A pilot study on the spatial distribution of iron concentration in the groundwater of Dimapur district, Nagaland, India

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Abstract:

The increasing uncontrollable anthropogenic activities, and geogenic intervention have majorly depleted the groundwater quality globally. Dimapur district, India is one such case polluted by the significant excess presence of iron concentration. Data reports on the assessment of groundwater quality are unfathomable in the region. Thus, our prime objective sets up What amount of iron concentration is present? How many of those data points possess a high concentration? and how the prediction model works in a particular area of Dimapur town. We then used a spatial non-parametric regression method on the experimental results to further predict the water parameters in areas where no water samples could be collected. Finally, we compare these contours for different water parameters and connect them with the geographic and functional properties of various locations in the studied region.

Keywords: *Dimapur; water quality; iron pollution; statistics; regression; distribution*

1. **Introduction**

Groundwater is the major freshwater resource for the nation's development and sustenance. The global population of about one-third entirely depends on groundwater and accounts to 7%, 36%, and 42% of groundwater water are used for manufacturing, household, and irrigation purposes. As such in India, around 90% of the groundwater accounts for irrigation purposes which is much higher in proportion than the global average usage of 40%, and an estimated value of 90 million rural households primarily dependent on irrigation supported by groundwater supplies. According to United Nation World Water Development Report 2022 (UN WWDR 2022), India has been considered the largest groundwater user with an evaluated groundwater withdrawal of 251 km^3/year. Over the past few decades, the increasing population (1.3 billion) in India and demands for use in domestic, irrigation, industrial, and recreational purposes have promoted unfathomable stress on the groundwater resources. Thus, the over-growing demand directly or indirectly leads to unsustainable, improper management, and overexploitation of water resources depleting the groundwater quality.

Various studies confirm the increasing rapid urbanization, fast-growing industrial activities, climate change, and agricultural practices have found to possess serious threats to groundwater quality/ resources in many countries. However, groundwater quality can be significantly influenced by natural events and geogenic leaching of inorganic ions bearing rocks, minerals, and soil depending from place to place. Such uncontrolled anthropogenic activity, improper management of waste, and natural events can severely increase the levels of organic contaminants, toxic metal ions metals, pesticides, nanoparticles, and emerging contaminants in groundwater in the long run. Among such contaminants, iron contamination in groundwater has been of great concern in many countries such as China, USA, Bangladesh, Africa and European countries. Iron constitutes the 4^{th} most abundant element in the earth crust mostly occurring in the combined state as oxides. Although iron is an essential element for many metabolic processes and functions, its overload in the human body can lead to lung cancer, breast cancer, diabetes, infertility, etc. Additionally, the presence of high iron concentration can lead to staining of materials, clothes, corrosion of water pipelines, and metallic taste/ foul smell (Kumar et al., 2017). Unscientific human activities and management may have directly or indirectly added up to the levels of iron content in the natural water resources/ aquifers. Numerous studies suggest the iron bearing rocks and minerals can prematurely sip through the process of leaching, dissolution, residential time, anionic and cationic exchange, and percolation, which significantly control the flow and hydrochemical quality of groundwater.

Such distribution and occurrence are highly evident depending on the rainfall, geomorphology and geology of the area.

Nagaland lies in the Northeastern part of India sharing its common borders with Arunachal Pradesh, Assam, Manipur, and Myanmar. At present, there are 16 districts in Nagaland, among which Dimapur is the fastest developing in terms of industrialization, urbanization, overall economic activities, etc. The demand for industrial commodities such as chemical fertilizers, inorganic compounds, various household chemical products, etc. has been particularly high in the Dimapur district over the years. Groundwater is an important resource of Dimapur area with the majority being dependent for drinking and recreational purposes, especially in the low-lying region. As per the 2011 census, Dimapur itself accounts for 34% of the urban pollution in the state. Such changes/increases in the demography in a small area can significantly increase the dependency on groundwater and result in a colossal pressure on the groundwater resources. Additionally, the rate of deforestation due to urbanization has led to a loss of 4.75 kha of relative tree cover equivalent to a 2.0% of the global total tree covers in the region (shown in the supplementary information, Fig. S1a - 1c) as reported in 'India State of Forest Report 2021'(Forest Survey of India, 2021). Such loss in the tree covers can significantly lead to a reduction in infiltration capacity and change the course of discharge, and physicochemical properties of surface and groundwater flowing through the watershed. Further, the over-exploitation caused by rampant dumping and burning of waste on the land resources can also leave a negative impact on the water quality.

However, with the increasing urbanization and population, reports of pollution data or water quality data in the Dimapur area either groundwater or surface water sources are hard to come by. Such over-lying conditions can be attributed to a lack of proper infrastructure, slow economic growth, and less scientific temperament (Kibami et al., 2013). With the available data/ literature on groundwater quality as reported by researchers and Groundwater Pollution Board, metal ion especially iron is the major key pollutant in the area owing to their presence of high concentration in the groundwater exceeding the WHO threshold limits in the region (Peseyie and Rao, 2017). It is evident that the pervasive anthropogenic activities may have directly added up to the levels of iron content in the natural water resources/ aquifers of the area (shown in the supplementary information, Fig. S2). Nonetheless, geogenic events can be the primary factors resulting in the higher concentration of iron as evident by the geomorphology and geogenic setting (soil/ rock/ mineral composition) of the area as per the literature survey.

Hence, though few water quality data on iron concentration are available that throw a light, most of the available data on groundwater in the region used a few sampling sites which resulted in high variability of their estimates (Naleo et al., 2020). Thus, a detailed study with data collected from a larger region is required to understand the level of contamination in the groundwater aquifers. In this present study, the groundwater quality in a vast area covering the Dimapur town where the growing problem is of concern was carried out. The key objective of this study is to investigate the level of iron from tube wells/boring wells, hand pump tubes, and dug wells. We focus on the other parameters like pH, electrical conductivity (EC), and total dissolved solids (TDS) which play a crucial role in determining the groundwater quality. This study also focuses on the spatial distribution pattern of the iron concentration and the other parameters based on the experimental data to connect the parameter values to the geographic and economic characteristics of the corresponding locations. Furthermore, we specialized moving average method to predict the parameters in non-collected water sample areas. The distribution pattern and prediction model applied in our study can also be used on a larger data point more rigorously and effectively to connects how each parameter behaves among themselves or at different seasons. Hence. the analysis results from the study have greater importance which can provide evidence of the groundwater problems in the region, bring forth remedial solutions, and sustainable management to protect the public health from associated ill effects of iron.

Materials and Methods

2.1. Study area

Dimapur district has an area of 927 km^2 with an average elevation of 260 m above sea level. The state receives an average rainfall of 1504.7 mm and with the temperature ranging from 21-38 ̊C during summer. The area enjoys a subtropical humid climate with an average temperature of around 26.8 ̊C during summer (July) and a minimum of about 7.0 ̊C in winter. Geographically it is located within the coordinates of 25.84'N latitude to 93.47'E longitude with a population density of 410/km^2 as per the 2011 census. The entire district can be categorized into four physiographic units viz alluvial plains, low to a moderate linear ridge, moderate hills, and high hills. The most common type of soil found in the studied region is red clay soil (tertiary group of rocks containing a high amount of iron oxide). The geomorphic units of the region study are mostly covered by structural hills and an alluvial plain. Generally, the area represents a sub-montane valley fill of quaternary sediments consisting mainly of clays and pebbles which essentially provide infiltration and replenishment of groundwater. While the tertiary rocks (which form the structural hills and residual hill) consist of shales and sandstone act as runoff zones with less potential for groundwater replenishment. Hydrogeology of the groundwater of the region occurs both in semi-consolidated and unconsolidated formations. The semi-consolidated formation represents the structure of the hilly terrain comprising sedimentary rocks belonging to Barail, Surma, and Tipam of the Tertiary age comprising ferruginous compact sandstone, clay, shale, boulder beds, pebbles, and siltstone. The rocks are usually joint and fractured where the course of runoff character and groundwater occurrence is water is manifested in the form of springs due to the development of secondary porosity like fractures, faults, joints, etc. While the unconsolidated formation occurs in the intermountain valley fill and piedmont plains areas along the foothills of Dimapur-Medziphema areas with aquifer thickness varying from place to place. The lithology unit in the lower-lying foothill is made up of gravels, clay, pebbles, slit, boulders, sand, and conglomerate beds of recent alluvial deposits. In brief, hydrogeology of the region indicates that joints, lineaments, faults, and fractures are the major controlling factors for the distribution and occurrence of groundwater.

2.2. Sampling and analysis of the groundwater sample

The water samples were collected randomly from 50 deep groundwater wells (tube well /boring well/shallow well, dug well displayed in Fig. 1a) with a depth ranging between10-150 m during the pre-monsoon season along with their GPS coordinates. The groundwater sample was collected in polyethylene terephthalate (PET) and high-density polyethylene (HDPE). The bottles were firstly cleaned with distilled water, dried and a known amount of chemical solution was used for storage of the water sample to avoid loss of the original concentration. Water parameters like electrical conductivity (EC), total dissolved solids (TDS), pH, and temperature were measured during field sampling using specialized test meters (HM Digital AP-2, HM Digital AP-1, and HANNA HI-98127). The iron concentration was analyzed by the iron-phenanthroline complexation spectrophotometric method using UV-VIS spectrophotometer Agilent Cary 100. In short, the absorbance of the complex iron species ($[Fe(phen)_3]^{2+}$, ferroin) at 510 nm in presence of excess phenanthroline was measured using 1.00 cm quartz cells. The overall reaction steps for the complexation of Fe^{2+} can be summarized as:

$$phen + \mathrm{Fe}^{2+} \rightleftharpoons [\mathrm{Fe}(phen)]^{2+}$$

$$phen + [\mathrm{Fe}(phen)]^{2+} \rightleftharpoons [\mathrm{Fe}(phen)_2]^{2+}$$

$$phen + [\mathrm{Fe}(phen)_2]^{2+} \rightleftharpoons [\mathrm{Fe}(phen)_3]^{2+}$$

$$H^+ + phen \rightleftharpoons phen\mathrm{H}^+$$

$$phen\mathrm{H}^+ + [\mathrm{Fe}(phen)_2]^{2+} \rightleftharpoons [\mathrm{Fe}(phen)_3]^{2+} + \mathrm{H}^+$$

The final product, ferroin is dark orange/red (in color) with an absorption maximum of 510 nm. The spectral diagrams of ferroin formation are displayed in Supplementary Information (Fig. S3). All sampling and analysis protocols were done using APHA 23rd edition, 2017 (Baird et al., 2017).

2.3. Statistical analysis of the groundwater

Various descriptive statistics were computed to collect the quantitative data into simple summaries (Supplementary, Table S1). Pearson's correlation coefficient was used to study the correlation between the two measured variables to understand the closeness of the relationship between variables. Both Pearson's correlation and descriptive statistics were performed using SPSS software (IBM SPSS Statistics 25). A spatial non-parametric moving average regression method was employed to monitor and understand the patterns of pollution in the region for iron concentration. A moving average method is an effective tool where the main function is to create a series of average values of different subsets of the full data set and was performed using the R software version 3.3.3. Briefly, the spatial distribution of the iron concentration in the groundwater was estimated via spatial nonparametric regression. To that goal, the ranges of latitude and longitude were divided into ten grids. At each of these hundred grid points, the iron concentration was estimated by the average of the iron concentrations in the water sample collected from wells within a circle of radius 0.01 centered at that grid point (Supplementary Fig. S4). The contours were drawn based on these estimated concentrations. The spatial distribution for other contaminants was estimated similarly.

3. Results and Discussion

3.1 Experimental analysis of collected groundwater sample

The data along with the levels of pH, EC, TDS, and the iron concentration obtained from the experimental analysis of the collected 50 groundwater samples are presented in Supplementary Table S2. The descriptive statistical summary of the monitored groundwater quality parameters is presented in Table 1a.

The pH measures the acidity and basicity of an aqueous solution and fundamentally determines the solubility and biological availability of chemical constituents. For example, at low pH, there is an increment of hydrogen ions which solubilize the heavy metals (present in rocks and soil as minerals) thereby increasing the metals cations and their toxicity in groundwater or surface water. While at pH above 7, essential plant nutrient is drastically affected leading to lesser production of nutrients. Whereas at high pH (pH>8.5), the taste of water turns more bitter and smelly which notably represents the build-up of magnesium and calcium carbonate in water. Thus, a higher pH can provoke skin dryness, and gastrointestinal and eye irritation. Additionally, pH also determines whether aquatic species can survive depending on how much amount of phosphorus is available in the water. The more vulnerable a species to the change in pH to the surrounding environment, the lesser chances for its survival/ production/population. Many studies confirm the synergistic effects on aquatic species where the chances of survival are fatal due to the presence of additional foreign components in water. As such, a fish that can stand at pH < 4.5 may lose the chances of survival at pH 5 if the same water contains arsenic as low as 0.1 mg/L. The pH of the deep well groundwater in the studied area was mostly acidic out of which 40% of the collected water sample exceeds the WHO guidelines (6.5 - 8.0) for Drinking water quality. The pH ranged from a minimum of 5.80 and a maximum of 8.20 with a mean of 6.75 ± 0.086.

An electrical conductivity test can be used as a build to understand the typical range for the various water body. This can be used as a criterion for monitoring and identifying significant changes in conductivity. This can potentially be used as a viable indicator for the discharge of contaminants entering the water bodies/aquifers. The conductivity value varies depending on the water source which may be severely increased through agricultural and industrial runoff, rainfall, and municipal wastewater. An important constituent for change in groundwater conductivity ideally is attributed to the seepage of organic material/ chemical components, anthropogenic activities, and sewage leaks. The EC of water plays a critical influence on aquatic life before their mobility to maximum tolerance level. An important parameter such as salts and other substances affect the water quality for irrigation, drinking, and recreational purposes. In our present study, the EC measurement ranged from 86 to 579 µS/cm with the mean value of 216.96 ± 15.314 with the mean value of 216.96 ± 15.314. All the collected water more or less showed no tolerance limit on the collected water sample.

Total dissolved solids (TDS) are the amount of inorganic and organic and materials (such as salts, metals, minerals, and ions) dissolved in a particular volume of water. TDS are essentially a measure of any soluble substances/particles disintegrated in water or are absorbed into the water. TDS come from various sources including natural and man-made. Natural sources of increased TDS accounts to adsorption of mineral (such as calcium, magnesium and potassium from rocks/ mineral composites) during the flow discharge of soil, rivers, springs, lakes, etc. While, anthropogenic human activity can also enhance the level of total dissolved solids in water. Such example includes chemical pesticides, fungicides, herbicides, and chlorine which proceeds as agricultural runoff, and from water treatment plants. Increased level of dissolved solids can generate technical effects visibly in the form of hard water leaving deposits/ films on fixtures, hot water boilers and water pipes, corrode pipes, and leaves a metallic taste on water. Based on the experimental results obtained from our study, the values of TDS were also within the tolerance limit with the maximum value to be 579 ppm. This result was in accordance with the EC value due to their direct relationship with each other.

Physiologically, iron is an important source for the body metabolism from oxygen transporter (haemoglobin) to storage and release of oxygen (myoglobin). It is an essential for various physiological processes such as erythropoiesis, cellular activities (oxidation/reduction of proteins), immune function, and act as a host defence mechanism. However, the excess iron in the body which is stored in heart, liver, and pancreas can lead to detrimental health effects causing diabetes, heart and liver disease. The overload of iron can be attributed to a higher amount of iron in dietary source or from contaminated water. As such, most of the health issues due to iron are from contaminated water bodies. Iron is a naturally occurring metals in the combined state in the form of ores/ minerals (oxides) as hematite (Fe_2O_3) and magnetite (Fe_3O_4). The minerals/ores containing iron are mined for industrial use and various other applications. During mining, some of iron containing minerals into the natural aqueous environment caused by anthropogenic activities. Likewise, iron in many regions (rural and suburban area) is a common problem, where its concentration is peaked more than the tolerance limit of 0.3 mg/L (WHO and EPA guidelines). Geogenic origin of iron contamination can add up the factors for its higher concentration in water, while other could be attributed to the dissolution from iron handpumps or borehole. This could be well-explained by the presence of iron eating bacteria which can combines with the free oxygen and convert the ferrous ion (Fe^{2+}) into an insoluble ferric ion (Fe3+) leaving a filamentous/ sticky/ slimy gel on the metal surface. The iron-bearing groundwater is brownish-orange in colour, causing stanning of clothes and pipes along with vexatious smell and metallic taste. Apparently, our study investigates the presence of iron and confirms the pretentious high amount in the groundwater system. Evidently, the experimental analysis depicts out of the 50-water sample collected, approximately about 80% accounts to cross the barrier of 0.3 mg/L tolerance limit. This can be evident by the presence of iron-bearing rock/ minerals (red clay soil / sedimentary rocks) and the presence of iron-eating bacteria (shown in the supplementary information, Fig. S2).

3.2 Statistical methods on the experimental data

The range and standard deviation give information about the spread of a given variable. The range in the case for pH EC, TDS, and iron is 2.40, 493, 272, 1.00138 which gives some information about the degree of maximum variability. Standard deviation measures the average deviation of the observations from their mean. The standard deviation value for pH, EC, TDS, and Fe were found to be 0.6118, 108.28, 60.33, and 0.2709 respectively. To objectively compare the spread of the four variables, we compute their coefficient of variation, which is the ratio of their standard deviations to their means. It appears that by a coefficient of variation, EC, TDS, and Fe show more variability with values of 0.499, 0.485, and 0.496 respectively (all close to 0.5), which is much larger than that of pH, which turns out to be 0.091.

Skewness describes the extent of asymmetry in a given distribution. The skewness value can be positive, negative, or zero. In positive skewness, the distribution extends with a long tail towards the right and similarly negative skewness towards the left (Čisar and Čisar, 2010). From Table 1a, the skewness value indicates that pH, EC, TDS, and Fe all show positive skewness with pH and Fe showing more symmetric distribution. The Excess Kurtosis gives information about the peakedness of a probability distribution (as compared to the bell curve) as well as the nature of its tail (Westfall, 2014). The results obtained (Table 1a) show both pH and Fe are of negative value (-0.821, -0.710) which explains the distribution is light tail presenting a platykurtic distribution. However, EC and TDS show a good positive value (2.136, 1.966) indicating the distribution has heavier tails depicting a leptokurtic distribution.

Pearson's correlation coefficients were used to establish the significance of relationships of the monitored water parameters in the groundwater (Table 1b). The pH shows a near-zero correlation with EC and TDS and a very strong negative correlation with Fe. This complies with the observation that the presence of metallic pollutants can change the pH in groundwater. Electrical conductivity (EC) shows a strong positive nearly perfect correlation (almost equal to 1) with TDS. Both EC and TDS show poor correlation with Fe with a value of 0.166 and 0.154. The primary focus of this article is laid on iron concentration and its correlation with other measures of pollution. The resultant value crossing the permissible limit with a higher iron concentration from the collected groundwater samples, a broader estimate of the spatial distribution of iron concentration in the groundwater of the Dimapur area would be beneficial in evaluating the degree of iron pollution. We employ the spatial moving average regression method described above to predict concentrations of the parameters under consideration in the areas where no data was collected.

The contour plots of the concentrations of various parameters under consideration are presented in Fig 2. The GPS coordinates for the sample points are given in a spherical black dot. For the iron concentration (Fig. 2a), the various predicted values ranged from a minimum of 0.23 mg/L to a maximum of 0.81 mg/L with a majority beyond the permissible limit of 0.3 mg/L. Likewise, the predicted values for pH (Fig. 2b) ranged from a minimum of 5.95 and a maximum of 8.20 with a few values beyond the permissible guidelines. The area within 25.92-25.93 latitude and 93.739-93.756 longitude shows a significant change of pH from 5.95- 6.9 (Fig. 2b) which may be due to the municipal waste dumping site lying adjacent to the Dhansiri river and the Dhobinala drainage that flows towards the area which later joins the river at the end. This explains the significant change in the pH in that small area. The contour plot (Fig. 2c) for TDS shows the majority of the predicted values are well within the permissible limit with only a few values (75, 80, 85, and 90 mg/L) beyond the WHO guidelines. The predicted values for electrical conductivity also show a significant distribution pattern with a minimum of 120 µS/cm and a maximum of 300 µS/cm (Fig. 2d).

The contour plots are further studied to gauge the match between the spatial concentration patterns between different variables. The contour plot between Fe and pH (Fig. 2e) shows intersecting contours, especially in Dimapur town and along the Dhansiri river. They are mostly parallel to each other on the higher grounds. However, the contours of Fe and TDS are mostly non-parallel (Fig. 2f). The same is true for the contours of pH and TDS (Supplementary Fig. S5a). Additionally, the contour plot for three parameters (Supplementary Fig. S5b & S5c) can give us information on how the distribution differs from each other. Herein, the contour plot between three parameters (Supplementary Fig. S5c), shows the EC and TDS follow almost the same distribution pattern which is not the same for pH.

Conclusion

Our brief study shows evidence of high iron concentration in groundwater of Dimapur city and its surrounding areas which in most places exceed the maximum threshold limits prescribed by WHO. This is also evident from the observed samples as well as our statistical estimate of the iron concentration and other parameters for the regions where no sample could be collected. The cause of such high iron content can be attributed to geogenic, caused by weathering of mineral-containing rocks as evident by the geomorphology setting of the region. However, unscientific human activity and rapid deforestation in the studied region possibly have enhanced and contributed to the level of pollution and resulted in the reduction of infiltration capacity, and the pivotal link catering to the source of underground aquifers. This piece of research work with the detailed statistical treatment is being done for Dimapur, Nagaland, for the first time and the striking results show the importance of such work. It is invariably visible from our study, that more detailed surveys, exploration, experiments, analyses, and remedial measures are urgently required to avoid the resulting health hazards among the population living in the studied area.

Considering the adverse effects of excess iron pollution in mind, it is, therefore, essential to monitor the groundwater seasonally to determine the levels of contamination in this studied area. Furthermore, the physicochemical parameters of other trace elements (such as As, Cr, Co, Mn, etc.) need to be monitored with a major geospatial/geomapping study to uncover the potential link from point to non-point sources of groundwater contamination. Studies with more resources and a larger sample size which can give more accurate insight into the levels of contaminants need to be undertaken urgently. It is to be noted that unplanned and unscientific development of groundwater resources, mostly driven by individual initiatives has led to the decline and degradation of the water quality in many places. The proper management of groundwater resources is a prerogative of the concerned government agencies and stakeholders. However, the absence of a knowledge-driven support system and lack of information are key barriers to sound strategies and planning for sustainable management of groundwater resources (conservation, regulation of extraction, and protection from pollution). Thus, with an alarming fast population, urbanization, and uncontrol human activity, necessary efforts for implementing suitable groundwater management strategies by all the stakeholders are urgently needed.

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Ethics approval

This study did not involve human participants, their data, or biological material.

Conflict of Interest

The authors declare that they have no conflict of interest.

Abbreviation:

APHA - American Public Health Association.

EC – electrical conductivity.

GPS - global positioning system.

pH – potential hydrogen.

TDS – total dissolved solids.

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Figures and Tables:

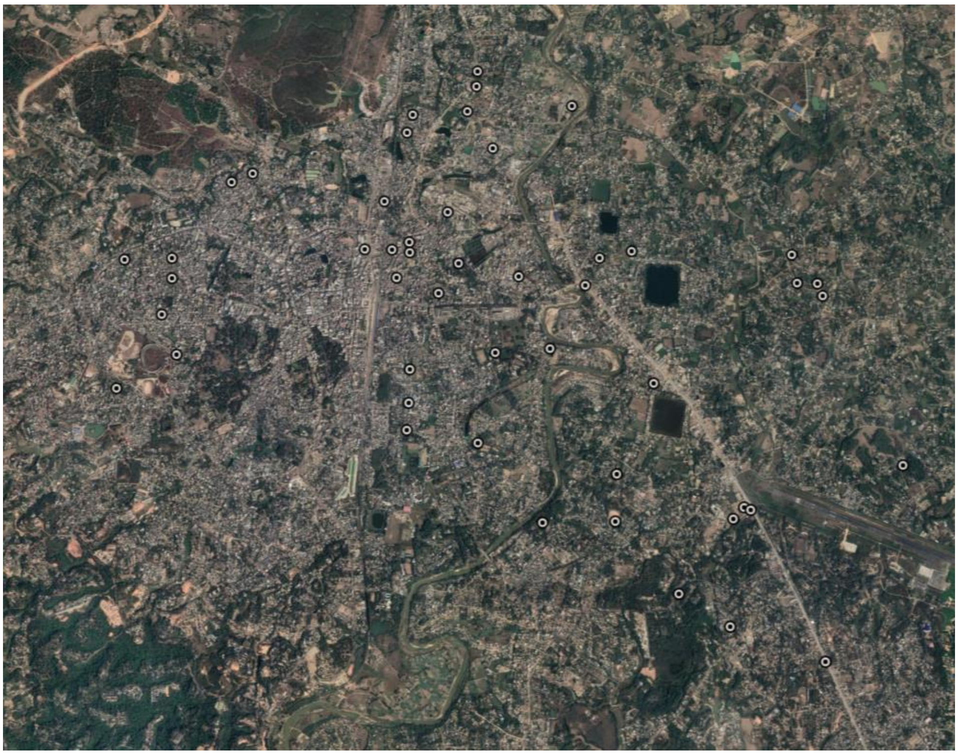

Fig. 1: Pictorial Image of Dimapur district with their GPS coordinates for data sampling (Shown in black and white circular dots)

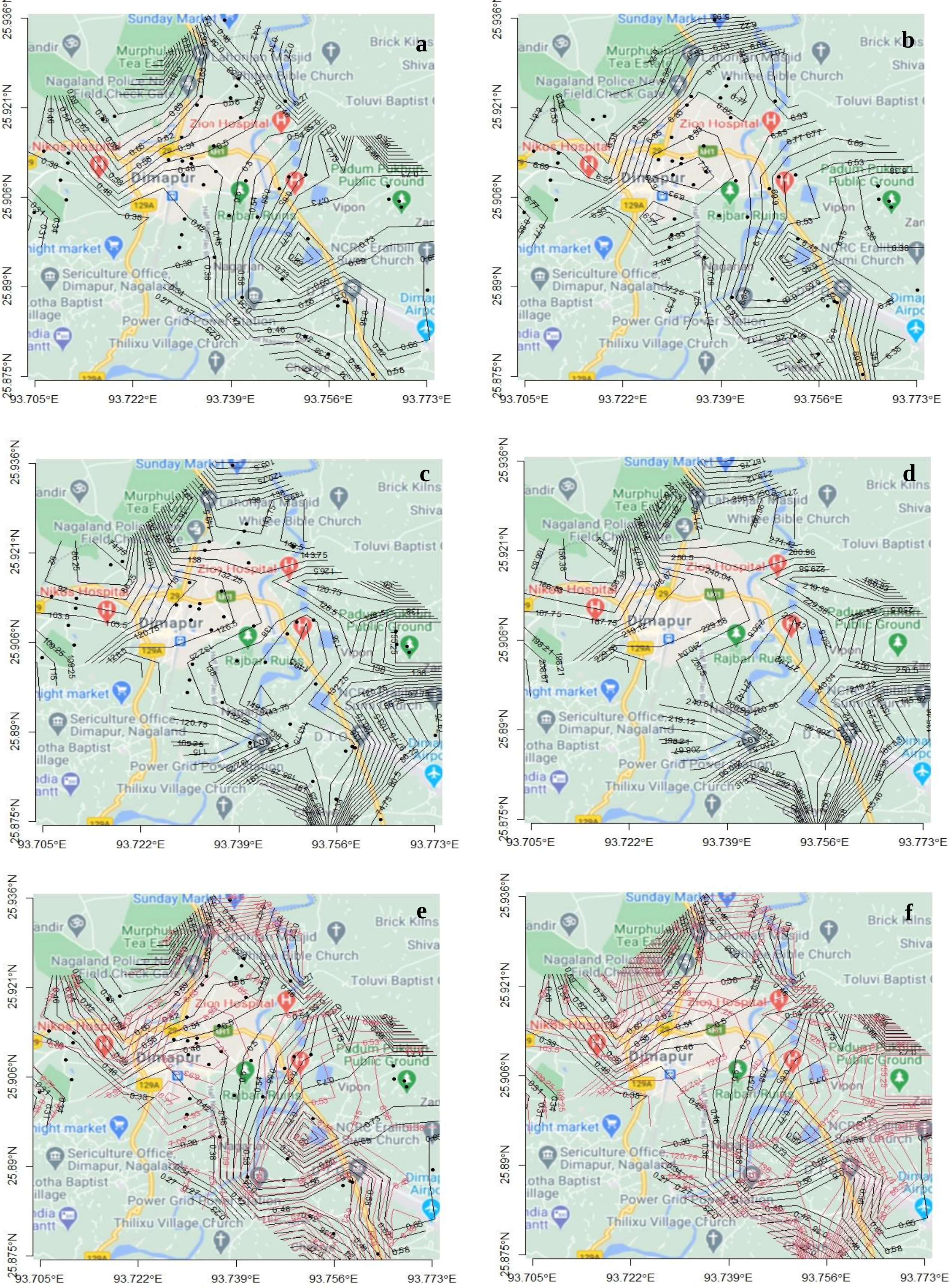

Fig. 2: The various distribution patterns of iron (Fe), pH, TDS, and EC are shown in 'a', 'b', 'c' & 'd' along with the comparative distribution patterns between two variables as such Fe vs pH ('e'), Fe vs TDS ('f').

Table 1. Statistical analyses of the monitored groundwater sample(s):

a. Descriptive statistics of the various parameters					
		pH	**EC**	**TDS**	**Fe**
Mean		6.75 ± 0.086	216.96 ± 15.314	124.50 ± 8.532	0.546 ± 0.038
Std deviation		0.612	108.28	60.33	0.2709
Variance		0.374	11725.26	3640.05	0.0731
Coefficient of Variation		0.091	0.499	0.485	0.496
Skewness		0.422	1.537	1.498	0.526
Excess Kurtosis		-0.821	2.136	1.966	-0.710
Range		2.40	493	272	1.0138
Min		5.80	86	53	0.1064
Max		8.20	579	325	1.1202
Percentile	**25**	6.255	141.00	84.50	0.33147
	50	6.700	194.50	115.50	0.48648
	75	7.200	263.00	152.50	0.7415
b. Pearson's Correlation coefficients of the monitored groundwater sample					
Parameters		**pH**	**EC**	**TDS**	**Fe**
pH		1			
EC		0.037	1		
TDS		0.049	0.995	1	
Fe		-0.665	0.166	0.154	1

A pilot study on spatial distribution of iron concentration in the ground water of Dimapur district, Nagaland, India

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Electronic Supplementary Information (ESI):

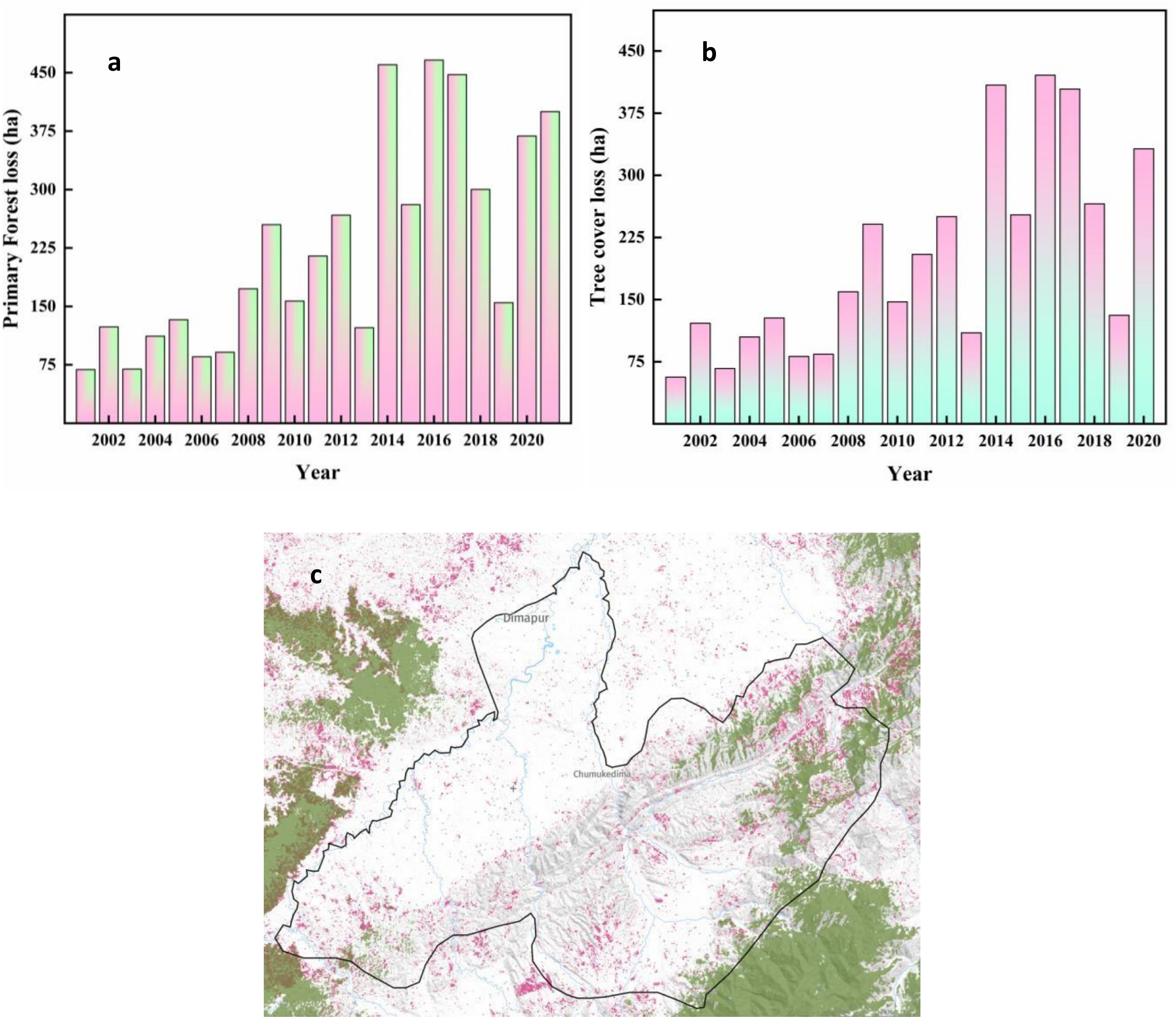

Fig. S1: Data on the primary forest loss (a), tree cover loss (b) between 2001-2020 and geographical map indicating tree cover loss (C) of Dimapur district, Nagaland. Data obtained from Global Forest watch (https://www.globalforestwatch.org/)

Fig. S2: Sources of drinking water, unwanted human activities and high concentration of iron.

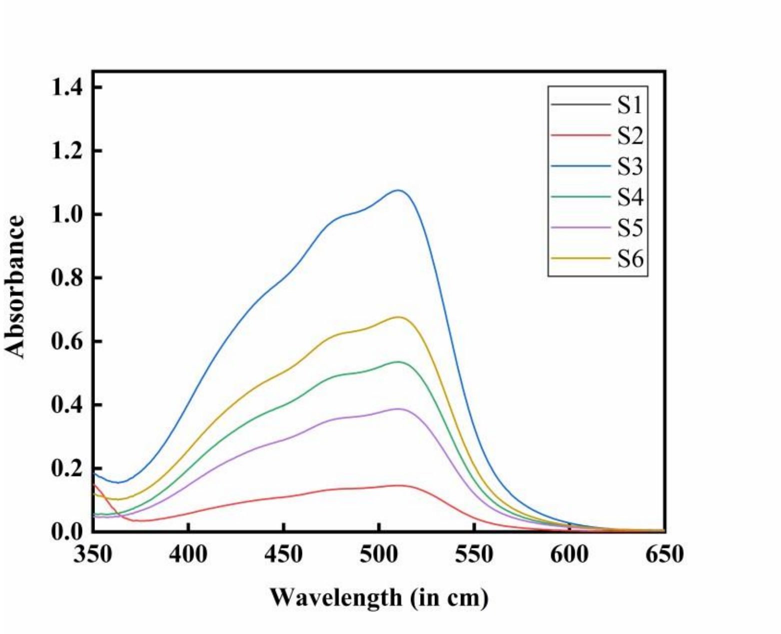

Fig. S3: UV-Vis spectra of Fe^{2+} complexation (ferroin) at 510 nm with some sample sites (labelled as S1-S6) as shown in the inset.

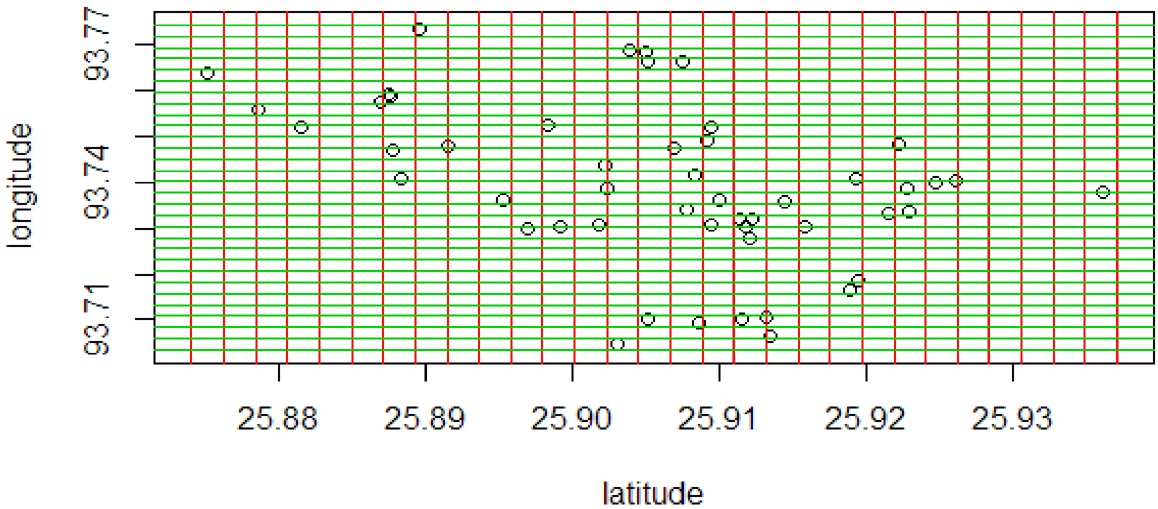

Fig. S4: Grid points with 0.01 circular radius computed on the experimental data set.

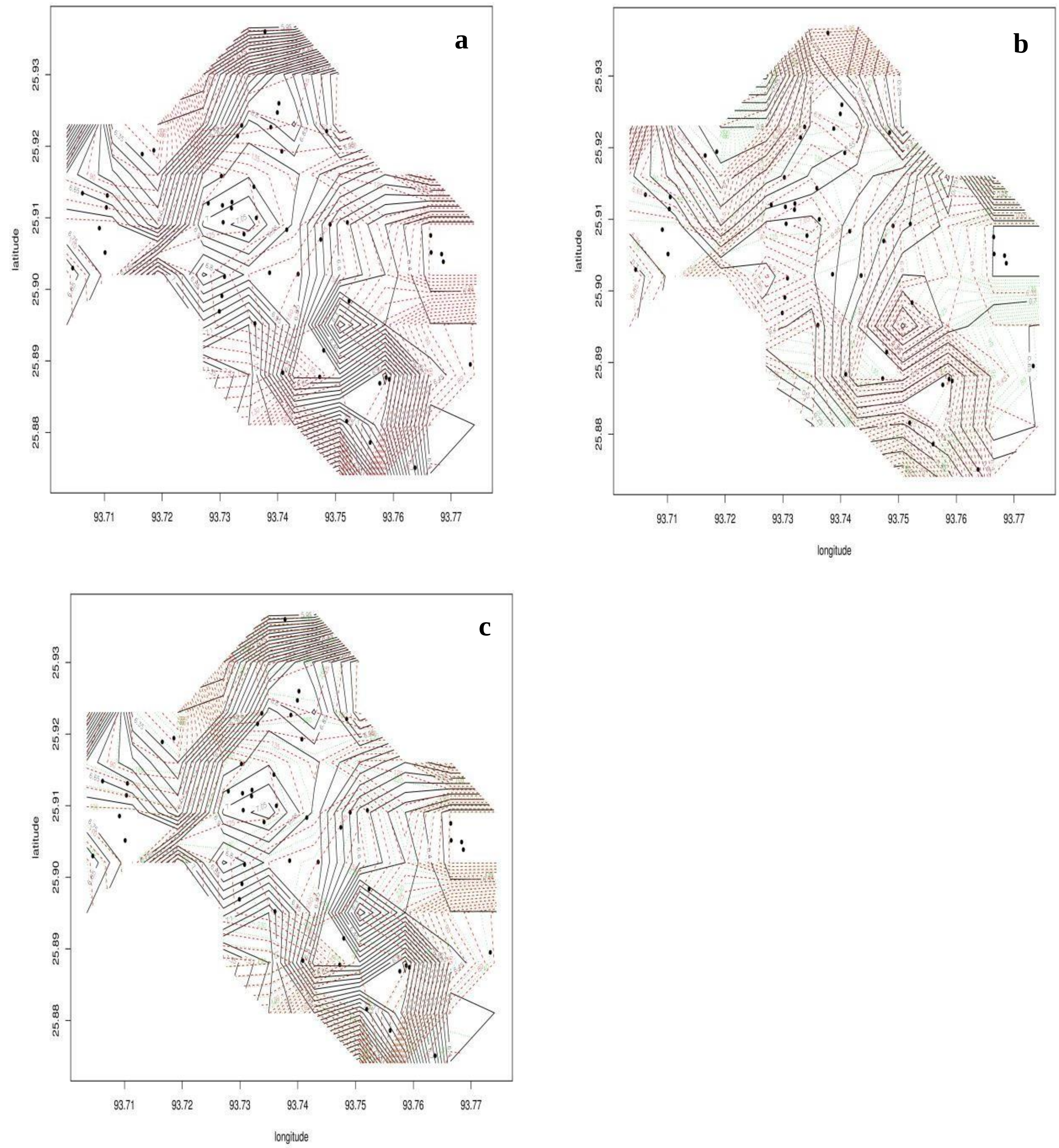

Fig S5: A comparative trend using the non- parametric method (moving average) between different parameters such as pH Vs TDS (a); Fe vs pH vs TDS (b); pH vs TDS vs EC (c).

Table S1: Equation of the descriptive data used in the experimental analysis.

SL No.	Statistical methods	Formula
1.	Mean	$X = \frac{1}{N}\sum_{i=1}^{N} X_i$
2.	Variance	$S^2 = \frac{1}{N-1}\sum_{i=1}^{N}(X_i - \bar{X})^2$
3.	Standard deviation	$\sigma = S$
4.	Coefficient of Variation	$cv = \frac{\sigma}{X}$
5.	Skewness	Skew = $\frac{1}{N}\sum_{i=1}^{N}\left[\frac{X_i - X}{\sigma}\right]^3$
6.	Excess Kurtosis	Ex Kurt = $\frac{1}{N}\sum_{i=1}^{N}\left[\frac{X_i - X}{\sigma}\right]^4$-3
7.	Range	Range = max - min
8.	Pearson's correlation coefficient	$r = \frac{(n\sum x_i\ y_i - \sum x_i \sum y_i)}{\sqrt{\{n\ \sum x_i^2 - (\sum x_i)^2\}\ \{n\ \sum y_i^2 - (\sum y_i)^2\}}}$

Table S2: Experimental analysis result of groundwater collected in the region

Sample No.	Latitude (N)	Longitude (E)	pH	Temperature (̊C)	EC (µS/cm)	TDS (mg/L)	Fe(mg/L)
1	25.90855	93.70913	6.8	23.3	159	98	0.144775
2	25.90514	93.71012	7.1	23.1	228	143	0.362069
3	25.90297	93.70451	6.8	22.8	217	122	0.284144
4	25.91344	93.70621	7.2	22.5	143	102	0.224073
5	25.91144	93.71034	6.1	23.0	102	62	0.709363
6	25.91311	93.7105	6.4	21.9	192	112	0.475518
7	25.9189	93.71655	6.8	22.3	86	53	0.538076
8	25.91943	93.71855	5.8	23.7	128	87	1.066078
9	25.92471	93.73993	6.7	21.5	197	110	0.530156
10	25.9229	93.73376	6.2	21.0	311	187	1.120259
11	25.91928	93.7407	6.4	21.4	233	145	0.729209
12	25.91434	93.73587	7.7	20.8	108	65	0.506875
13	25.92212	93.74846	7.1	20.7	262	156	0.236366
14	25.93602	93.73779	5.9	21.2	151	95	0.456206
15	25.92266	93.7388	7.8	22.3	346	207	0.38372
16	25.92599	93.7402	6.8	22.8	220	127	0.435267
17	25.92143	93.73304	6.2	21.9	128	76	0.670267
18	25.91584	93.73025	7.2	22.3	472	271	0.357436
19	25.90833	93.74156	6.2	23.7	245	139	0.336327
20	25.91173	93.73043	8.2	24.0	124	85	0.497443
21	25.91219	93.73207	7.7	23.4	117	69	0.353191
22	25.90998	93.73629	7.3	21.7	238	142	0.286078
23	25.90771	93.73416	6.2	22.4	141	83	0.444774
24	25.90937	93.73055	6.7	22.5	220	127	0.397091
25	25.91134	93.732	6.5	23.0	152	95	0.464327
26	25.90214	93.74353	6.6	21.4	511	288	0.895792
27	25.90232	93.73859	7.9	22.3	266	152	0.388293
28	25.89523	93.73605	7.3	21.7	133	85	0.57439
29	25.88951	93.77333	6.4	21.5	115	74	0.646551
30	25.90177	93.73079	6.9	22.5	276	158	0.239595
31	25.89908	93.73034	6.5	22.0	266	164	0.594194
32	25.89692	93.72989	7.4	21.4	176	108	0.268814
33	25.88835	93.74087	7.2	22.2	225	134	0.188975
34	25.88158	93.75193	7.7	23.1	579	325	0.316302
35	25.8786	93.75598	7.9	21.8	153	89	0.106405
36	25.90386	93.76866	6.4	21.0	164	91	0.678396
37	25.90515	93.76654	6.2	21.4	338	186	0.928589
38	25.88768	93.75876	6.1	20.8	178	117	0.785388
39	25.88742	93.75931	6.3	20.7	141	78	0.819437
40	25.90492	93.76836	5.9	21.7	460	268	1.112813
41	25.89147	93.74796	5.8	21.4	329	181	1.094249
42	25.89836	93.75235	7.8	22.2	270	154	0.910445
43	25.88777	93.74726	6.4	23.1	149	82	0.725373
44	25.90934	93.75205	6.7	21.8	214	118	0.8656
45	25.91202	93.72797	6.4	21.0	159	87	0.847747
46	25.88688	93.75766	7.1	21.4	223	125	0.400962
47	25.87507	93.76376	6.4	20.8	125	69	0.553593
48	25.90908	93.74906	6.1	21.2	214	123	0.77873
49	25.90753	93.76647	6.8	21.7	121	78	0.280567
50	25.90697	93.74745	7.3	20.9	143	79	0.316911