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RESEARCH ARTICLE

Assessment of silica content in groundwater of Peninsular Indian region using statistical techniques

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Abstract. The groundwater resources from open dug wells are the ultimate and inevitable drinking water source in Chennai municipality. These are of shallow depth of 8 to 10m with a static water depth range of 30 to 75 m. This study's objective was to assess silica (in the form of Silicon Dioxide, SiO2) in groundwater and to establish their baseline concentration. Twelve wells were monitored in the study area, in some parameters, namely: Chloride (Cl^-), Total Dissolved Solids (TDS), pH, Electrical Conductivity (EC), and SiO_2. We examined the existing relationship between silica and other measured water quality parameters (Cl^-, pH, TDS, and EC) using Spearman correlation matrix analysis in SPSS software and Normalized Difference Dispersal Index (NDDI) in Simplex Numerix software that was applied to identify the hotspots of SiO_2. The water pH ranges from 8.09 to 8.37 (slightly alkaline) with an appreciable amount of TDS (730.50 to 1294.50 ppm). The groundwater also contains abundant silica (15.50 to 24.0 ppm), Cl^- (106 to 438 ppm), and EC (759.50 to 1837.50 µS/cm). Further, a geostatistical tool was used to derive NDDI map of groundwater quality parameters and quantified site-specific variations in parameters, namely SiO_2, Cl^-, pH, TDS, and EC values. Average NDDI value enrichment was exhibited by SiO_2 (0.09, ≈ 0.1) it reflects accretion, while average NDDI values of Cl^- (–0.09, ≈–0.1), EC (–0.04), TDS (–0.03), and pH (–0.02), it outlined that by dilution in particular groundwater parameter.

1. Introduction

Silica (Si) is the most abundant substantial component, being after oxygen. It makes up more than 25 percent of the earth's crust. Si not often occurs in component form; almost all exist as compounds (Krauskopf 1967). The usually known compound of Si is Silicon Dioxide (SiO_2), otherwise called silica. The primary source of Si is also sedimentary rocks-sandstones, shale, and slate (Krauskopf 1967). Due to the abundance of Si in the peninsular regions, it has become a major chemical constituent of natural water bodies. According to Hem (1985), the major cause of present Si in natural groundwaters is Si minerals' chemical breakdown in rock and sediments by chemical weathering (Jansen *et al., 2010).* Seepage (or percolate) of earth's crust components such as Si etc., into drinking water, are a cause of concern. Silica has been identified as an environmental nephrotoxin (Ghahramani 2010). Over decades, epidemiological research documented a strong link between exposure to Si and kidney disease (Stratta *et al.,* 2001, Osorio *et al.,* 1987, Hauglustaine *et al.,* 1980). Humans and animals have also shown that high levels of SiO_2 in drinking water cause kidney disease (based on experimental studies, Dobbie and Smith1982).

Conventional and routine analysis of Si not performed for hydrogeochemical studies of groundwater systems, whereas many studies show the water quality evaluation (Adji et al., 2017; Singh et al., 2013; Singh et al., 2015; Nemčić-Jurec et al., 2019; Mohariret al., 2019; Maliqi et al., 2020). Due to this fact that limited works of literature exist on the relationship of silica with parameters, such as water-rock interaction (Marchand *et al.,* 2002, Fournier, 1983), temperature conditions at the time of silica acquisition (Fournier 1983), regional heat flow values (Swanberg and Morgan 1978) and depth to the aquifer. This study is an attempt to highlight the significance of Si analysis in groundwater. Si is generated as a result of chemical breakdown of Si minerals from rocks (underground rocks) and sediments by chemical weathering process (when groundwater circulating) and therefore, the source of Silica (SiO_2) in groundwater is almost due to water-rock interaction (Hem, 1985). The concentration of SiO_2 in groundwater varies range 1 to 30 ppm is an acceptable limit; the average 17 ppm value has come under good condition (Giggenbach *et al., 1985).* Marchand *et al. (2002) reveal that Si in groundwater increases due to interaction with Si rocks and that the Si content is linked to the residence time of water* *underground. Relatively high Si in groundwater, therefore, implies more water-rock interaction process, which, in turn, may be related to various aquifer factors, such as permeability, lithology, and residence time. In another study, Si contamination is due to distinguish rainfall, short residence time shallow groundwater from longer residence time deeper groundwater (*Yousafzai *et al.*, 2010).

In the present study, a geostatistical tool was also used to generating NDDI maps of groundwater quality parameters (Cl, pH, TDS, EC) as suggested by Rawat *et al. (2017, 2018a)*. NDDI mapping is a functional tool for evaluating and comparing spatio-temporal variations in groundwater variables (Rawat *et al.*, 2017, 2018a). Geostatistical mapping techniques have been widely applied in different fields, including water quality in bays (Chehata *et al.*, 2007), watersheds (Todd *et al.*, 2010), soil properties (Lopez-Granados *et al.*, 2005), precipitation (Nour *et al.*, 2006), river discharges (Sauquet, 2006), air pollution (Wackernagel *et al.*, 2004), river and groundwater quality (Gautam *et al.* 2020; Singh *et al.*, 2020) and study of lakes (Amin *et al.*, 2013; Singh *et al.*, 2018). Most of these studies focus mainly on spatio-temporal statistics and groundwater quality, and a quantitative comparative appraisal of site-specific dispersion and attenuation of chemical elements sparse (Rawat *et al.*, 2017a, b & c and 2018a, b& c, Jacintha *et al.*, 2016; Rawat *et al.*, 2019a and 2019b). However, in the present study, a binary approach was followed using geochemical data and GIS (*ArcGIS-10*) based output images (Rawat *et al.*, 2018d).

Chennai, the study area, is the capital of Tamil Nadu state of India **(Figure. 1).** Within the study area, there are two rivers; the Koovam river (in North) and the Adyar river (in South), while the Bay of Bengal Coast is in the East (Saravanan *et al.*, 2018 a & b). The study area is located between latitude 13°4'55.98" to 13°0'7.50" (North) and longitude 80°17'22.37" to 80° 8'42.20" (East), with the elevation varying between 5 m above mean sea level (Saravanan et al., 2018 a, b& c) near the coast to about15 m in the western boundary (Figure. 1a). Geologically, the alluvial deposits rest on the hard rock on the eastern and southern parts (Figure. 1b), contour map (Figure. 1c), and digital elevation map (Figure. 1d) of the study area. The hard rock is mainly Charnockites of the Archaean age (Saravanan et al., 2018 a, b & c). In the northern and western parts, the alluvium rests over the tertiary and Gondwana groups of rocks (Saravanan et al., 2018 a & b). The average thickness of alluvium varies from 10 m along the southern boundary to a maximum of 30 m in the study area's central and eastern parts (Saravanan et al., 2018 a, b & c). Shallow open dug wells of depth varying from 8 to 10m and borewells in the depth range of 30 to 75m are the common groundwater extraction structures in the area (Saravanan et al.,2018 a, b & c).

Climate and rainfall

The study area comes under a tropical climate. From April to June, the period is generally hot and from December to February is cool (Saravanan et al., 2018 a, b & c). The average annual temperature is 24.3 (min.) to 32.9°C (max). The extreme temperatures recorded are 13.9 and 45°C (Saravanan *et al., 2018 a, b & c). The humidity is generally high, and the percentage of humidity ranges between 58 and 84. The study area receives the central part of the rainfall during the north-east monsoon period in October, November, and December (Saravanan et al.,2018 a, b & c). The southwest monsoon rainfall between June and September is generally erratic, and the summer rains are negligible (Saravanan et al., 2018 a & b). The average annual rainfall recorded in the Meenambakkam Observatory is 1323.7 mm, and in the Nungambakkam Observatory is 1285.6 mm. Around 60 percent of the annual rainfall is contributed from the northeast monsoon, 30 percent from the southwest monsoon, and the balance of around 10 percent is contributed from winter and summer rainfall (Saravanan et al.,2018 a, b & c).*

Data collection

A total of 11 (under state government-controlled) open dug well water data was collected from Central Groundwater Board-Chennai (CGWB-C). CGWB-C collected water samples between June and September (regular practice, pre, and post-monsoon). Samples were analyzed for pH, EC, TDS Cl, and Si by CGWB-C. According to the data set from 1999 to 2003, Si was monitored after CGWB-C did not record in 2003. Also, a survey of a topographic map (scale 1:50,000) was used to prepare the base map.

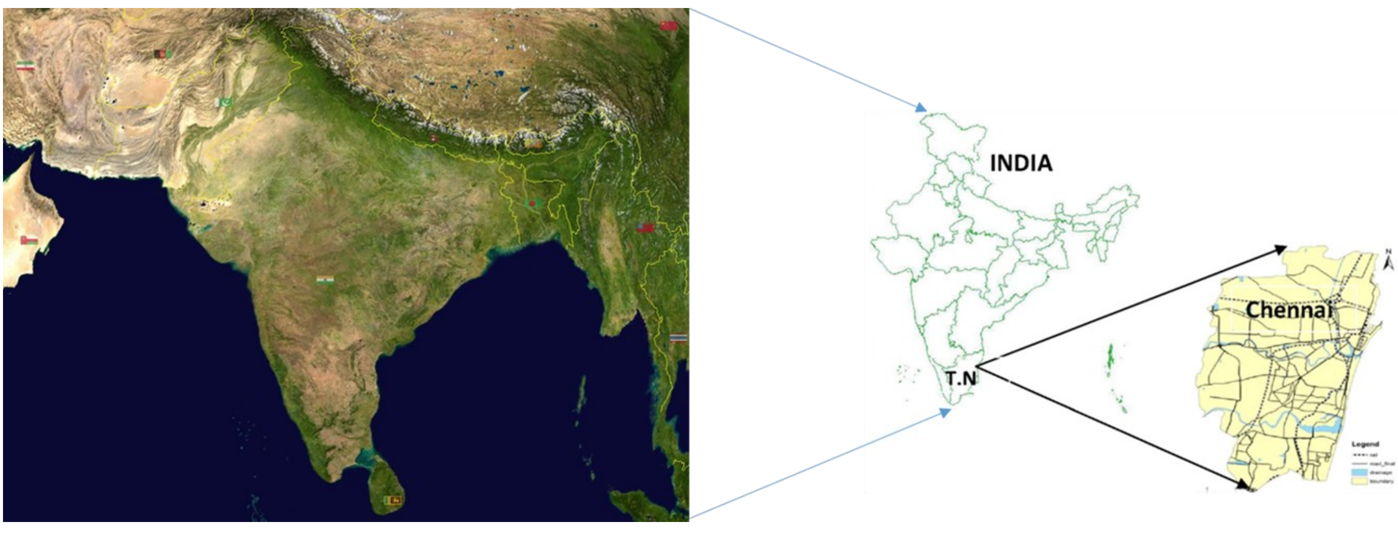


Figure 1a. Location map of the study area

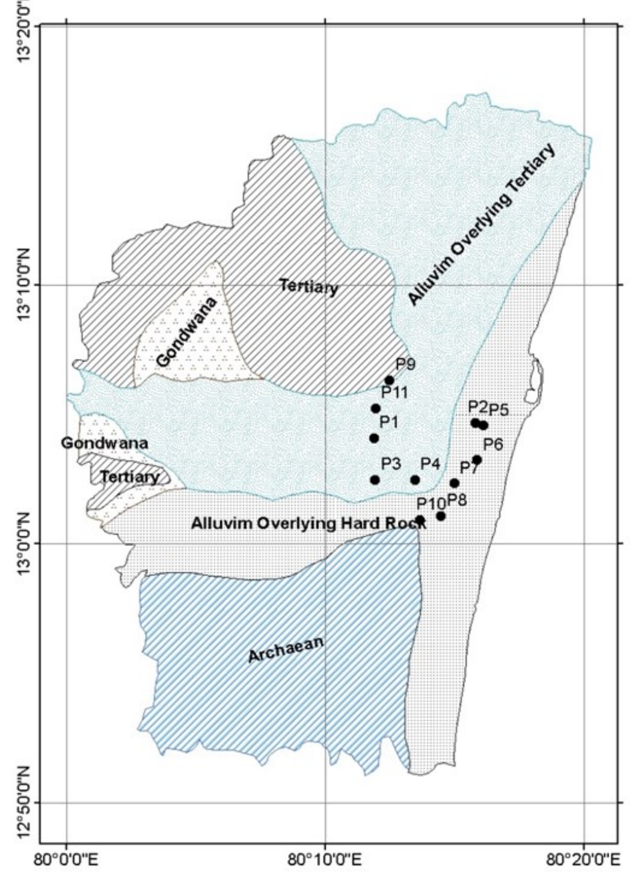


Figure 1b. Geological map of the study area

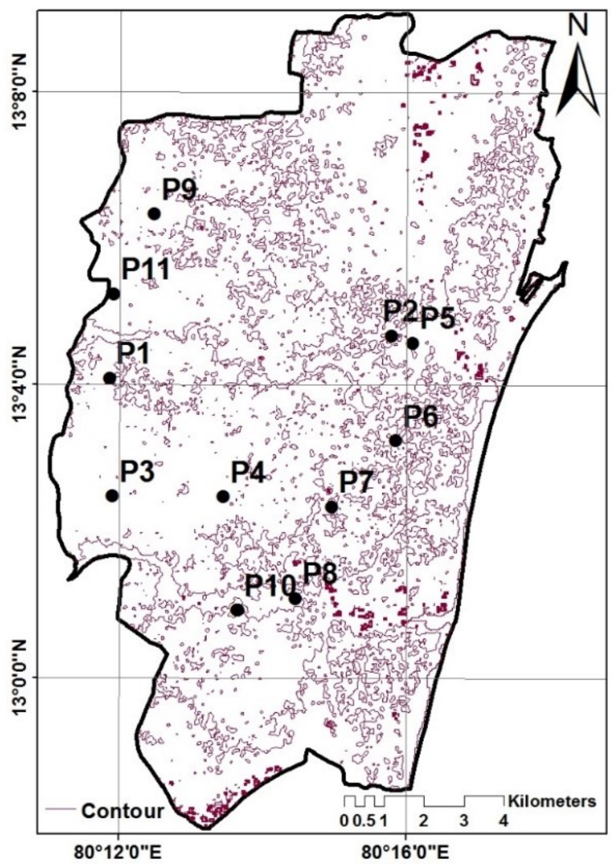


Figure 1c. Contour map of the study area

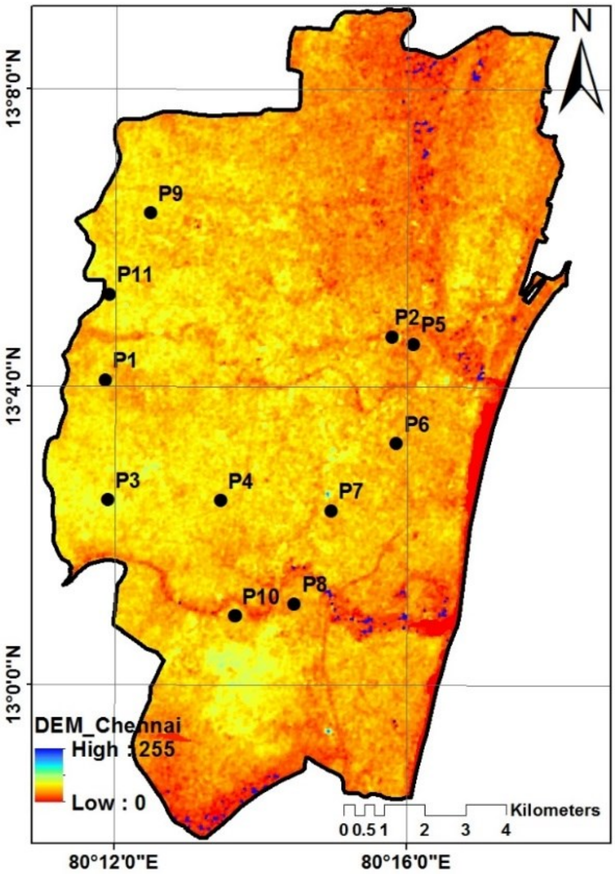


Figure 1d. DEM map of the study area

Normalized Difference Dispersal Index (NDDI)

The Normalized Difference Dispersal Index (NDDI) is a statistical index and is easy to use. It is the ratio of the concentration of ions in different seasons. It produces a net difference map of chemical constituents in two different seasons (post-pre monsoon) and reveals the spatial and temporal variability of chemical species. The NDDI can be calculated as Eq. (1):

$$NDDI = \frac{Concentration\left(post\,monsoon - pre\,monsoon\right)}{Concentration\left(post\,monsoon + pre\,monsoon\right)} \quad (1)$$

It ranges between −1 (absolute dilution) and +1 (absolute accretion). The NDDI based maps were prepared using Arc-GIS10 (Software) based on NDDI point data.

Correlation analysis

The correlation coefficient is an essential statistical tool, and its value ranges from -1(negative correlation) to +1 (positive correlation). The correlation coefficient analysis was performed in Microsoft Office Excel 2007, the correlation matrix of the post, pre-monsoon, and NDDI parameters were also processed. It suggests the tendency of the water quality parameters.

3. Results and Discussion

NDDI mapping

The NDDI maps conspicuously categorize, demarcate, and quantify the spot-specific enrichment of chemical parameters in the groundwater samples. NDDI values for pH ranges from +0.01 to −0.14 (Fig. 2), whereas average values were recorded as −0.02 (Fig. 2). It represents the limited but uniform and almost absolute dilution Fig. 3(a). Moreover, one hot spot appeared along with a pink color patch (Royapettah location, Fig. 3(a) and Table 1) with the highest index values as −0.051to > 0.0because this area is closest to the sea. The NDDI image observed that the dilution processes are happening effectively (red color area). The NDDI value of EC ranges from +0.10 to −0.31 (Fig. 2), with a median of −0.04 was obtained. The NDDI image Fig. 3(b) of EC illustrates a fair amount of spatial variations in accretion plume (reddish patch along with KK Nagar, T.vNagar, and Velachery location, Table 1) and highly dilution patch (along with Egmore location, Table 1) of pink color. While most of the study area having normal stages (with green color patch). The NDDI map of EC Fig.3(b) was analyzed and illustrated that abundant diffusion of higher and lower pre and post-monsoon seasons values were attributed to the changes. Conversely, average (−0.03) and min (−0.31) values for TDS was opposing and ranged between +0.01 to −0.31 (Figure. 2), while the median value in the study area reveal that most of the study area come under absolute dilution process for TDS parameter Fig. 3(c). The study area is also showing two pink colure patches of enrichment Figure. 3(c). NDDI values of Cl Fig. 3(d) varied between +0.14 to −0.51 (Fig. 2) and showing abundant diffusion or dilution Fig.3(d). Figure 3(d) revealed that a dilution process appeared with two hot spots (red color patches) along with KK Nagar and Velachery locations (Table 1). For SiO_2, NDDI values vary between +0.09 (≈ +0.1) and −0.07(≈ −0.1) with a median of +0.31 (Figure. 2). This represents widespread and almost absolute accrual of average value during pre and post-monsoon seasons because Figure 3 (e) shows most of the study area having red color (accrual) while two small areas of pink color appear in the rage of −0.002 (significantly less dilution process at Koyambedu location, Table 1). Figure 3(e) was clearly established that a particular variation of SiO_2 in pre and post monsoons totally changed when the NDDI process was applied. Figure 3(a) to (e) proved that the NDDI process was working well for dilution accrual and absolute accrual studies.

Descriptive statistics

Tables 2 and 3 tabulated the descriptive statistics for 11 CGWB-C open borewells for the study period of 1999 to 2003 (for post and pre-monsoon). From Table 2 (Fig. 4a), the average value (8.3) of 11 borewells during the post-monsoon (or 4 years post-monsoon) period is under the standard value according to WHO-2006 (pH=6.5–8.5) while the average maximum pH value in Koyambedu well (8.37) in four-year post-monsoon is also within WHO-2006 limit. Table 3 (pre-monsoon, Fig. 4 b) average value of 11 wells during pre-monsoon period is excised by the WHO-2006 maximum pH value of 8.5 for Chintadripet well while other wells are under WHO-2006 limit.

From post-monsoon in Table 2, the minimum and average value of EC for study area are good or low as the permissible limit of WHO-2006 (300 μS/cm) while maximum (Figure. 4a) value (at Villivakkam) of EC is almost

Table 1. NDDI values at a different location

Locations	$SiO_{2\,NDDI}$	Cl_{NDDI}	pH_{NDDI}	EC_{NDDI}	TDS_{NDDI}
Koyambedu	-0.07	-0.01	0.01	-0.03	-0.02
Egmore	0.19	-0.41	-0.01	-0.05	-0.05
K.K. Nagar	0.00	0.14	-0.02	0.10	0.11
T. Nagar	0.04	-0.04	-0.01	0.01	-0.01
Chintadripet	-0.01	-0.51	-0.03	-0.33	-0.31
Royapettah	0.15	-0.04	-0.14	-0.06	-0.05
Eldams road	0.09	-0.15	-0.01	-0.15	-0.12
Kotturpuram	0.31	0.06	-0.02	0.03	0.04
Villivakkam	0.02	-0.03	-0.01	-0.04	-0.04
Velachery	0.04	-0.10	0.00	-0.02	-0.01
Thirumangalam	0.04	-0.06	-0.01	-0.02	-0.02

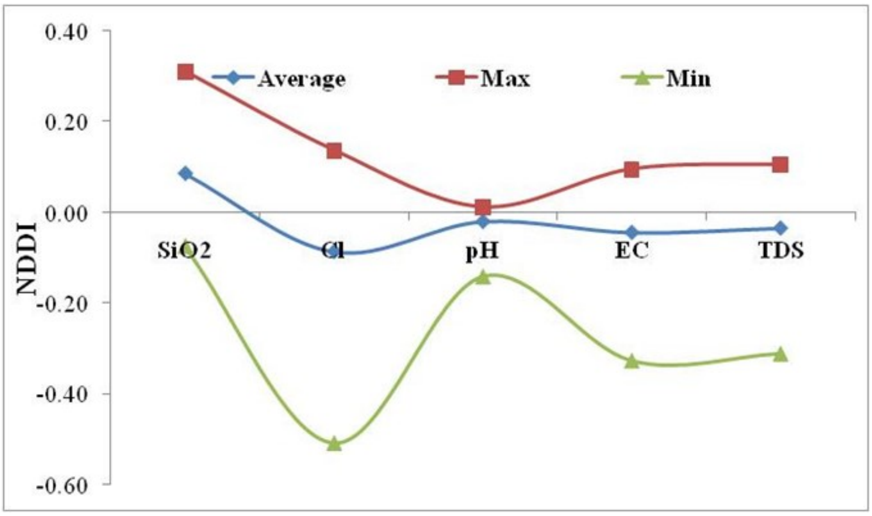
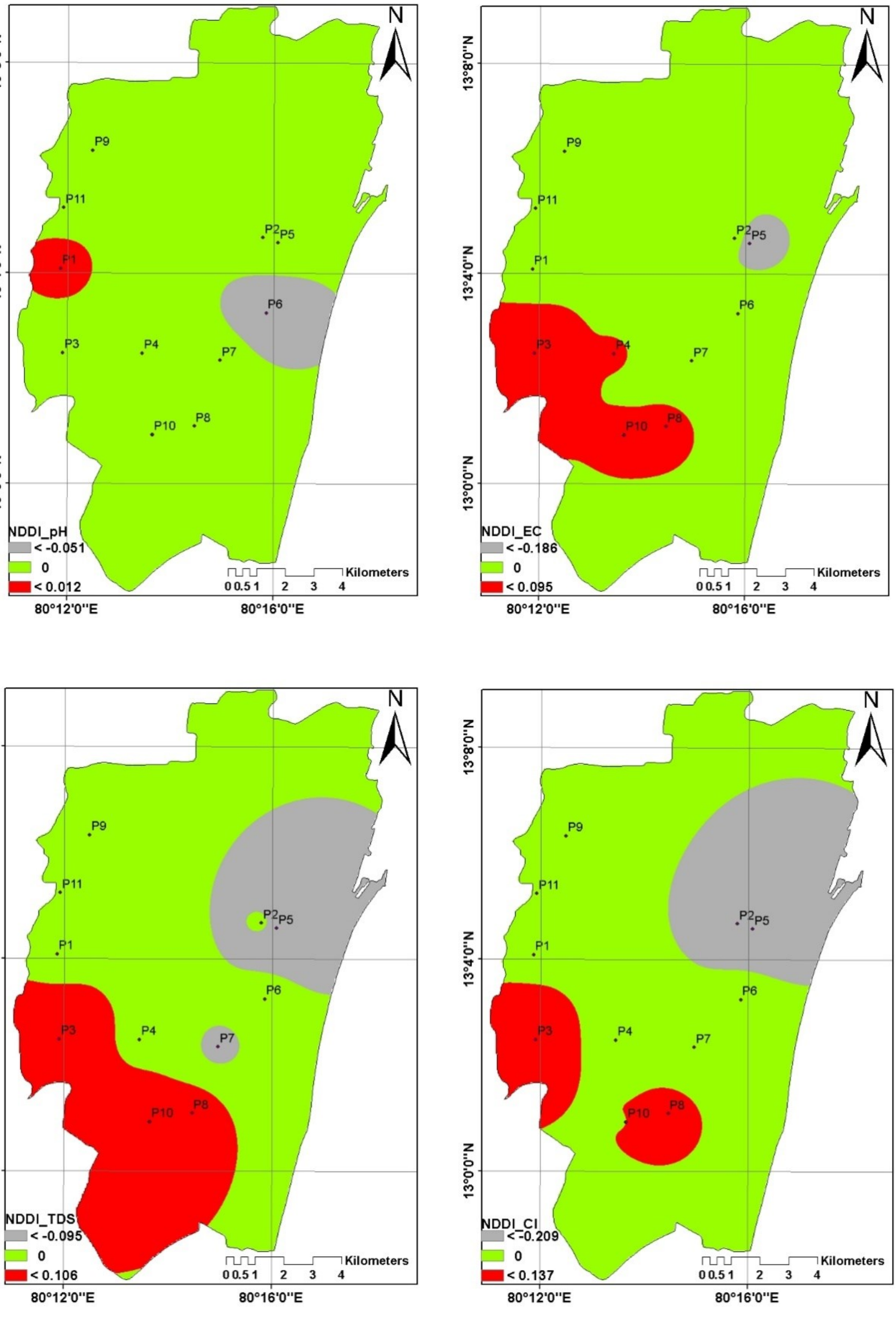


Figure. 2. NDDI conspicuously categorization of water quality parameters at study area.


NDDI_pH
< -0.051
0
< 0.012
NDDI_EC
< -0.186
0
< 0.095
NDDI_TDS
< -0.095
0
< 0.106
NDDI_Cl
< -0.209
0
< 0.137
P1
P2
P3
P4
P5
P6
P7
P8
P9
P10
P11
N
Kilometers
0 0.5 1 2 3 4
13°8'0"N
13°4'0"N
13°0'0"N
80°12'0"E
80°16'0"E

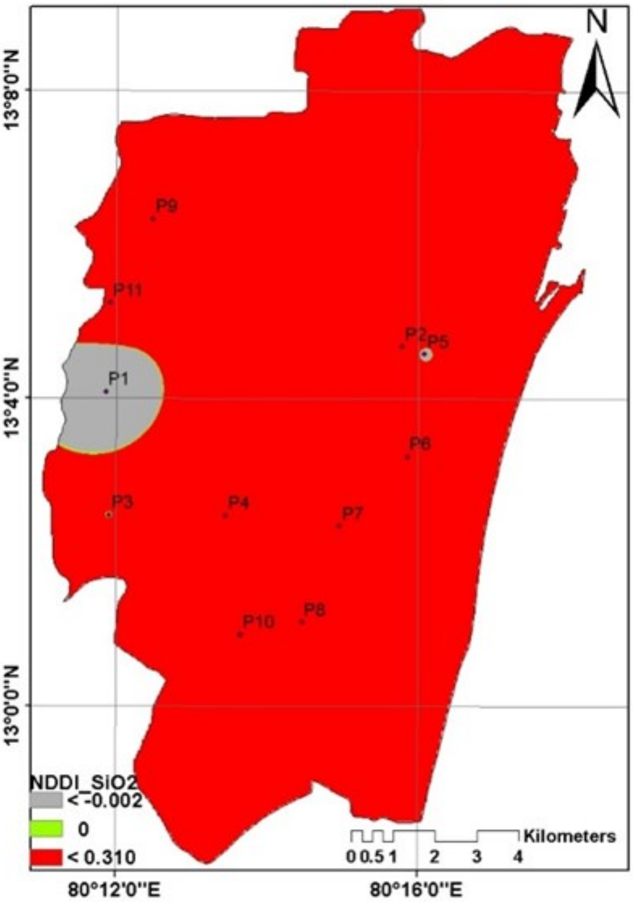


Figure 3.(a) Variation of NDDI value of pH on surface of study area. **(b)** Variation of NDDI value of EC on surface of study area. **(c)** Variation of NDDI value of TDS on surface of study area. **(d)** Variation of NDDI value of Cl on surface of study area and**(e)** Variation of NDDI value of SiO_2 on surface of study area

1.3 time of standard deviation value for EC as WHO-2006 (1400µS/cm). Average EC value during pre-monsoon is also low (1.07 time of standard deviation), higher than S.D. value of EC while minimum (1118 µS/cm) at T. Nagar (Jubilee Road)), and maximum (Figure. 4b, 2080µS/cm or 1.49 time of S.D. of EC at Velachery (Forest Department)) value for 11 CGWB-C open borewells.

Based on WHO-2006 TDS (500 ppm) permissible limit, post-monsoon Table 3 showing TDS min (517ppm at Chintadripet) and average (947.25ppm) value for 11 open borewells are under the permissible limit but the maximum value in the study area during last 4 years post-monsoon (Fig. 4b) is almost 1.36 time (at Velachery (Forest Department)) of WHO-2006 value (1000 ppm). The pre-monsoon in Table 2 clearly reveals that average minimum values of 11 wells are higher (1.41 times) than post-monsoon collation data sets, and it is 730.5 ppm (at T. Nagar, Jubilee Road). However, the average value during pre-monsoon increases (979.88 ppm) compared to post-monsoon.

Table 2 shows that Cl during the post-monsoon, 4 out of 11 CGWB-C open borewells, namely, Velachery (460 ppm), Kotturpuram (438 ppm), K.K. Nagar (275 ppm) and Villivakkam (259 ppm) in the study area were beyond the 250 ppm (WHO-2006 limit value), while the average value (Fig. 4a) of Cl for 11 wells for 4 years is found as 230ppm. Nevertheless, the maximum value of Cl during the post-monsoon was recorded as 460 ppm, which 1.84 times more than the WHO-2006 limit value for Cl. From pre-monsoon (Table 3), it is clear that min (139 ppm atRoyapettah) and max (Figure. 4b, 557 ppm and 2.23 time of standard deviation, at Velachery) value for the study area is changing from post-monsoon, and again max Cl value for the study area is cross the WHO-2006 limit.

From Table 2, average and min value of SiO_2 for the study area during the last study period post-monsoon were 19.95 ppm and 15.5ppm (at Koyambedu) respectively, both values are under the permissible limit as a base on reviews of the literature (because any S.D. value of Si in drinking water is not prescribed by IS 10500 (Bureau of Indian Standards and WHO) for Si. Meanwhile, during the pre-monsoon, these values have fluctuated. Overall, these values similar to post-monsoon, as shown in Table 3. The average and min values of SiO_2 for the study area during the study period of post-monsoon were 17 ppm and 10.5 ppm (at Kotturpuram) respectively, both values are still under the permissible limit.

During the descriptive statistics examining hydrogeochemical parameters for 11 CGWB-C open borewells within the study area, we found EC parameter was dominant as min, max, and average points of view during post and pre-monsoon.

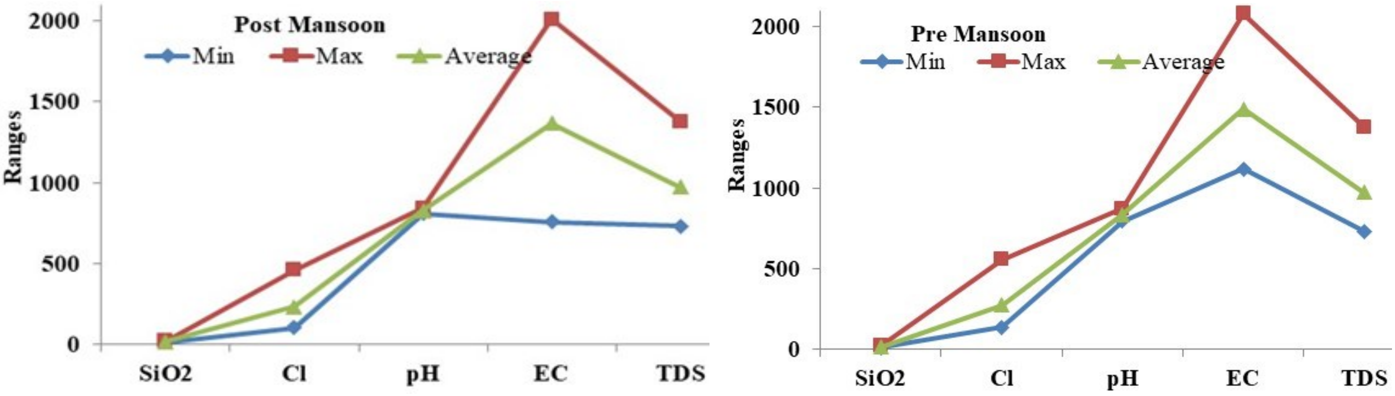


Figure. 4 (a, b). The mean content of different water quality constituents limit in the study area

Table 2. Post-monsoon descriptive statistics

Parameters	Range	Min.	Max.	Mean		Sd. D	Vari.	Ske.		Kurtosis	
	Stat.	Stat.	Stat.	Stat.	Sd. E	Stat.	Stat.	Stat.	Sd. E	Stat.	Sd. E
SiO_2	8.5	15.5	24.0	19.9	0.9	2.8	8.0	0.1	0.7	-1.0	1.3
Cl	354.0	106.0	460.0	234.6	36.0	119.4	14259	1.1	0.7	0.2	1.3
pH	0.3	8.1	8.4	8.3	0.0	0.1	0.0	-0.6	0.8	-0.3	1.5
EC	1250.0	759.5	2009.5	1366.4	114.3	379.2	143804	0.4	0.7	-0.5	1.3
TDS	646.5	730.5	1377.0	973.5	79.0	236.9	56122	0.8	0.7	-0.8	1.4

Table 3. Pre-monsoon descriptive statistics

Parameters	Range	Min.	Max.	Mean		Sd. D	Vari.	Ske.		Kurtosis	
	Stat.	Stat.	Stat.	Stat.	Sd. E	Stat.	Stat.	Stat.	Sd. E	Stat.	Sd. E
SiO_2	11.0	10.5	21.5	16.7	1.2	3.5	12.3	-0.3	0.7	-0.4	1.4
Cl	417.8	139.2	557.0	275.5	36.0	119.5	14279	1.3	0.7	2.2	1.3
pH	0.8	8.0	8.8	8.4	0.1	0.2	0.1	-0.1	0.7	0.2	1.3
EC	962.5	1118	2080.5	1488.3	119.4	358.3	128384	0.8	0.7	-0.9	1.4
TDS	643.5	723.5	1367.0	963.5	69.0	235.9	56118	0.7	0.8	-0.7	1.3

Correlation analysis

Figures 5 (a to d) and 6 (a to d) show the correlation of SiO_2 with respect to other selected groundwater parameters. SiO_2 values have been related to Cl (Fig.5a),pH (Fig. 5b), EC (Fig. 5c) and TDS (Fig. 5d). On SiO_2–Cl plot, samples Villivakkam, K.K. Nagar and Thirumangalam occupy a small cluster defined by higher SiO_2 values of 19.5–20ppm and relatively high Cl values of 200–275ppm. These monitoring locations suggest a normal SiO_2–Cl relationship, suggesting a dominant role of water-rock interaction during pre-monsoon. Groundwater sample from Velachery is anomalously enriched in Cl probably due to seepage from highly contaminated surface water.SiO_2–TDS plot (Fig. 5d) is nearly a curve (vertical) indicating that silica values have a good explicit relationship with TDS values and any TDS value of 900 to <1000ppm (Villivakkam, Chintadripet, Kotturpuram, Velachery and Thirumangalam) may be possible for nearly identical SiO_2 concentration during pre-monsoon. If the bulk of solute acquisition (TDS) had resulted from water-rock interaction, a positive correlation between SiO_2 and TDS would have been logically expected. Therefore, it may be inferred that relatively high concentration levels of TDS are related to anthropogenic rather than a geogenic phenomenon. Similarly, the trend is showing by the SiO_2–TDS plot during pre-monsoon (Figure. 6d). Generally, in the study area, groundwater pH is slightly alkaline in neutral in all location points, and it does not show any relation with SiO_2 during pre-monsoon (SiO_2–pH, Fig. 6b).

However, there was no good correlation found between SiO2 and other parameter's plots (Fig. 6 a, b, and c) except SiO2–TDS plot (Figure. 6d); this relationship reduces in comparison of pre-monsoon. This is maybe due to an insufficient increment in TDS concerning SiO_2 in comparison to pre-monsoon.

Correlation matrix analysis

Correlation matrix Pearson (r), Kendall's (Nonparametric), and Spearman's (rho) analysis was conducted for post and pre-monsoon characterization using SPSS Software. Based on the SPSS output report, as a matrix table (Table 4a, b, c (Post-monsoon) and 5a, b, c (Pre-monsoon), and matrix image (Figure. 7 a and b) form, TDS and EC have a strong correlation of 0.99 (≈1), at 0.01 level 2-tailed during pre-monsoon also reveal from the figure (Fig. 7 b, Table 5a). Similarly, the correlation of Cl with EC (0.79, Table 5a) and TDS (0.79, Table 5a) is significant at the 0.05 level (2-tailed), while Cl and pH were negatively correlated (at 0.05 level) with -0.80 according to Pearson correlation matrix. From Kendall's correlation, Cl having a good correlation (0.71, Table 5b) with EC and TDS, while Spearman's correlation also shows a good correlation but in an improved version (Table 5c with EC and TDS at the 0.05 level (2-tailed).

In Table 4a, Cl with EC (0.81, Figure. 7 a) shows an increasing trend in the compassion of pre-monsoon while the correlation between Cl and TDS decreases with the compassion of pre and a less negative correlation developed between Cl and pH during post-monsoon. Table 4b (and Figure. 7 a) showed that Cl and EC had unchanged Kendall's correlation during post-monsoon. Meanwhile, a strong Kendall correlation was vanishing for Cl and TDS (Table 4b). Table 4c revealed that Cl correlated with EC (0.88) but not with TDS. Similarly, TDS correlated with EC but not Cl (Table 4c) during post-monsoon.

The EC generally is an indication of electrolyte in the dissolved constituents of the groundwater, while the high values of the EC (1000µS/cm) in some of the locations may indicate sewage contamination in these areas (Rawat *et al., 2018a &b; Gautam et al., 2015; Gautam et al., 2018). The TDS rich location indicates the presence of solutes and the dissolved constituents' mixing process in the groundwater. The variation in EC and TDS level in the sampled open borewells might have been occasioned by differential sedimentation along the water column in CGWB-C open borewells (Sobulo 1991; Bamgbose et al. 2001). In most locations, both the EC and TDS values are still within the permissible limit as 500 to 1000 µS/cm and 500 to 1400* ppm, respectively (WHO 1971, 1993). The measured value of silica in the groundwater implies that silica is one of the major chemical components of the water samples from the CGWB-C open borewells. These high values of dissolved silica with a range of 0.5 to 19.9 ppm must have been favored by both the high Si content

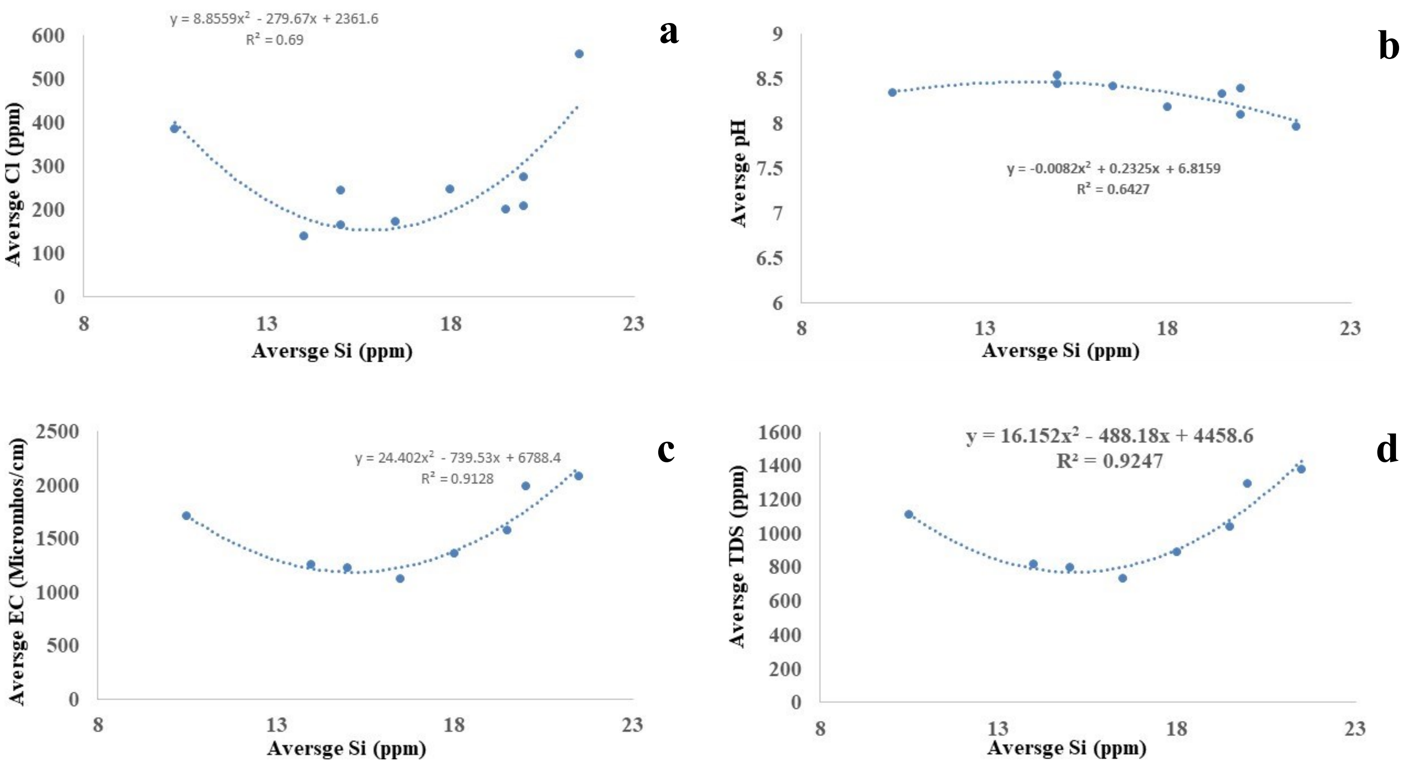


Figure 5. (a to d) Correlation-ship (during pre-monsoon) of SiO_2 with other G.W. parameters

Table 4.Correlation matrix for post-monsoon

a (Pearson, r_p)					
	SiO_2	Cl	pH	EC	TDS
SiO_2	1	0.03	.142	0.29	-0.03
Cl	0.03	1	-0.44	0.81	0.51
pH	0.14	-0.44	1	-0.23	-0.28
EC	0.29	0.81	-0.23	1	0.69
TDS	-0.03	0.51	-0.28	0.69	1
b (Kendall's, r_k)					
	SiO_2	Cl	pH	EC	TDS
SiO_2	1	0.04	0.25	0.18	0.04
Cl	0.04	1	0.07	0.71	0.43
pH	0.25	0.07	1	-0.07	-0.07
EC	0.18	0.71	-0.07	1	0.57
TDS	0.04	0.43	-0.07	0.57	1
c (Spearman's rho. r_s)					
	SiO_2	Cl	pH	EC	TDS
SiO_2	1	0.04	0.29	0.29	-0.05
Cl	0.04	1	0.02	0.88	0.59
pH	0.23	0.02	1	-0.07	-0.21
EC	0.29	0.88	-.071	1	0.71
TDS	-0.05	0.59	-0.21	0.71	1

Table 5. Correlation matrix of pre-monsoon

a (Pearson, r_p)					
	SiO_2	Cl	pH	EC	TDS
SiO_2	1	0.18	-0.51	0.41	0.43
Cl	0.18	1	-0.80	0.79	0.79
pH	-0.51	-0.80	1	-0.54	-0.56
EC	0.41	0.79	-0.54	1.00	0.99
TDS	0.43	0.80	-0.56	0.99	1
b (Kendall's, r_k)					
	SiO_2	Cl	pH	EC	TDS
SiO_2	1	0.43	-0.43	0.52	0.52
Cl	0.43	1	-0.62	0.71	0.71
pH	-0.43	-0.62	1	-0.33	-0.33
EC	0.52	0.71	-0.33	1	1
TDS	0.52	0.71	-0.33	1	1
c (Spearman's rho. r_s)					
	SiO_2	Cl	pH	EC	TDS
SiO_2	1	0.43	-0.57	0.61	0.61
Cl	0.43	1	-0.71	0.89	0.89
pH	-0.57	-0.71	1	-0.61	-0.61
EC	0.61	0.89	-0.61	1	1
TDS	0.61	0.89	-0.61	1	1

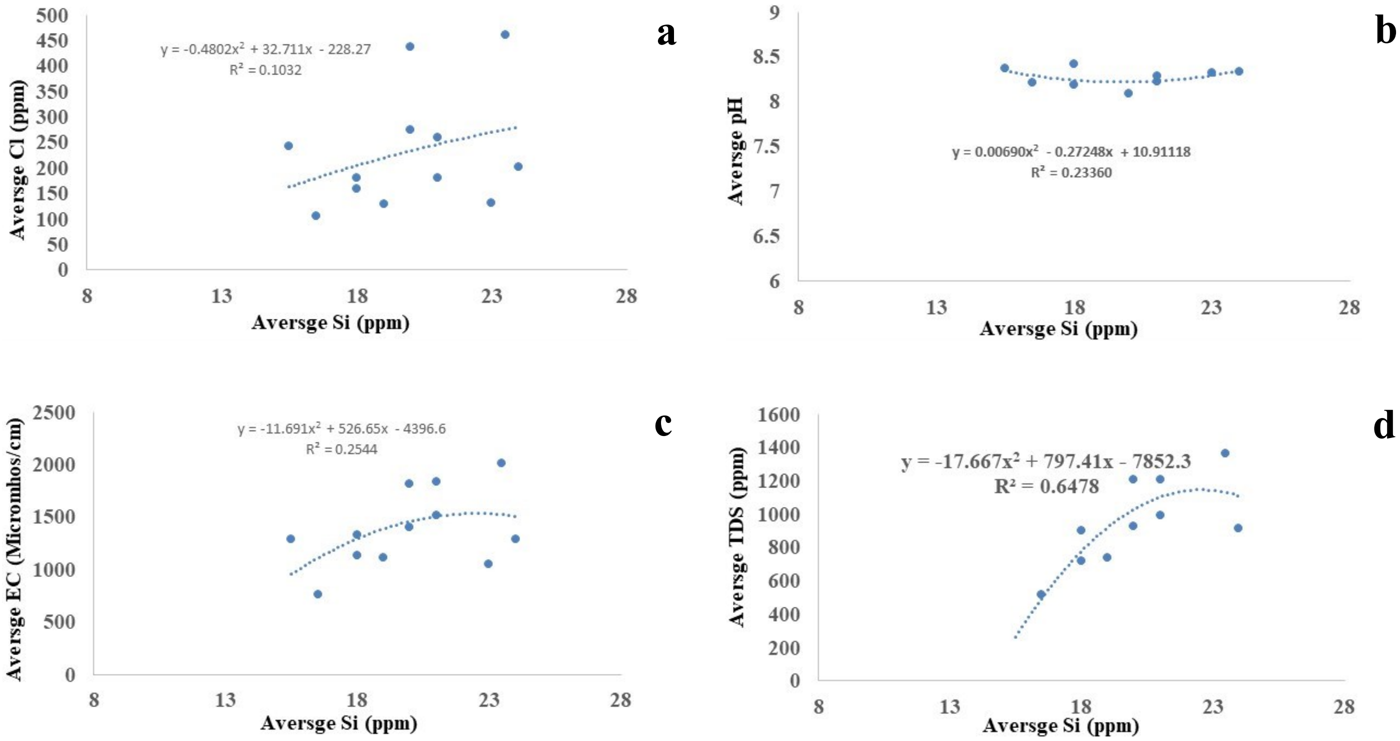
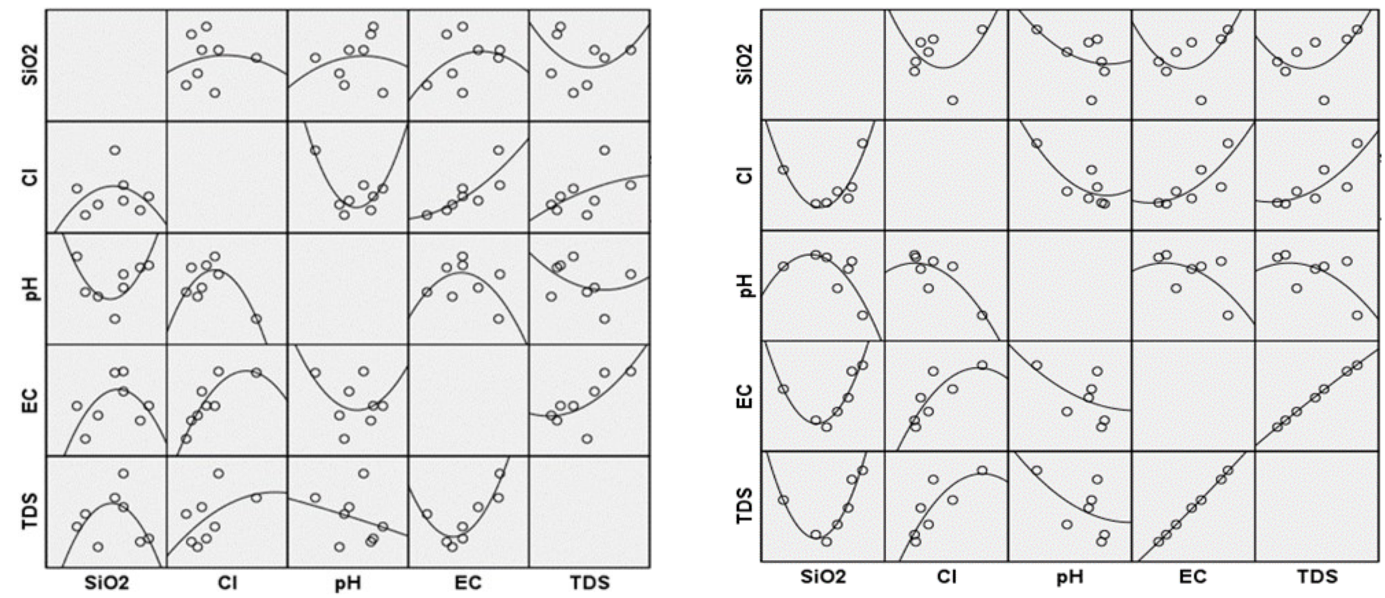


Figure 6. (a to d). Correlation-ship (during post-monsoon) of SiO_2 with other groundwater parameters



a b

Figure7. (a) Post-monsoon and (b) Pre-monsoon correlation matrix

of the host parent rocks and the high degree of weathering that characterizes the peninsular regions. As a result of the favorable climatic conditions (high temperature and rainfall) in the peninsular regions, the silicate minerals are easily weathered, thereby releasing more of the crystalline silica (SiO_2) in solution.

Based on NEST (1991) suggestion, more rainwater harvesting/stored underground than is available on the surface (this policy is applicable or adopted in our study area). This fact may be the reason why the groundwater in the study area had more Si loads. A high value of Si in the study area's groundwater may be due to existing rocks and a high degree of interaction with groundwater that characterizes these regions. The observed minimum levels of Si in the CGWB-C open borewells from the study area indicate that the source of the Si element in groundwater is more of chemical weathering of the existing/host rock than anthropogenic phenomenon (Iler, 1979). As a study by Hem (1970), weathering of silicate minerals is one of the most important causes of high Si concentrations in groundwater. The Si element in groundwater may be partly from the weathered profile of the basement complex rocks, which have been found to be rich in mineral concentration (Palacky and Kadekaru 1979). The correlation analysis in Table 4 (a, b, c) and 5 (a, b, c) shows that a non-significant positive and weak negative correlation was established between Si and pH. The bivariate plots depicted in Figure 5 (a to d) further confirms the weak associations between Si load of the CGWB -C open borewells, and Cl, pH, & EC during post-monsoon. Perhaps the level of Si is negligible in water to cause any illness.

4. Conclusion

Si values, when related to a rather conservative ion Cl or total solute concentration, may provide valuable information that can help identify the source of chemical species and play a significant role in managing and conserving precious groundwater resources. It is therefore strongly recommended that silica determinations should be taken up in all groundwater investigations. Though the health implications of dissolved Si in drinking water are yet to be documented, the Si standard in drinking water should be established by the appropriate environmental agencies in various countries. This will assist in the close monitoring of silica load in the water resources of the tropical regions characterized by intensive weathering.

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