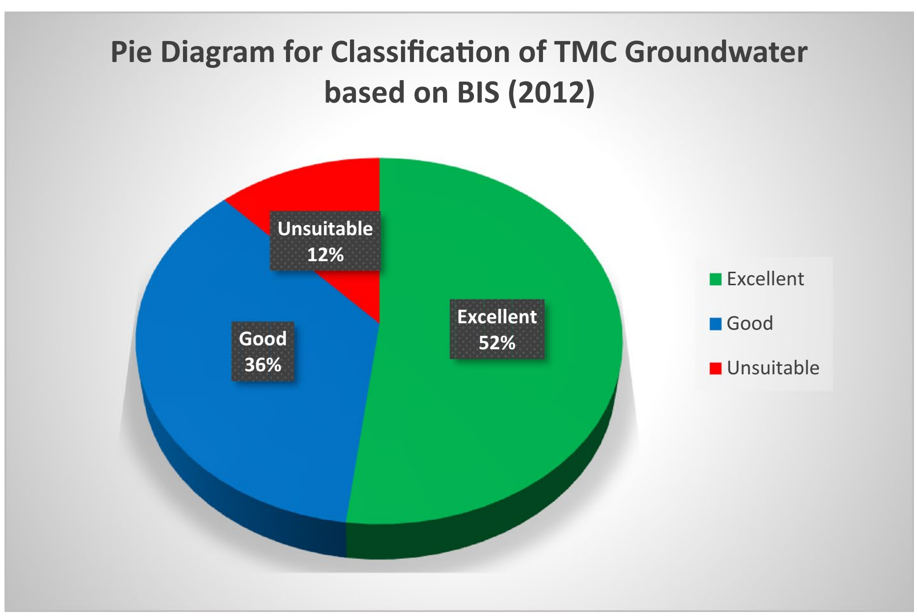

Fig. 11 Zone wise distribution of physicochemical parameters in groundwater samples of TMC region

Table 10 Zone wise groundwater suitability for drinking and industrial purposes

Sr. no.	Zones	Water quality for drinking	Water quality for industrial purpose
1	Residential	Excellent	Excellent
2	Industrial	Good	Excellent
3	Construction	Good	Excellent
4	Forest	Excellent	Excellent
5	Surrounding Thane Creek	Unsuitable	Good

by Tetavli Kausa (350 mg/l) and Rutu Park (204 mg/l) which indicated that groundwater in this region is highly polluted. Landfills, fertilizers, domestic wastages, and leaching from upper layers of soil are some of the major sources of Cl^- ions (Gautam et al. 2018; Vasanthavigar et al. 2012). In terms of Cl^- ions, underground water showed good to excellent quality for industrial and drinking purpose.

Lithium (Li^+)

Li^+ ions in groundwater depend on major factors like geology, topology, and hydrology (Kavanagh et al. 2017). Li^+ ions are the least amongst other physicochemical parameters. Li^+ values are varied between 0.1 to 0.4 (Fig. 10) with a mean value of 0.17 mg/l. Naupada, Owala, and Gaimukh showed the highest concentration of Li^+ ions. However, Li^+ was completely absent in the northeastern and southern parts of the TMC region. There is no health-based guideline for Li^+ ions. Drinking water parameters were compared with WHO (2017) and BIS (2012). Statistics of these parameters have represented in Table 7.

Correlation matrix

Karl Pearson's correlation coefficient matrix (Table 8) measures the strength of relationships between two or more variables (Singh et al. 2009, 2015; Liu et al. 2003). "The variables showing correlation coefficient are considered to be strongly correlated (for $r > 0.7$), where (r) values between 0.5 and 0.7 indicate moderate correlation, while ($r < 0.3$) is weak correlation" (Panaskar et al. 2016). As clear from Table 8, Cl^- ions revealed a strong positive correlation with EC ($r = 0.89$). This relationship demonstrates that Cl^- ions in groundwater are high due to the presence of high EC content. Cl^- and EC showed moderate correlation with TH, Mg^{2+} and K^+ ions. TH was highly correlated with Mg^{2+} ($r = 0.85$) and Ca^{2+} ($r = 0.86$). This indicates that "the cations may have percolated into underground water and thereby increased its hardness" (AlSuhaimi et al. 2016). pH showed a weak correlation (both positive and negative) with almost all the parameters.

Drinking and industrial suitability

The suitability of the TMC region's groundwater for drinking and industrial purposes were evaluated as per the standards set by WHO (2017) and BIS (2012). The values of the physical parameters of groundwater in the TMC region showed that pH ranged from 6.37 to 8.58 with a mean of 6.8 (Fig. 3) and 88% of the samples were under the recommended limit (6.5–8.5) as per WHO (2017) and BIS (2012). However, the ground water sample of Rutu Park exceeded the permissible limit of 8.5 due to the effects of anthropogenic causes such as domestic effluents from houses nearby artificial rills. The average EC content in the TMC region was 712.96 mg/l with a range from 103 to 1747 mg/l (Fig. 4). There are no health-based guidelines for EC. According to Richards classification (1954), 48% of the samples containing EC fall under good water quality and 40% of the samples were within the permissible limit. Moreover, samples of Vasant Vihar, Gaimukh and Owala showed excellent groundwater quality in terms of EC content. Table 6 displays that the majority of samples are within the permissible limit as per the standards prescribed by WHO (2017). Therefore, underground water in the TMC region is safe to use for drinking.

The desirable limit of Ca^{2+} ions in groundwater is specified as 75 mg/l according to BIS (2012). The majority of Ca^{2+} ions (72%) in the study area fall within the permissible limit. Thus, water quality is excellent and safe for drinking purposes. On the other hand, samples of Samta Nagar, Chitalsar, Jyotiba Temple, Nitin Company and Tetavli Kausa exceeded the permissible limit of 200 mg/l as per the norms set by BIS (2012). Hence, water in these areas is unsuitable for drinking purpose. Mg^{2+} ions in subsurface water at Rutu Park, Vasant Vihar, Nitin Company and Gaimukh were below the desirable limit of 30 mg/l as per the guidelines of BIS (2012). However, 84% of the samples were under the permissible limit (100 mg/l) and thus, water is safe for drinking. There are no strict guidelines for the presence of K^+ and, Li^+ ions in subsurface water. The minimum desirable limit for Cl^- ions in underground water is 250 mg/l (BIS 2012). Only 8% of the samples (Mumbra Colony and Tetavli Kausa) were above the desirable limit. Hence, Cl^- ions in water is deficient to use for drinking. As can be seen in Table 10, residential and forest zones have excellent groundwater quality for drinking purpose. Good water quality observed in industrial and construction zones but surrounding to Thane creek zone, groundwater is not suitable for drinking purposes. For the whole TMC region, as can be seen in Fig. 11, about half of the samples (52%) have excellent water quality and 36% of the samples belong to the good category. However, only 12% of the samples in the study area are unsuitable for drinking (BIS 2012). This indicates that groundwater in 88% of the study area is safe for drinking purposes (Fig. 12).

For industrial purposes, total hardness and Cl^- ions in high amounts cause corrosion and incrustation, especially, in pipes supplying water to industries. Table 6 illustrates that samples of Samta Nagar, Jyotiba Temple, Chitalsar, Mumbra Colony and Tetavli Kausa has a very high total hardness. Subsurface water in these areas has surpassed the 250 mg/l TH limit as per WHO (2017). Hence, groundwater is unsuitable for industrial uses. This high TH in water is mainly due to the presence of Ca^{2+} and Mg^{2+} ions. The maximum recommended limit for Cl^- ions in groundwater is 500 mg/l (WHO 2017). Table 3 shows that all the samples in the study area are within the recommended limit. Thus, subsurface water is safe to use for industrial purposes. Treatment methods like de-alkalinisation, desalinization, water boiling along with the use of anti-corrosion pipes should be implemented to avoid corrosion (Raju et al. 2011). In terms of zone wise, an area near to the Thane creek showed good water quality for industrial purposes (Table 10). Similarly, excellent water quality observed for all the remaining zones.

Conclusion

Groundwater quality of the TMC region assessed for drinking and industrial purposes as per the standards specified by BIS (2012) and WHO (2017). The physicochemical characteristics of 25 groundwater samples showed significant variation in subsurface water chemistry.

The order of dominance of cations and anions are $Cl^- > Ca^{2+} > Mg^{2+} > K^+ > Li^+$. EC and TH showed the highest standard deviation due to variation in their sources. This high variation generally attributed to both natural (rock–water interaction in groundwater aquifer) and anthropogenic factors. TH and EC showed higher concentrations in the samples surrounding Thane creek and artificial rills than forest and construction zones. This infers that anthropogenic activities have greater influence than the natural process (water–rock interaction). EC showed a strong positive correlation with Cl^- ions. Similarly, TH too exhibited a strong positive correlation with Ca^{2+} and Mg^{2+} ions.

Residential and forest zones have excellent water quality for drinking purposes, whereas, zone surrounding Thane creek has unsuitable water quality due to the presence of high Mg^{2+} ions. However, for industrial purposes, water quality is good in the zone surrounding Thane creek. Similarly, for the rest of the zones, groundwater is excellent and can be widely used for industrial purposes. Overall, in the TMC region, 88% of the samples have excellent to good water quality. Only 12% of the study area is unsuitable for drinking and most of this is surrounding Thane creek.

There may be variation in groundwater quality parameters in pre and post-monsoon seasons in the TMC region. Hence, it is important to assess the underground water quality before and after the monsoon season in India (Moharir et al. 2019). It is recommended that a periodic assessment of groundwater quality in the TMC region should be done regularly, especially in the surrounding zone of Thane creek to preserve sustainable water quality.

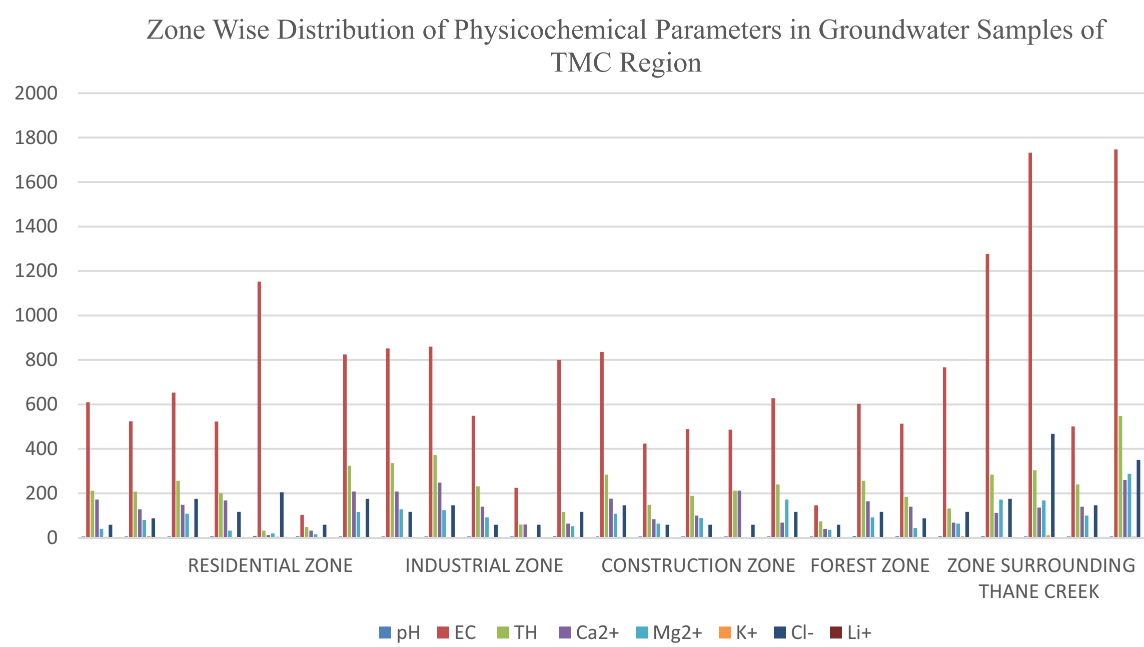

Fig. 12 Pie diagram for classification of TMC groundwater based on BIS (2012)

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Compliance with ethical standards

Conflict of interest No potential conflict of interest was reported by the authors.

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