Magnetic and Soil Parameters as a Potential Indicator of Soil Pollution

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Abstract

The aim of this study was to look into the effect of land use or human activity on soil samples and to distinguish between pollution from anthropogenic sources or natural sources using magnetic susceptibility and statistical method. In soil samples from Tiruvannamalai Dist, Tamilnadu, magnetic susceptibility measurements at low frequency (lf) and high frequency (hf) were carried out. The physic-chemical properties such as % of sand, silt, clay, Electrical conductivity (EC) and pH in soil samples were determined using the standard methods. This research involves the identification of ferrimagntic minerals in soil samples from various locations in Tiruvannamalai, Tamil Nadu, using frequency-dependent susceptibility. The mean value of low and high frequency magnetic susceptibility are found to be 273.39 $\times 10^{-8} m^3\ kg^{-1}$ and 270.51$\times 10^{-8} m^3 kg^{-1}$ respectively. In some locations, the magnetic enhancement value suggests a high concentration of ferrimagntic minerals in the soil. Multivariate statistical analysis, such as factor analysis (FA), Pearson correlation (PC), and cluster analysis (CA), is used to determine the role of physic-chemical parameters on magnetic susceptibilities and to assess the contamination level of soil samples. This analysis revealed that magnetic susceptibility can be used as a proxy for determining the level of contamination in the soil.

1. Introduction

Anthropogenic activities such as disposal of waste water, usage of organic chemicals, mining, smelting, industry, power production, pesticides production, fuel leakage from vehicles and spillage are the main sources of increase the various pollutions in the soil environment. Magnetic measurements on soil, sediment and rocks are used to identify the different pollution sources (Senthil kumar et al., 2020). Naturally the magnetic susceptibility of soil is due to three main sources: lithogenic and pedogenic due to physical, chemical and biological processes. Soil magnetic susceptibility is impacted by physicochemical properties, age, temperature, biological activity, and human activities, in comparison to its parent material (Bouhsane and Bouhlassa, 2018).

Magnetic susceptibility variations (MS) are caused by a variety of factors, including differences in lithology (lithogenic/geogenic), soil formation processes (pedogenesis), and anthropogenic inputs of magnetic material (Newson, 1988; Dearing 1996, Maher, 1986). Saddiki et al.(2009) reported that lithology is the most important factor influencing magnetic susceptibility variations. Many scholars have concentrated on the magnetic properties of soil and their relationship with Physico-chemical properties in the last few years, and several countries have been studied using magnetic susceptibility (Ramasamy et al. 2014; Senthil kumar et al., 2020).

Magnetic susceptibility determination can be a useful, sensitive, and fast method for determining a significant parameter in mineralogy and granulometry (Canbay, 2010). This approach has become increasingly popular in recent years as a means of identifying the sources of different levels of pollution. Furthermore, environmental methods that use the magnetic properties of soil have been commonly used. This method has become increasingly popular in recent years as a means of identifying the sources of different levels of pollution. Furthermore, environmental scientists have commonly used method that use the magnetic properties of soil, and they have proven to be fairly useful determinants in pollution research (Harikrishnan, et al., 2018). Firmly magnetic particle concentrations, grain sizes, grain shapes, and mineralogy all influence magnetic susceptibility (MS). The primary goal of this study is to (i) determine the physic-chemical properties of soils in Tiruvannamalai, Tamil Nadu ((% of sand, silt, clay, pH, and electrical conductivity) (ii) determine the magnetic susceptibilities in soils and determine the level of ferromagnetic minerals (ii) study the relation between the physic-chemical properties and magnetic susceptibilities in soils using multivariate statistical techniques.

2. Study Area

Location, Climate and Geology

The study area for this research is the district of Tiruvannamalai spanning over an area of 6188 km^2 located at 11.55°& 13.15° North Latitude and 78.20°& 79.50° East Longitude (Figure 1). The average population is 2,464,875 according to census 2011, with over 63% of the working population engaged in agriculture [DSH, 2018]. The average annual rainfall is reported to be only 813.1mm [Report 2014] and is regularly prone to drought during summer.

The digital geospatial layers for the preparation of lithological map were obtained from the Geological Survey of India [GSI]. Figure 2 shows the land cover of the district divided into square grids (10.85 km x 10.85 km) using QGIS – open source mapping software. A location was identified in each grid depending on the availability and approachability of the sampling site (Durai Ganesh et al 2020). The geological study of this region indicates the presence of igneous and metamorphic rocks in general. The lithological map of the study area in Figure 3 shows the presence of Granites, Charkonites, Migmatite-Gneiss, Peninsular Gneiss, Sukinda Ultramafics and Alkaline Complexes. Granites and Charnokites are well known for the presence of uranium in them, this provides an ample reason to choose Tiruvannamalai District for this study.

3. Materials And Methods

3.1. Sample collection and preparation

Soil samples were collected in the Tiruvannamalai district, Tamilnadu using grid method. At each grid point, samples were taken from depth: 0–5 cm for various sites. At each of the location, four samples were collected at each point and one sample at center point. These samples were taken to form a bulk sample of around 1 kg, which was air-dried and larger stone fragments or shells were hand-picked out. The samples were sub-sampled and passed through a 2-mm sieve using the coning and quartering process (Ravisankar et al., 2015). An agate mortar was used to grind the samples to a fine powder. All powder samples were kept in desiccators until they were analyzed.

3.2. Determination of Physico-chemical properties

Soil (% of sand, silt and clay) are carried out by mechanical sieve shaker method. This method is very efficient to find the percentage of sand, silt, and clay in samples (Sonaye and Baxi 2012). A sieve shaker with sieves of various sizes (12 mm, 150 mm, and 200 mm) set in ascending order. The top sieve, which has the largest screen openings, receives a weighed sample. The gaps in the lower sieves in the column are smaller than those in the upper sieve. The receiver is a round pan that lies at the bottom of the column. A mechanical shaker is usually used to position the column and it shakes normally the column. The sample on each sieve is weighed after the shaking is finished. The percentage of sand, slit, and clay in samples is then determined using the equation:

$$Soil\ characteristics\ (\%) = \frac{W1}{W2} \times 100 \text{ -------(1)}$$

Where, W1 represent that weight of the sample retained in each sieve and W2 represent that total weight of the sample taken.

The degree of acidity or alkalinity in samples suspended in water and 0.01 M calcium chloride solution is determined by using a potentiometer to measure pH. Prior to the analysis of samples, the potentiometer is calibrated using buffer solutions with known pH. A digital electrical conductivity meter was used for measurements. A solution of 0.005 N KCl has an electrical conductivity of 720±1 dS/m at 25 °C prepared solution as the reference solution (Shivanna, and Nagendrappa 2014). The EC is reported in deci-siemens per meter. Twenty-five grams of sample mixed with 40 mL of deionizer water, resulting in water/soil ratio of 2:1. The 4-h equilibration period provides time for some slowly soluble constituents to approach solution equilibrium. Then, an electrode was inserted into solution to measure the conductivity of sample.

3.3. Magnetic susceptibility (x) measurements

The samples were air dried at room temperature in the laboratory to reduce the mass contribution of water and prevent any chemical reactions. They were then sieved with a 1 mm sieve mesh to remove particles such as glass, plant waste, refuse, and small stones (Zhang et al., 2011). The sieved samples were placed in a plastic container and taken to the lab for further analysis. The magnetic susceptibility measurements were then carried out on the sieved samples packaged in a 10 ml plastic container at laboratory temperature. Measurements of magnetic susceptibility were made at both low (0.465 kHz) and high (4.65 kHz) frequencies using MS2B dual frequency susceptibility meter linked to a computer operated using a Multisus2 software. All measurements were conducted at the 1.0 sensitivity setting. Each sample was measured five times in two different frequencies (low and high) and an average is calculated.

For natural samples which generally exhibit a continuous and nearly constant grain size distribution, can be used as a proxy for relative changes in concentration in pedogenic fined – grained magnetic particles (Liu *et al*, 2005). Hence frequency dependent susceptibility (cfd) was calculated from the expression (Dearing. 1999)

$$\chi_{fd}\ (\%) = \left[\frac{(\chi_{lf}-\chi_{hf})}{\chi_{lf}}\right] \times 100 \quad \text{----------------------- (1)}$$

3.4. Multivariate statistical analysis

The multivariate statistical analysis, such as pearson correlation, factor and cluster analysis were performed between physic-chemical properties and magnetic susceptibility in soil samples to understand the existing relation between them. This relationship was used to identify the natural and artificial sources of pollution. The statistical software SPSS (Statistical Package for Social Science16.0 version) was used to perform the statistical analysis.

4. Results And Discussion

4.1. Physio-Chemical Parameters

Soil physico-chemical properties are associated with strong chemical bonds and physical properties such as soil texture are usually used to indicate the size distribution of mineral particles and are considered as crucial factors affecting the soil mineral accumulation. The physio-chemical parameters measured in the study are temperature, pH and Electrical conductivity. of the samples was measured and results of the physicochemical properties of soils of Thiruvannamalai district, Tamil Nadu are presented in Table 1. Physical properties such as % of sand, silt and clay are determined and this results shows that particle size was dominated by sand, followed by silt and then clay, which revealed coarse soils with low supply of nutrients and moisture (Osakwe and Okolie, 2015).

4.1.1.pH

In the analysis of soil chemistry, the pH value is extremely significant. It is a significant determinant of plant and animal nutrient availability. One of the most common analyses in soil testing is the pH test. pH is a calculation of the activity of hydrogen ions in a sample and is used to determine its acidity. The pH levels are measured on a scale of 0 to 14, with 7.0 being considered neutral. Acids are considered as solutions with a pH below 7.0, while bases are with a pH between 7.0 and 14.0. The pH of soil samples ranged from 5.5 to 8.76, with the lowest value (TVM 8) at Neepathurai and the highest at Sathanoor (TVM 47) are noticed in the study area. It is observed from the results; around 43% of samples show that alkaline where remaining 57% of samples are acidic in nature. The guidelines recommend the safety limit of p^H to be between 7.5 and 8.5. It clearly indicates that all the samples are within the permissible limit.

4.1.2. Electrical Conductivity (EC)

Electrical Conductivity is a measure of the ability of water to pass an electrical current. EC indicates the amount of dissolved substances (salts). Electrical conductivity is expressed in mmhoS/cm (mS/cm). There is a relation between the electrical conductivity and the concentration of salts in milliequivalents per liter. Every 10 meq/liter of salts (cation concentration) creates 1 mS/cm EC. The sum of cations should equal the sum of anions. Low electrical conductivity is an indicator of pristine or background conditions but in the presence of low pH can indicate the removal of most salts. High conductivity (1000– 10,000 mS/cm) is an indicator of saline conditions caused by high evaporation, saline irrigation returns or runoff and caustic or alkaline industrial processes.

In the study area electrical conductivity is found to range from 61.3 to 743 μS/cm. The values of EC measured in soil samples in the locations of Nedungavadi (TVM 46) and Randam (TVM 59) are recorded low and high values of electrical conductivity. The electrical conductivity (EC) of the soil samples ranged from 61.3 to 743 (ds cm^{-1}). These values indicated significant presence of inorganic ions in the soil (Fuller et al., 1995).

4.1.3. Spatial contouring of pH and electrical conductivity (EC)

Figure 4 and 5 plot showing a contour map superimposed on the shape of Tiruvannamlai District for pH and EC of the study area. In Figure 4 each line is labeled to identify the pH in the study area. To see the variation of EC in the sampling area a contour map has been plotted Figure 5. The contour lines are representative of EC and can be used to know the EC at any point in the map.

4.1.3. Sand, Slit and Clay Analysis

Table 1 shows the results of the sand, silt, clay, and physicochemical parameters. Sand percentages range from 61% to 90%, with an average of 76.46 percent among all stations. When compared to slilt and clay in the study area, sand is the most abundant constituent in all sampling locations. The high percentage of sand in the Seangadi (TVM 21) location could indicate a high content of quartz, whereas the lowest percentage of sand in the Nedungavadi (TVM 46) location indicated a low content of light minerals in the study region (Ravisankar et al 2019). The concentrations of silt range from 7% to 27 percent, with an average of 15.15 percent. Nedungavadi (TVM 46) has a high percentage of slit, which may be attributed to the primary minerals (Lal and Shukla, 2004). The clay content varies from 2% to 16%, with an average of 8.38 percent. The high clay content in Pudhupattu (TVM 5) suggests that the soil samples contain more organic carbon.

4.1.4. Piper diagram for grain Size Analysis

A.M. developed a piper diagram in 1953 with the aim of classifying the studied quantities based on the parameters of interest. Many different computer programmes, such as Aqua chem and Grapher, are available on the market to plot piper diagrams. The piper diagram of slit, sand, and clay was drawn using Grapher 14 in this analysis. The 63 samples from the study are plotted in Figure 6. As seen by the diamond in the piper diagrams, all of the samples are categorized as sand, slit, or clay. As compared to slit or clay, sand is the most dominant shape in the triangle. The piper diagram, which demonstrates that sand is the key composition of soil in the study region, clearly establishes the grain size analysis of soil samples.

4.2. Magnetic susceptibilities in soils

Table 1 shows the magnetic susceptibility values for top-soil samples taken in the study region. Low frequency magnetic susceptibility values range from $23.25 \times 10^{-5}\ m^3\ kg^{-1}$ to $1664.9 \times 10^{-5} m^3\ kg^{-1}$ with an average value of $273.39 \times 10^{-5} m^3 kg^{-1}$. Low frequency magnetic susceptibility measurements show higher results than high frequency magnetic susceptibility measurements in all soil samples. This significant magnetic enhancement indicates that the soil contains a high concentration of ferromagnetic minerals, resulting in increased pollution (Jordanova et al, 2003, Hu et al, 2007, Yang et al, 2007). Anthropogenic magnetic mineral inputs are responsible for the higher magnetic enhancement in soil samples. Vehicle emissions (vehicular exhaust, absorption) are likely sources of anthropogenic magnetic particles. Different fractions of particles produced in exhaust pipes and released into the atmosphere make up vehicular emissions.

4.3. Percentage frequency dependent susceptibility

Percentage frequency dependent susceptibility %FD is used to approximate the total concentration of SP grains, while coarse multi domain (MD) magnetic grains are frequency independent as they show similar susceptibility values at low and high frequencies. Dearing (1999) proposed a model for the interpretation of frequency dependence as follows: FD (%) value Interpretation Low FD (%) < 2.0% virtually no SP grains; Medium FD (%) 2.0– 10.0 % Admixture of SP and coarser non-SP grains or SP; High FD (%) 10.0 – 14.0% virtually all (> 75%) SP grains Very high FD (%) >14 % Rare values, erroneous measurements, weak samples or contamination. Based on the semi quantitative model above, the results of this work demonstrated that most of the samples (about 64%) have a virtually no SP grains in the samples and remaining 36% of samples shows that admixture of SP and coarser non-SP grains. The sample TVM 45 shows the high value of %FD indicates virtually all (> 75%) SP grains and TVM 50 has the %FD 22.07 value reveals that high contamination by magnetic mineral in the soil samples

4.4. Pearson correlation analysis

Correlation is a bi-variate analysis that determines the strength of association between two variables. The value of the correlation coefficient ranges between +1 and -1 in terms of the strength of the relationship. A value of ± 1 indicated that the two variables are perfectly associated (Senthil kumar et al., 2020;Harikrishan et al., 2018). The relationship between the two variables would become weaker as the correlation coefficient value shows zero. The sign of the coefficient indicates the relationship's direction; a + sign indicates a positive relationship, while a - sign indicates a negative relationship. Table 2 shows the results of correlation analysis on physico-chemical properties and magnetic susceptibilities parameters in this study. The percentages of silt and clay indicate a clear negative relationship with the percentage of sand. This means that soil samples in the study area only contain the maximum percentage of sand. As can be seen from table, a weak positive correlation was observed between LF (r=0.111), HF (r=0.111) and % of sand whereas LF and HF shows that it has a weak negative correlation with % of silt, clay, EC and pH. This represented that % of sand content enhance the level of magnetic minerals in the soil samples.

4.5 Factor analysis (FA)

Factor analysis was performed for compressing a large amount of data into a smaller, more manageable and understandable set. FA successfully helps the analysis of meaningful information by extracting meaningful information from raw data by using established correlations among various parameters that are being observed (Chaturvedi and Raghubanshi 2015). FA technique finds relationships between variables by extracting eigen values and eigen vectors from the covariance matrix of original variables, thus reducing the dimensionality of the data set. Table 3 displays the varimax rotated factor variables for physico-chemical properties and magnetic susceptibilities. Factor I and Factor II, as shown in the table -3, were extracted from the data set and explained about 78.5 percent of the total variability. Factor I has a variance extraction of 26.65%, which is mostly due to high positive loadings of percent sand, LF, and HF, while Factor II has a variance extraction of 14.20 percent due to percent silt, clay, EC, pH, and percent FD loads. These results are good agreement with correlation analysis.

4.6. Cluster analysis (CA)

Cluster Analysis multivariate technique in which clusters are created in a sequential manner, starting with the most similar pair of objects and moving to higher clusters. A distance can be represented by the difference between analytical values from both samples, and the Euclidean distance normally indicates how close two samples are (Otto 1998).The average linkage method was used to perform this technique on the normalised data collection, with Euclidean distances as a measure of similarity. This analysis examines the distances between clusters using the analysis of variance approach, attempting to minimise the number of squares of any two clusters that can be generated at each steps. Figure 7 shows the derived dentogram of two clusters. Cluster I derived due to % of sand, silt, clay, pH, EC and %FD. Cluster II derived due to LF and HF. This means that magnetic susceptibilities are primarily related to the amount of sand in soil samples.

5. Conclusion

This paper presents the result of magnetic susceptibility and Physico-chemical properties of topsoils in different areas of Tiruvannamalai district of various human activity locations. The results of the work shows that particle size was dominated by sand, followed by silt and then clay in samples and 57% of samples are acidic in nature. The results of the percentage frequency dependence showed that most of the samples have a virtually no SP grains hence observed magnetic susceptibility values results from a combination of pedogenic and anthropogenic sources. Statistical results reveals that % of sand mainly associated with the low and high frequency magnetic susceptibilities in the soil samples.

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Tables

Table 1 Physico-chemical properties and Magnetic susceptibilities in soils of Tiruvannamalai district, Tamil Nadu

S.No	Sample ID	Location Name	Latitude	Longitude	Physico-chemical Properties					Magnetic susceptibilities		
					Sand %	Slit %	Clay %	Conductivity (MS)	pH	LF*	HF*	%FD
1	TVM 1	Anakkavaur	12°38'06.08"	79°32'38.21"	65	21	14	137	6.19	382.56	381.2	0.36
2	TVM 2	Vengodu	12°35'00.50"	79°42'10.59"	64	24	12	139	7.88	26.2	25.23	3.7
3	TVM 3	Agarapalayam	12°42'27.55"	79°14'56.16"	72	17	11	105.6	7.03	103.34	102.12	1.18
4	TVM 4	poosimalaikuppam	12°46'44.40"	79°14'44.14"	70	20	10	123	5.8	279.23	274.12	1.83
5	TVM 5	Pudhupattu	12°36'58.39"	79°18'06.66"	61	23	16	96.3	7.11	35.12	34.12	2.85
6	TVM 6	Randamkorrattar	12°43'5.54"	79°22'58.46"	80	13	7	120	7.92	392.54	391.76	0.2
7	TVM 7	Naradapattu	12°12'54.58"	78°41'06.25"	78	12	10	262	6.13	225.56	224.34	0.54
8	TVM 8	Neepathurai	12°09'44.33"	78°38'54.47"	76	15	9	137	5.5	84.32	82.34	2.35
9	TVM 9	Pakkaripalayam	12°17'14.34"	78°46'22.11"	82	11	7	119	6.2	309.53	307.27	0.73
10	TVM 10	Pinjur	12°15'24.41"	78°48'18.19"	73	18	9	130.5	7.16	1410.25	1405.87	0.31
11	TVM 11	Mansurabath	12°24'22.63"	79°12'47.32"	76	14	10	160	6.15	368.23	367.98	0.07
12	TVM 12	Pulivandal	12°30'34.38"	79°10'55.91"	64	21	15	228	6.16	60.24	59.45	1.31
13	TVM 13	Seyanandal	12°27'51.21"	79°15'44.90"	77	15	8	160.4	8.01	108.67	107.45	1.12
14	TVM 14	Devanathur	12°37'20.69"	79°23'45.15"	80	12	8	148	7.8	480.45	477.56	0.6
15	TVM 15	Murugathanpoondi	12°42'04.94"	79°28'54.94"	79	14	7	136	7.13	303.24	301.56	0.55
16	TVM 16	Nadumbarai	12°42'24.21"	79°33'35.34"	75	16	9	125	7.99	30.65	30.56	0.29
17	TVM 17	Parasur	12°38'38.17"	79°29'02.15"	80	11	9	69.5	6.07	170.9	169.89	0.59
18	TVM 18	Kilayur	12°27'12.75"	78°46'30.53"	80	13	7	159.2	7.6	70.23	67.54	3.83
19	TVM 19	Nammiyambattu	12°40'35.59"	78°59'18.00"	77	18	5	412	6.06	133.89	130.24	2.73
20	TVM 20	Palamarthur	12°33'23.55"	78°51'49.09"	75	14	11	163.2	7.91	46.65	46.12	1.14
21	TVM 21	Seangadi	12°34'50.91"	79°01'49.07"	90	8	2	252	6.22	197.45	196.67	0.4
22	TVM 22	Veerappanur	12°37'49.55"	78°55'06.46"	64	24	12	144	6.32	99.8	99.67	0.13
23	TVM 23	Kidampalayam	12°29'43.40"	79°00'22.51"	70	19	11	201	6.08	165.32	165.78	0.92
24	TVM 24	Parvathimalai	12°26'42.89"	79°00'10.33"	81	12	7	120	6.25	253.23	252.78	0.18
25	TVM 25	Parvathimalai RF	12°25'14.23"	78°54'55.38"	82	11	7	120	6.29	1151.23	1142.45	0.76
26	TVM 26	Pillur	12°25'50.55"	79°05'31.78"	85	10	5	103.3	6.97	297.45	294.45	1.01
27	TVM 27	Angunam	12°05’58.21”	79°10’50.79"	90	7	3	123.8	7.04	649.1	645.34	0.58
28	TVM 28	Panniyur	12°06’56.14”	79°15’00.80"	88	8	4	679	6.34	394.67	393.54	0.29
29	TVM 29	Sevarapundi	12°18’55.10”	79°15’26.54"	89	9	2	118.1	7.3	432.76	415.56	3.97
30	TVM 30	Vedanatham	12°12’51.31”	79°11’39.18"	69	21	10	132.8	7.09	80.23	79.12	1.38
31	TVM 31	Melnanthiyambadi	12°26'42.64"	79°23'32.77"	81	11	8	137	6.75	54.45	52.12	4.28

32	TVM 32	Melpoondi	12°30'50.70"	79°21'57.89"	82	14	4	212	6.27	211.56	210.9	0.31
33	TVM 33	Vallam	12°31'16.88"	79°29'05.69"	86	9	5	72.4	6.75	1173.56	1171.23	0.2
34	TVM 34	Kanji	12°21'14.60"	78°57'41.36"	65	20	15	118	6.2	101.12	98.56	2.53
35	TVM 35	Monnormangalam	12°20'39.79"	78°51'13.91"	88	9	3	233	6.3	24.13	24.08	0.21
36	TVM 36	Ananthapuram	12°41'14.54"	79°07'25.22"	66	22	12	97.8	6.42	109.14	108.67	0.43
37	TVM 37	Edaipirai	12°29'42.32"	79°04'11.39"	88	9	3	89.3	7.06	58.45	57.65	1.37
38	TVM 38	Illupakkam	12°37'30.87"	79°11'58.18"	68	20	12	112	6.32	1664.9	1648	1.02
39	TVM 39	Thurinjikuppam	12°36'32.79"	79°07'17.97"	73	17	10	140	6.18	35.67	34.34	3.73
40	TVM 40	Seeyamangalam	12°25'54.09"	79°28'15.03"	88	8	4	152	8.13	69.89	67.78	3.02
41	TVM 41	Theyyar	12°23'37.51"	79°35'40.43"	65	21	14	144	7.75	23.25	22.76	2.11
42	TVM 42	Beemarapati	12°02' 27.18"	78°44'32.70"	72	17	11	118	6.12	921.78	905.89	1.72
43	TVM 43	Kuvilam	12°02'46.38"	78°54'51.39"	85	12	3	94.3	8.61	83.89	80.89	3.58
44	TVM 44	Malamanjanur	12°07' 38.58"	78°52'13.71"	71	19	10	131	6.15	162.67	161.76	0.56
45	TVM 45	Melpasar	12°06' 22.15"	78°44'33.54"	64	20	16	117.1	7.32	39.67	35.65	10.13
46	TVM 46	Nedungavadi	12°13'52.46"	78°56'50.23"	61	27	12	61.3	6.68	52.78	49.43	6.35
47	TVM 47	Sathanoor	12°12' 22.88"	78°51'27.46"	70	20	10	109.2	8.76	56.89	52.5	7.72
48	TVM 48	Vakkilapattu	12°07'46.85"	78°59'37.26"	81	12	7	712.04	6.45	23.5	22.34	4.94
49	TVM 49	Devanur	12°02'05.48"	79°05'25.13"	80	12	8	112.1	7.47	39.12	36.76	6.03
50	TVM 50	Kattompoondi	12°07'16.08"	79°05'02.03"	81	15	4	78.5	7.86	25.78	20.09	22.07
51	TVM 51	Melathikam	12°12'25.79"	79°04'46.54"	69	20	11	709	6.26	166.12	164.43	1.02
52	TVM 52	Virthuvilanginan	12°02'23.12"	79°09'38.20"	65	22	13	122	6.12	480.67	477.41	0.68
53	TVM 53	Karunthuvambadi	12°19'49.27"	79°03'50.62"	75	16	9	83.9	7	32.56	32.45	0.34
54	TVM 54	Mangalam	12°19'48.33"	79°10'57.77"	87	9	4	282	7.89	99.9	95.45	4.45
55	TVM 55	Badhur	12°26'56.57"	79°41'39.92"	88	10	2	113.2	6.41	569.76	568.12	0.29
56	TVM 56	Vazhur	12°30'59.93"	79°40'13.52"	72	18	10	108.8	7.55	85.12	82.34	3.27
57	TVM 57	Vengunam	12°31'12.10"	79°36'30.36"	86	11	3	83.7	6.87	63.34	61.01	3.68
58	TVM 58	Abdullapuram	12°47'03.42"	79°40'25.24"	69	19	12	108.5	7.42	37.23	36.78	1.21
59	TVM 59	Randam	12°47'15.45"	79°28'13.28"	84	10	6	743	7.56	457.09	453.78	0.72
60	TVM 60	Sodiambakkam	12°43'39.32"	79°41'22.92"	69	20	11	71	6.6	410.89	402.1	2.14
61	TVM	Vembakkam	12°47'12.71"	79°35'27.77"	80	12	8	92.3	6.84	523.76	518.76	0.95

	61											
62	TVM 62	Devikapuram	12°29'43.73"	79°15'11.49"	79	15	6	413.01	7.22	475.08	473.67	0.3
63	TVM 63	Ramasanikuppam	12°43'13.15"	79°10'35.56"	87	8	5	94.5	6.06	146.56	142.09	3.05
Minimum					61	7	2	61.3	5.5	23.25	20.09	0.07
Maximum					90	27	16	743	8.76	1664.9	1648	22.07
Average					76.46	15.15	8.38	177.62	6.873	273.38	270.50	2.227

Table 2 Pearson correlation analysis physico-chemical properties and magnetic susceptibilities

Variables	Sand %	Silt %	Clay %	EC	pH	LF*	HF*	%FD
Sand %	1							
Slit %	-0.969	1						
Clay %	-0.944	0.833	1					
EC	0.166	-0.159	-0.158	1				
pH	0.106	-0.078	-0.133	-0.111	1			
LF*	0.111	-0.123	-0.084	-0.045	-0.191	1		
HF*	0.111	-0.124	-0.084	-0.044	-0.191	1.000	1	
%FD	-0.050	0.101	-0.022	-0.108	0.335	-0.290	-0.293	1.000

Table 3 Factor analysis of physico-chemical properties and magnetic susceptibilities

Variables	Factors	
	1	2
Sand %	0.093	0.182
Slit %	-0.105	-0.178
Clay %	-0.067	-0.171
EC	-0.150	0.989
pH	-0.177	-0.139
LF*	0.994	0.105
HF*	0.994	0.107
%FD	-0.277	-0.152
% of variance explained	**26.65**	**14.20**

Figures

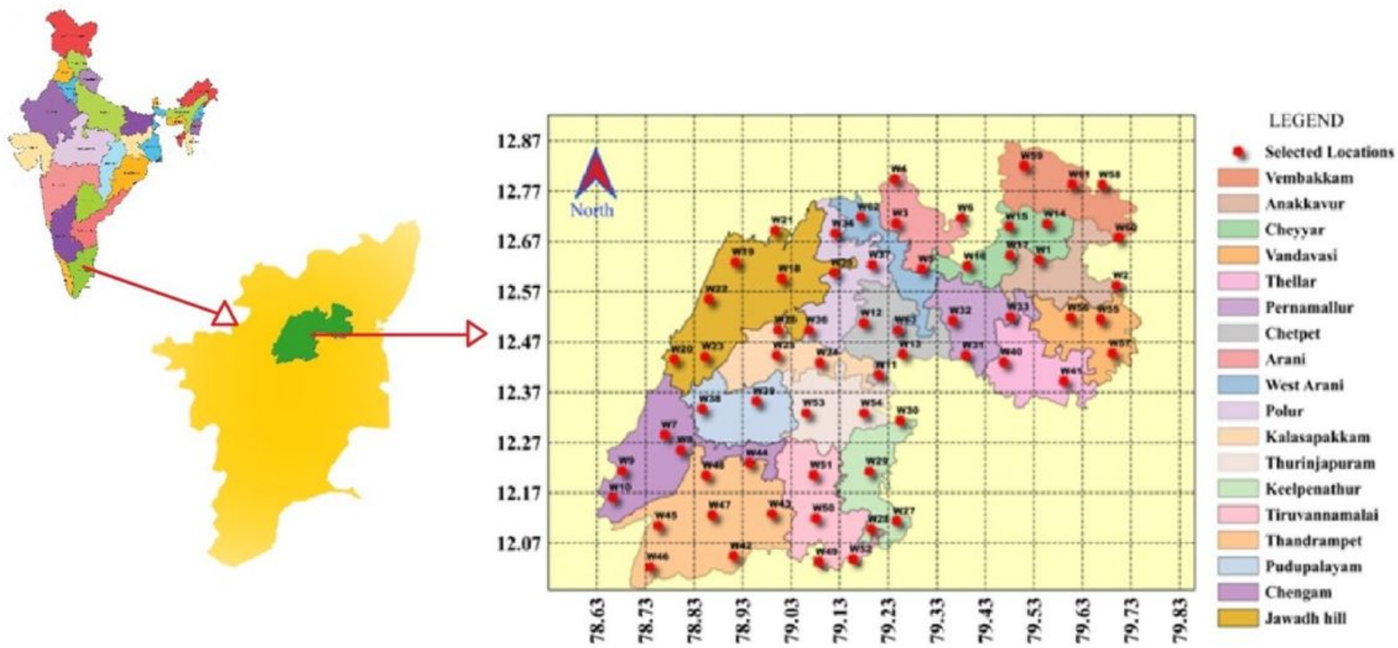

Figure 1

Location of the study area - Tiruvannamalai District. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

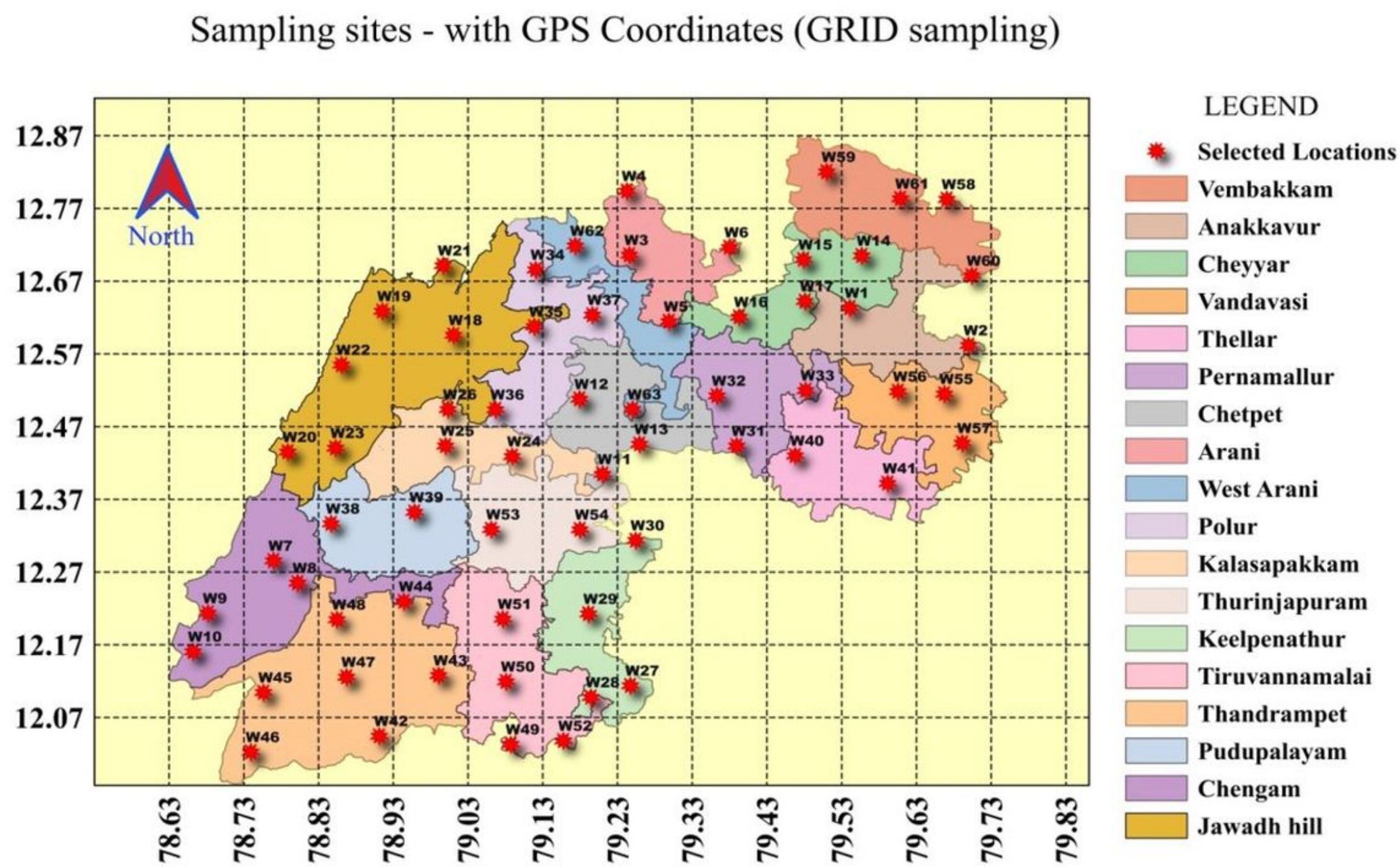

Figure 2

Sampling Sites with GPS Coordinates within the grids. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

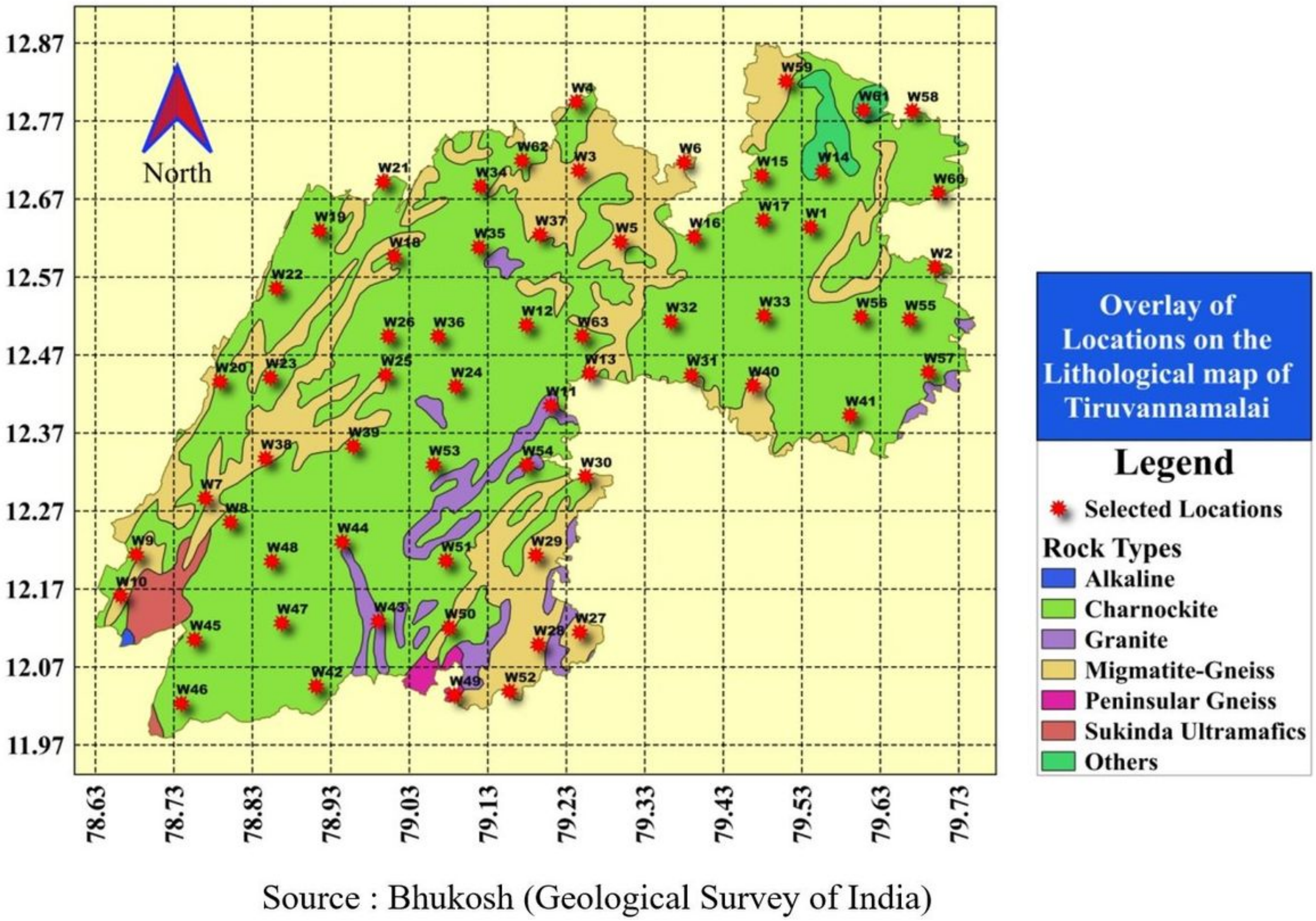

Figure 3

Overlay of sampling locations on the lithology of the study area. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

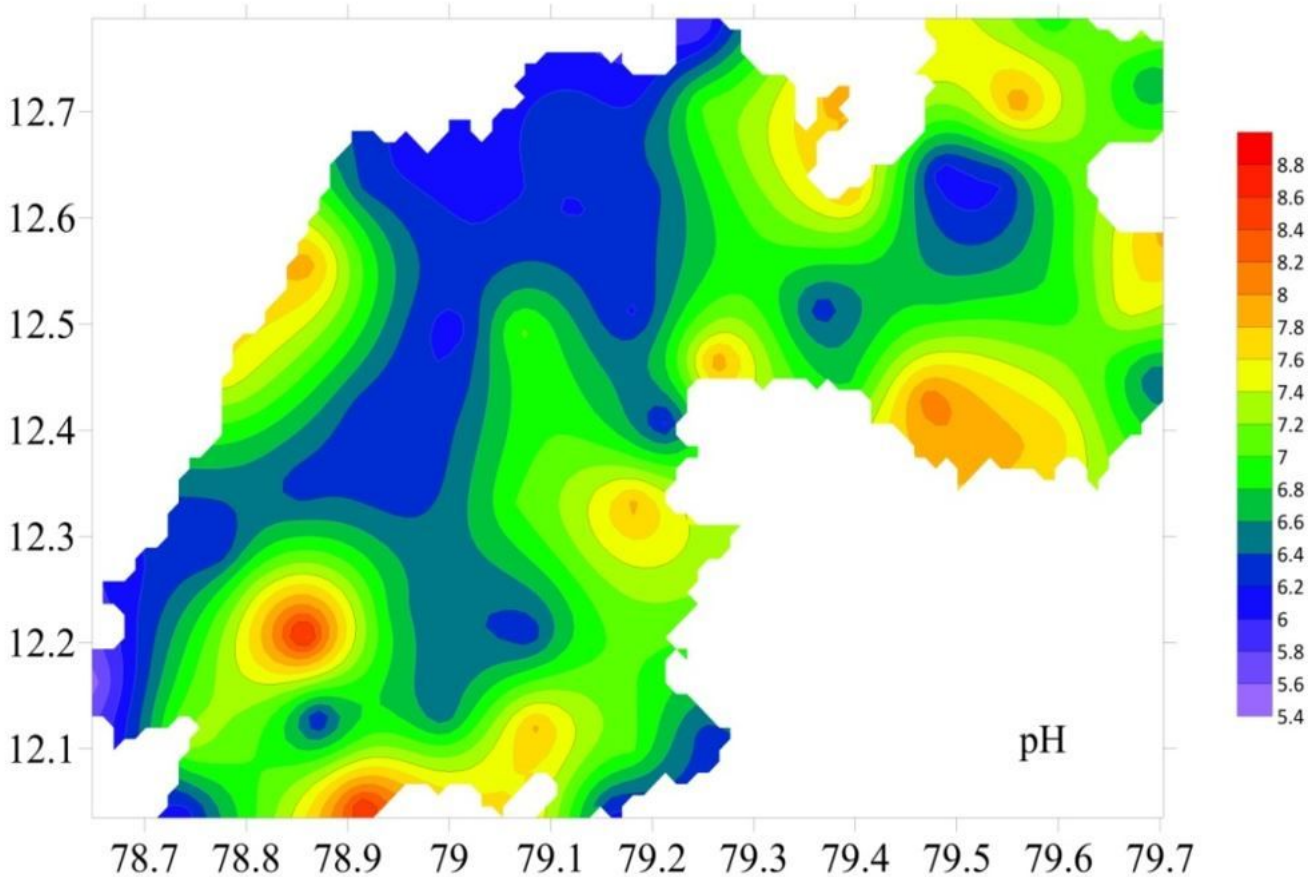

Figure 4

pH spatial contour map. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

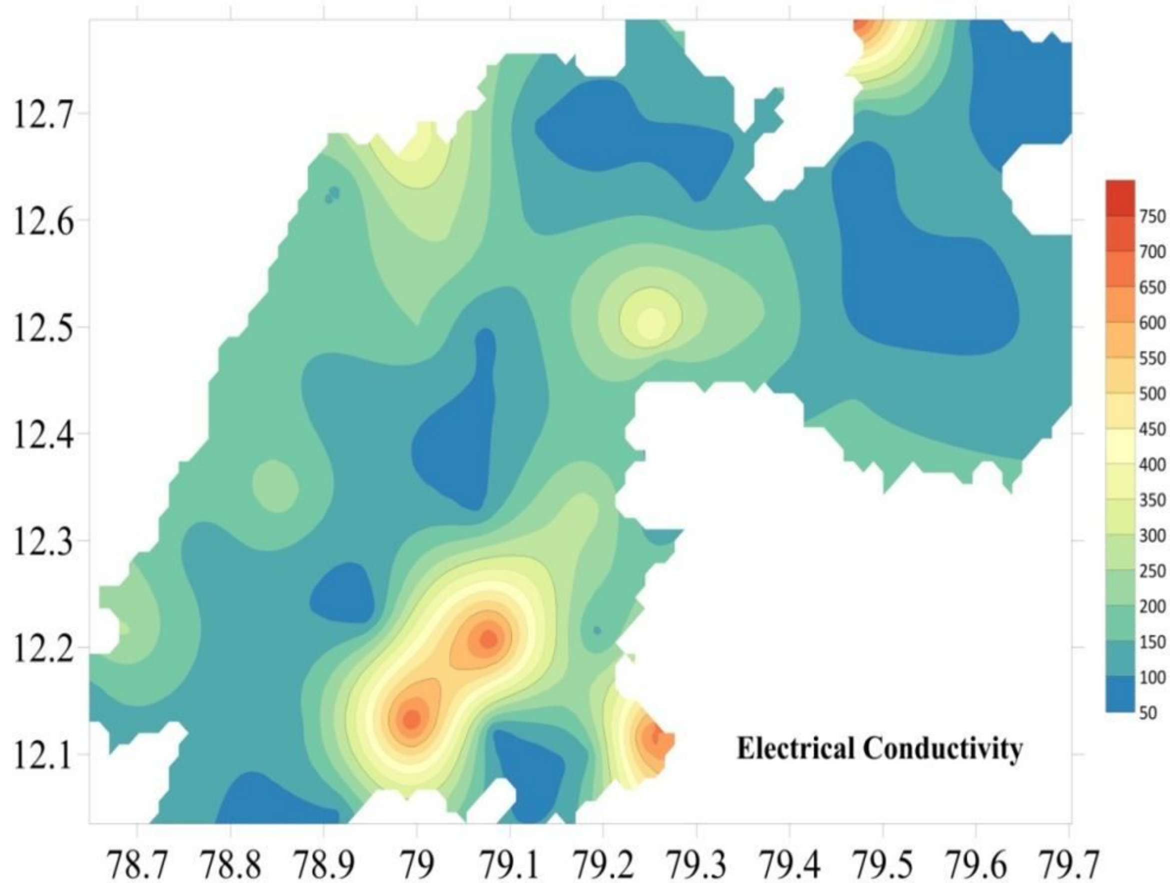

Figure 5

Electrical conductivity. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

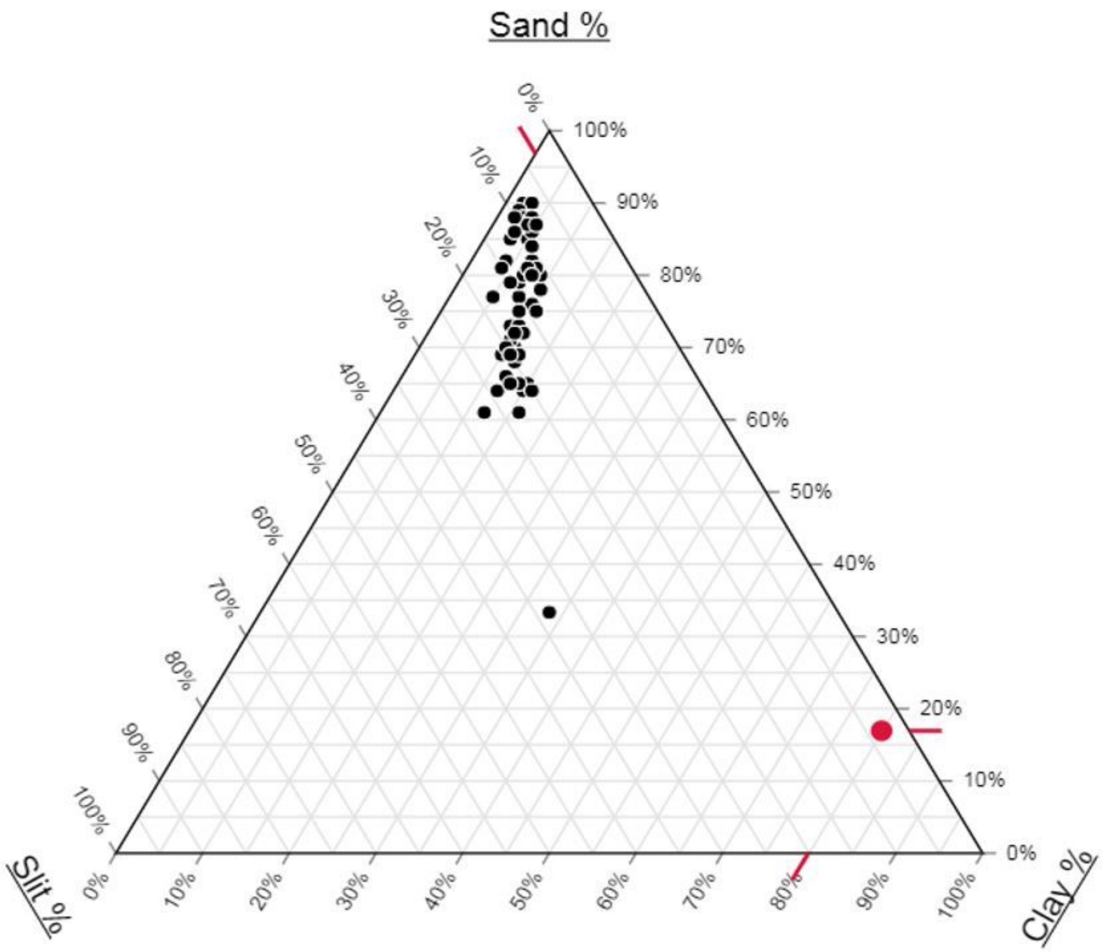

Figure 6

Piper diagram of grain size analysis

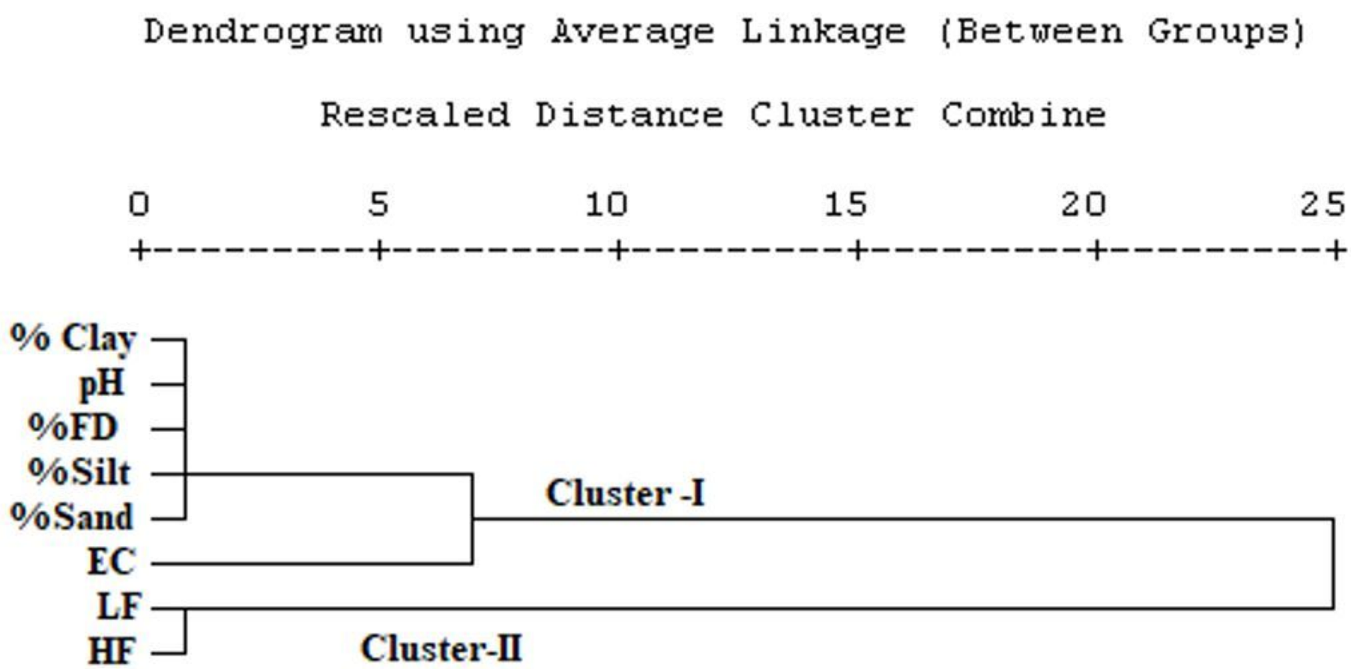

Figure 7

Dendrogram of cluster analysis