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Correlation between Chemical and Index Properties of Soils of Hyderabad Region

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Abstract

Each soil has unique nature of the characteristics and its properties are beyond the control of the designer. Since the soil parameters varies from site to site or location to location, thus selecting the reliable properties of soil is always a challenge for the Geotechnical Engineers. One of the option is intense soil investigations. However, there are various soil properties whose determination is time consuming and expansive. Geotechnical Engineer usually tries to develop mathematical equations specific to a particular soil type. However, a mathematical formula that is more reliable for the type of soil in which the link is genuine. In the light of above discussion, index and chemical properties were not investigated in most of the areas of Hyderabad region. Also correlation between chemical and index properties were not investigated. Correlation between chemical and index properties were not well understood. Thus it is important to develop the appropriate mathematical equations to be able to access the local area. The aim of this study is to determine index and chemical properties of soil selected from different locations of Hyderabad Region and also develop correlation between chemical and index properties of soils of Hyderabad region. Regression analysis have been carried out between Index and chemical properties. Such correlations may be of use to geotechnical engineers, in preliminary estimates of index and chemical properties of soils Hyderabad region and perhaps reduce testing requirements. The data obtained from independent laboratory tests on soils sourced from several locations in Hyderabad region were subjected to regression analysis after the samples had been grouped in A-4, A-6, and A-7-6 using AASHTO classification system. The derived Regression equations can be used to estimate the index and chemical properties of soils in Hyderabad region.

Keywords: Index Properties; Chemical Properties; AASHTO Classification System; Regression Analysis.

1. Introduction

Correlation between the soil properties has an important role in the geotechnical engineering. They can be used to obtain values of soil property that has not been measured during the testing program or they can help in getting the additional data where only a few direct measurement of the property have been made. Many researchers have been working on correlations between different soils properties throughout the short history of soil mechanics [1]. The correlated properties of soils generally include soil particle size and its plasticity, permeability, density, consolidation, settlement, California bearing ratio, shrinkage and swelling characteristics and shear strength. However, very little work has been done on the correlation of chemical properties. The formation of soil is the result of gradual chemical and physical weathering of rocks overlong period of time. The detailed chemical composition of soil is generally of very little interest to the geotechnical engineers. However, the information about the presence of constituents such as organic

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matter, chlorides, sulphates and carbonates is quite often required [1]. Also the degree of acidity or alkanity of soil measured in terms of PH value, and its electrical conductivity are sometimes needed [1]. Since the soil parameters varies from site to site or location to location, thus selecting the reliable properties of soil is always a challenge for the Geotechnical Engineers. One of the option is intense soil investigations. However, there are various soil properties whose determination is time consuming and expansive. Geotechnical Engineer usually tries to develop mathematical equations specific to a particular soil type. However, a mathematical formula that is more reliable for the type of soil in which the link is genuine. Thus it is important to develop the appropriate mathematical equations to be able to access the local area. In order to facilitate the local construction industry, many researchers developed correlations between index properties.

On the other hand, information regarding the index properties of soils is of great importance before they can be used in any of the geotechnical works. These properties encompass various soil characteristics such as grain size distribution, consistency, specific gravity etc. and chemical properties include sulphate content, chloride content, Organic matter content, electric conductivity and PH value [1]. On the other hand index and chemical properties were not investigated in most of the areas of Hyderabad region. Also correlation between chemical and index properties were not investigated. Correlation between chemical and index properties were not well understood. Therefore the necessity of this research is to determine the index and chemical properties of selected soils from Hyderabad region, and to correlate between those properties.

2. Literature Review

The correlation between index and chemical properties soft clay of Malaysia was studied by many researchers and have developed various correlations between the index and chemical properties of the clay soil, specific gravity [1]. The equations of correlation have been developed between liquid limit, plastic limit, soil PH value, conductivity and organic matter content of soil [1]. Terzaghi have correlated compression index with the liquid limit of soil [2]. Skempton also developed a correlation between compression index with the liquid limit of soil [3]. Researchers have correlated plasticity index and moisture content of soil. The results shows by the equation IP = 0.68w – 6.8 [4]. Mitchell et al. [5] had correlated the liquid limit and plastic limit with the clay content of soil. Another correlation was developed between moisture content and clay content of soils by giving different equations of upper and lower limit [6].

Very limited studies have been conducted on chemical properties of soil. Few studies have correlate the index and mechanical properties of shale. Lashkaripur et al. [7] developed a correlation between index and mechanical properties of shales and shows the high correlations exist between water content, porosity, point load index, tensile strength and modulus of elasticity with uniaxial compressive strength, whereas correlations between density, elastic wave, velocities and poison's ratio with compressive strength are poor.

Iqbal et al. [8] developed a co-relationship between CBR and Index properties of Jamshoro soil. By utilizing MLRA approach gives a good relationship between Soaked CBR, L.L, P.I and % finer. From the book, soil properties and their correlations correlated between the index properties [9]. For correlating soaked CBR value with the index properties of soil collected from different areas of bagalkot models are developed for correlating CBR value [10]. For determining undrained shear strength parameters from plasticity index a correlation between undrained shear strength and plasticity index of tropical clays has been developed [11]. Correlation between CBR and physical properties of Gujrat region in both soaked and unsoaked condition was developed and found satisfactory value of R^2 [12]. Another empirical correlation between electrical resistivity and Engineering properties of soil was developed and found satisfactory value [13]. Compaction behavior and characteristics of fine grained soils with reference to compaction energy was studied [14]. It is difficult to measure the strength of soft clay therefore, it is necessary to develop a relationship between the yield stress and index properties of super soft clay [15]. With the addition of cement, swelling potential and value of CBR can be increased [16].

This paper mentions correlations which have been developed through SLRA and MLRA on chemical and index properties of various soil samples in Hyderabad region. Index and chemical properties of these soil samples have been determined through laboratory testing according to AASHTO and ASTM procedures. Though only 20 number of samples have been analyzed but this paper provides a way of developing a relationship between the properties. The major benefit from this research outcome is that the developed correlations will be utilized for directly obtaining value of chemical properties instead of performing tests.

3. Research Methodology

The samples for this research work have been collected from various places of Hyderabad region. Twenty samples have been collected from depth about 2 – 4 feet and index and chemical properties of soil have been determined as given in Table 1 and 2. The soil was classified according to AASHTO Method.

Based on the soil samples taken from the sites, laboratory tests were performed on twenty samples in geotechnical laboratories of Civil Engineering Department of Mehran University of Engineering and Technology, Jamshoro. The following different kinds of tests have been performed.

- Natural Water Content Determination: Oven Drying Method (AASHTO T265-86 ASTM D2216-82)
- Sieve Analysis (AASHTO T88-86, ASTM D423-82)
- Liquid Limit (Fall Cone or Cone Penetration Method): More reliability hence Used in research (AASHTO T90, ASTM D-423)
- Plastic Limit (Glass Plate Method): (3 mm thread) (AASHTO T91-86, ASTM D424-82)
- Organic Content Test
- Chloride Content Test (Titration method)
- Electrical Conductivity Test
- PH
- Sulphate Content Test

The conventional Test referred above were carried out in twenty three soil samples and a series of test results were obtained. Based on the results of the plasticity, the grain size distribution, the soil classification was performed and shows that the entire sample is classified as fine-grained soil. According to the AASHTO classification system, most of the soil that is found is A-7-6, A-6 and A-4. Summary of laboratory test results are given in Table 1.

Procedure for Sample Preparation for Chemical Tests

Take 30 gram of soil and pass from #40 sieve and then add 300 ml distilled water, after adding water boil at 105° C for 20 minutes, after boiling add 50 ml extra water and then pass from filter paper and collected in measuring cylinder and chemical test is conducted.

3.1. Single Linear Regression Analysis

A SLRA provides an attempt to develop a correlation between two variables only in which one is the response (dependent) variable and other is explanatory (independent) variable. In this research work chemical properties are dependent variables and index properties of soils is independent variable. Graph is plotted between chemical and index properties and a suitable trend line is drawn through the plotted points for obtaining the value of coefficient of determination (R^2). The value of R^2 provides a measure of how well the future outcomes are likely to be predicted by the model. Generally speaking, any correlation greater than 0.88 is usually considered as best fit.

3.2. Multiple Linear Regression Analysis

A MLRA provides an attempt to develop a correlation between more than two variables. One is the response (dependent variable) and others are explanatory (independent) variables. In this research work, chemical properties are dependent variables and all other index properties are independent variables. In this equation, chemical property is function of all other index properties. The equation will be created as follows:

$$Y = b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3 + b_4 x_4 + \ldots\ldots\ldots\ldots\ldots b_n X_n$$

Where b_0, b_1, b_2, b_3, b_4 are constant and Y is chemical property and x_1 , x_2 , x_3, x_4 , x_n are index properties considered for analysis.

The values of these constants can be obtained by using Data analysis Tool bar of Microsoft excel and then putting these values with their corresponding soil properties in order to obtain a suitable equation.

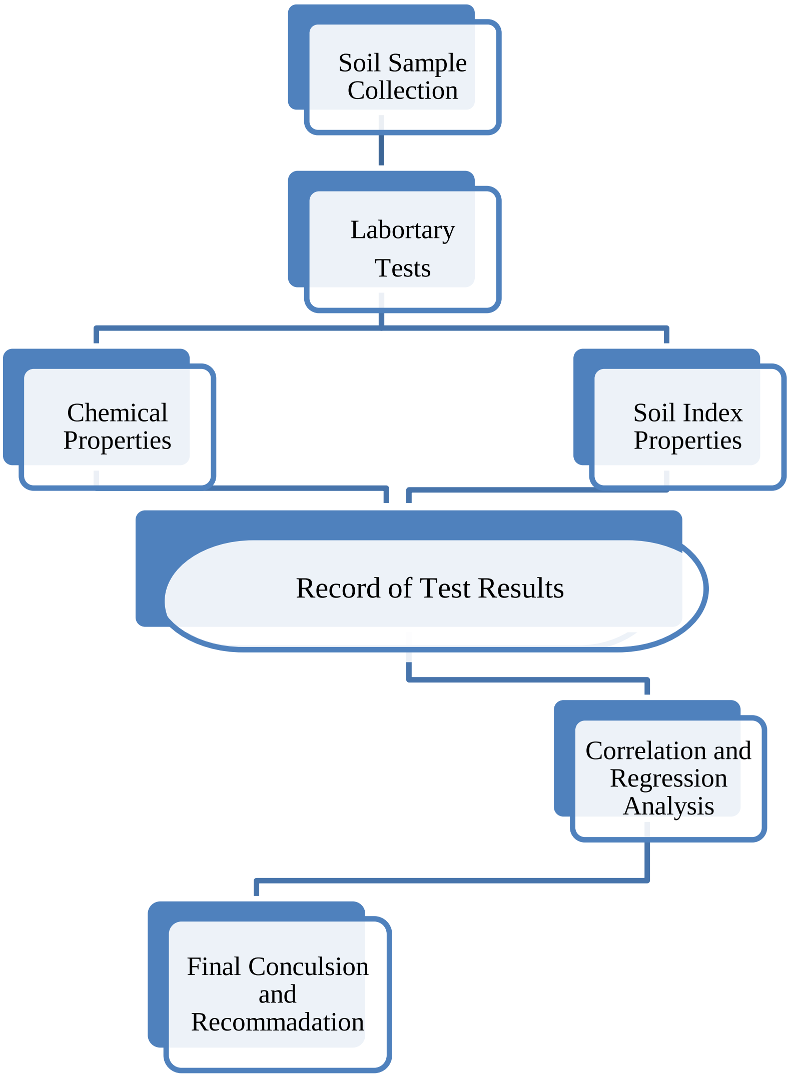

Figure 1. Flow Chart of Research Methodology

3.3. Experimental Procedure

The samples for this research work have been collected from various places of Hyderabad region. Twenty (20) samples have been collected from depths of about 2 – 4 feet and laboratory tests for LL, PL, PI, particle size distribution and chemical properties organic matter content, chloride content, sulphates content, PH value and electric conductivity have been performed on these samples at Geotechnical laboratory. Department of Civil Engineering and Environmental Engineering, MUET, Jamshoro according to AASHTO and ASTM Specification [9]. The soil classification of these samples have been done according to AASHTO method. The results are given in Table 1 along with % finer passing from #200 sieve for each sample.

4. Results and Discussion

4.1. Natural Moisture Content

The natural moisture content with depth is shown in Table 1. The natural moisture for soil samples ranges from 2.08% to 30.57%.

4.2. Atterberg Limits

Liquid limit, W_L, Plastic limit, W_P and Plasticity index I_P of Soil samples with depth are shown in Table 1. Range of Liquid limit, W_L, Plastic limit, W_P and Plasticity index I_P of Soil samples from 23% to 46%.

Table 1. Laboratory Results for Soil Samples

Sample No:	Location	Depth	Sieve Sizes				Atterberg Limits				
			No:4	No:10	No:40	No:200	Liquid Limit	Plastic Limit	Plasticity Index	Group	N.M. C
01	Awal Square Qasimabad	2'-8"	100.00	100.00	99.85	76.01	29	21	8	A-4	4.93
02	Happy Homes Qasimabad	3'-0"	99.86	99.70	99.49	82.11	36	23	13	A-6	6.29
03	Power House Qasimabad	2'-9"	100.00	100.00	99.93	77.31	27	17	10	A-4	23.69
04	Ponam Petrol Pump Qasimabad	3'-6"	99.88	99.88	99.69	61.44	25	16	9	A-4	30.57
05	Jamia Masjid Near Qasim Chowk	3'-1"	99.33	99.03	98.58	61.61	23	15	8	A-4	23.77
06	Qadir Avenue (Entrance)	4'-0"	100.00	99.90	99.66	85.35	30	19	11	A-6	9.29
07	Qadir Avenue (Centre)	4'-0"	100.00	99.60	99.01	87.44	32	20	12	A-6	7.31
08	National Super Mart Hala Naka	2'-0"	100.00	99.93	99.85	96.11	32	21	11	A-6	11.53
09	ISRA Village R/S	3'-3"	100.00	100.00	99.95	93.46	37	24	13	A-6	8.95
10	ISRA Village L/S	3'-7"	100.00	100.00	99.41	96.49	35	22	13	A-6	9.40
11	Bypass View Sceme Near Toyota Motors (Centre)	2'-8"	100.00	100.00	99.82	99.12	44	24	20	A-7-6	2.08
12	Bypass View Sceme Near Toyota Motors (L/S)	3'-0"	98.31	97.66	95.54	88.31	31	20	11	A-6	2.37
13	Bypass View Sceme Near Toyota Motors (R/S)	3'-0"	100.00	99.54	99.15	86.68	34	23	11	A-6	3.23
14	Back Side of Rajputana Hospital L/S	2'-11"	100.00	99.34	98.08	87.57	33	22	11	A-6	17.17
15	Back Side of Rajputana Hospital R/S	3'-0"	100.00	99.53	99.26	89.35	35	22	13	A-6	21.81
16	Bhitai Nagar (Centre)	2'-6"	100.00	99.69	99.34	95.02	38	23	15	A-6	7.43
17	Bhitai Nagar (L/S)	2'-8"	99.85	99.43	99.19	98.78	46	26	20	A-7-6	7.79
18	Abdullah Town Qasimabad near Highway	3'-1"	100.00	100.00	99.72	98.34	41	22	19	A-7-6	6.48
19	Liaqat Colony Hyderabad	4'-0"	100.00	100.00	99.75	97.92	44	23	21	A-7-6	8.88
20	Rehman Town Phuleli	3'-4"	100.00	100.00	99.55	96.89	38	22	16	A-6	2.77

4.3. PH Test

PH value of soil samples are shown in Table 2. The range of PH value for samples ranges from 7.58 up to 7.96.

4.4. Conductivity Test

Conductivity of soil samples are shown in Table 2. The range of conductivity for soil samples ranges from 1.01 ms/cm to 3.02 ms/cm.

4.5. Sulphate Content

Its value ranges from 0.24 to 1.8 mg/gm.

4.6. Chloride Content

Chloride content value of soil samples are shown in Table 2. The range of chloride content value for samples ranges from 1 up to 12 mg/gm.

4.7. Organic Content

Organic content value of soil samples are shown in Table 2. The range of organic content value for samples ranges from 3.174 % up to 8.02 %.

Table 2. Chemical Test Results for Soil Samples

Sample No:	Location	Organic Impurities	Electric Conductivity (ms/cm)	PH	Chloride Content (mg/gm)	Sulphate Content (mg/gm)
01	Awal Square Qasimabad	3.637	1.92	7.6	1.997	1.1
02	Happy Homes Qasimabad	3.177	1.15	7.63	1.933	1.25
03	Power House Qasimabad	3.685	2.9	7.66	4	1.2
04	Ponam Petrol Pump Qasimabad	4.119	1.51	7.65	2	0.9
05	Jamia Masjid Near Qasim Chowk	4.176	2.97	7.7	5	0.7
06	Qadir Avenue (Entrance)	3.174	0.59	7.96	0.93	0.3
07	Qadir Avenue (Centre)	5.571	0.86	7.95	1	0.4
08	National Super Mart Hala Naka	7.265	2.17	7.62	1	1.4
09	ISRA Village R/S	6.204	2.37	7.78	1.925	2
10	ISRA Village L/S	4.085	1.36	7.75	1.806	1.8
11	Bypass View Sceme Near Toyota Motors (Centre)	7.383	2.54	7.72	7	0.9
12	Bypass View Sceme Near Toyota Motors (L/S)	5.727	1.03	7.68	3	0.6
13	Bypass View Sceme Near Toyota Motors (R/S)	5.7	1.39	7.58	5	1
14	Back Side of Rajputana Hospital L/S	6.447	2.38	7.65	7	1.35
15	Back Side of Rajputana Hospital R/S	6.612	2.35	7.66	5	0.85
16	Bhitai Nagar (Centre)	7.714	2.4	7.62	6	0.95
17	Bhitai Nagar (L/S)	8.203	2.54	7.63	5	0.9
18	Abdullah Town Qasimabad near Highway	6.252	1.01	7.87	3	0.85
19	Liaqat Colony Hyderabad	5.541	1.07	7.83	6	0.85
20	Rehman Town Phuleli	6.584	3.02	7.72	12	0.24

5. Correlations / Models

The table of laboratory test results along with graphs is presented section 4. Now correlations / models are developed in the form of linear equations between index and chemical properties first by SLRA and then collectively by MLRA.

5.1. Correlation by Single Linear Regression Analysis

The correlation by SLRA were developed and are described in Model 1 – 20, as shown in Figure 2 to Figure 21, indicating linear relationship between the variables. Some models gave very low value of reliability R^2. However, in this paper, all models are shown.

5.1.1. Model-1: Correlation of Organic Content with Liquid Limit

Figure 2 represents a graph, which shows a correlation between organic content and Liquid Limit of soil samples. The mathematical relation between the two parameters is shown in Equation 1. It can be seen that the reliability factor R^2 obtained from this equation is only 0.4198.

$$\text{Organic Content} = 0.1582(LL) + 0.0769 \qquad R^2 = 0.4198 \tag{1}$$

It can be seen in all figures that there are too many regression lines because equations have been generated using linear, logarithmic, exponential and power equations which are mentioned in Table 3.

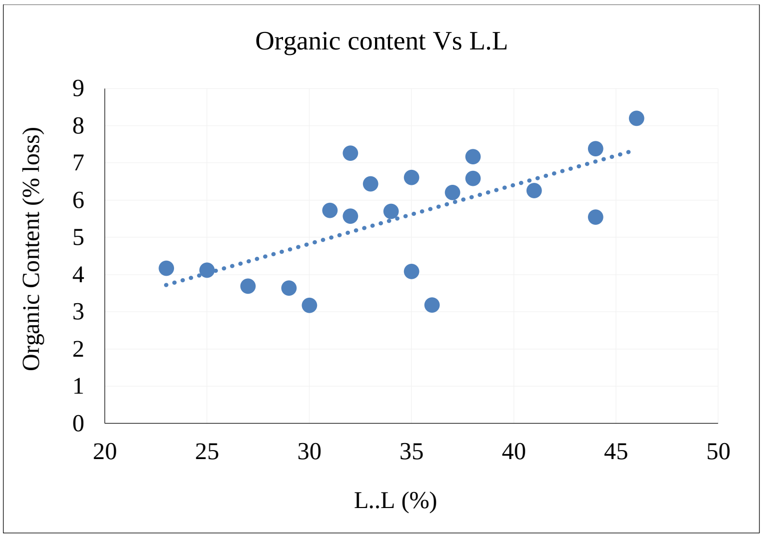

Figure 2. Relationship of Organic content with Liquid limit

5.1.2. Model-2: Correlation of Organic Content with Plastic Limit

Figure 3 represents a graph, which shows a correlation between organic content and PL of soil samples. The mathematical relation between the two parameters is shown in Equation 2. It can be seen that the reliability factor R^2 obtained from this equation is only 0.3747.Following equation shows only linear equation other power, exponential and logarithmic equations are shown in Table 3.

$$\text{Organic Content} = 0.3378(PL) - 1.6457 \quad R^2 = 0.3747 \tag{2}$$

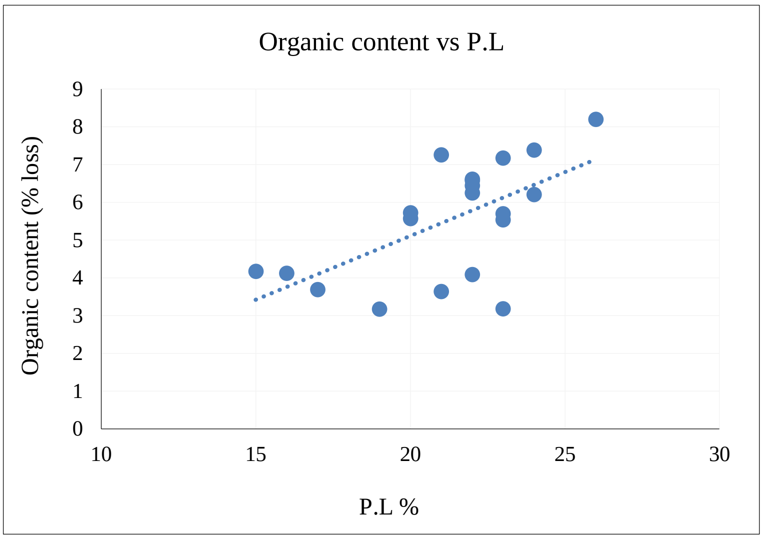

Figure 3. Relationship of Organic Content with Plastic limit

5.1.3. Model-3: Correlation of Organic Content with Plasticity Index

Figure 4 represents a graph, which shows a correlation between organic content and Plasticity Index of soil samples. The mathematical relation between the two parameters is shown in Equation 3. It can be seen that the reliability factor R^2 obtained from this equation is only 0.3466. From Figure 4, it can be seen that there are many regression lines because we have made linear, power, exponential and logarithmic equations**.** Following equation shows only linear equation other power, exponential and logarithmic equations are shown in Table 3.

$$\text{Organic Content} = 0.2243(PI) + 2.5611 \quad R^2 = 0.3466 \tag{3}$$

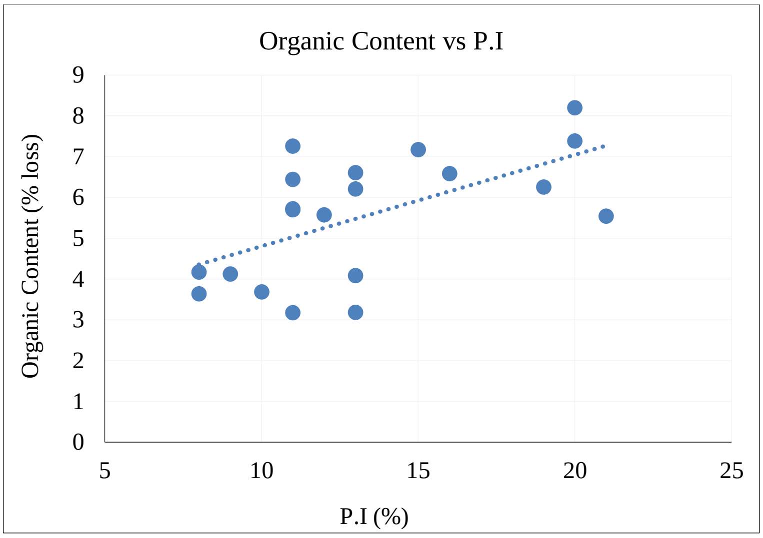

Figure 4. Relationship of Organic content with Plasticity Index

5.1.4. Model-4: Correlation of Organic Content with % Finer Passing From #200 sieve (% F)

Figure 5 represents a graph, which shows a correlation between organic content and % Finer of soil samples. The mathematical relation between the two parameters is shown in Equation 4. It can be seen that the reliability factor R^2 obtained from this equation is only 0.4458. From figure it can be seen that there are many regression lines because we have made linear, power, exponential and logarithmic equations. Following equation shows only linear equation other power, exponential and logarithmic equations are shown in Table 3.

$$\text{Organic Content} = 0.09(\%\ F) - 2.3611 \quad R^2 = 0.4458 \tag{4}$$

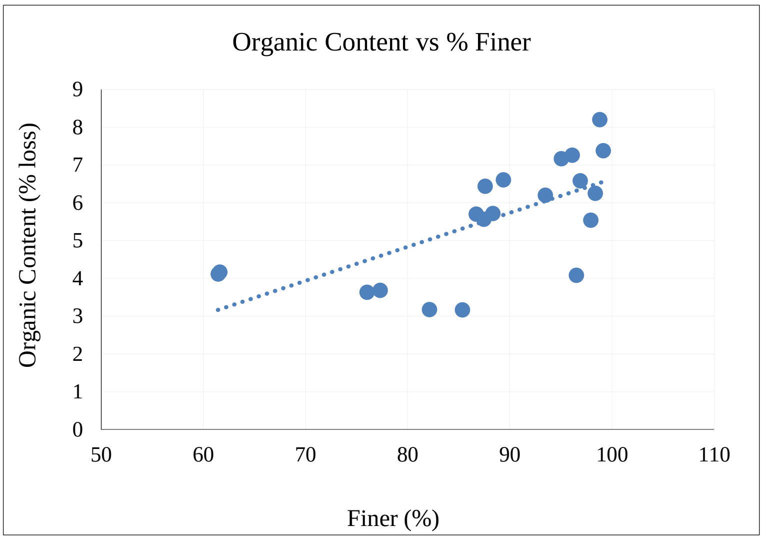

Figure 5. Relationship of Organic content with % Finer

5.1.5. Model-5: Correlation of Sulphate Content with % Finer Passing from #200 sieve (% F)

Figure 6 represents a graph, which shows a correlation between sulphate content and % F of soil samples. The mathematical relation between the two parameters is shown in Equation 5. It can be seen that the reliability factor R^2 obtained from this equation is only 0.0119. Following equation shows only linear equation other power, exponential and logarithmic equations are shown in Table 3.

$$\text{Sulphate Content} = 0.0043(\%\ F) + 0.5992 \quad R^2 = 0.0119 \tag{5}$$

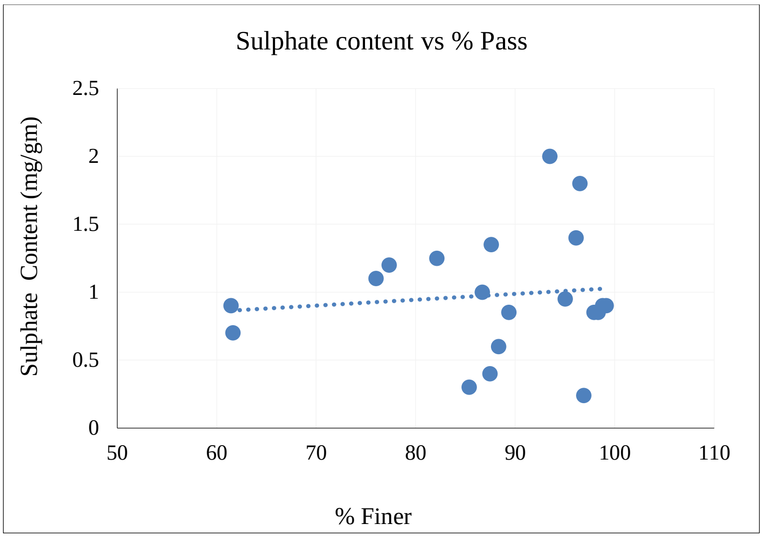

Figure 6. Relationship of Sulphate Content with % Finer

5.1.6. Model-6: Correlation of Sulphate Content with Liquid Limit

Figure 7 represents a graph, which shows a correlation between sulphate content and liquid limit of soil samples. The mathematical relation between the two parameters is shown in Equation 6. It can be seen that the reliability factor R^2 obtained from this equation is only 0.0027. Following equation shows only linear equation other power, exponential and logarithmic equations are shown in Table 3.

$$\text{Sulphate Content} = 0.0037(LL) + 0.8501 \quad R^2 = 0.0027 \tag{6}$$

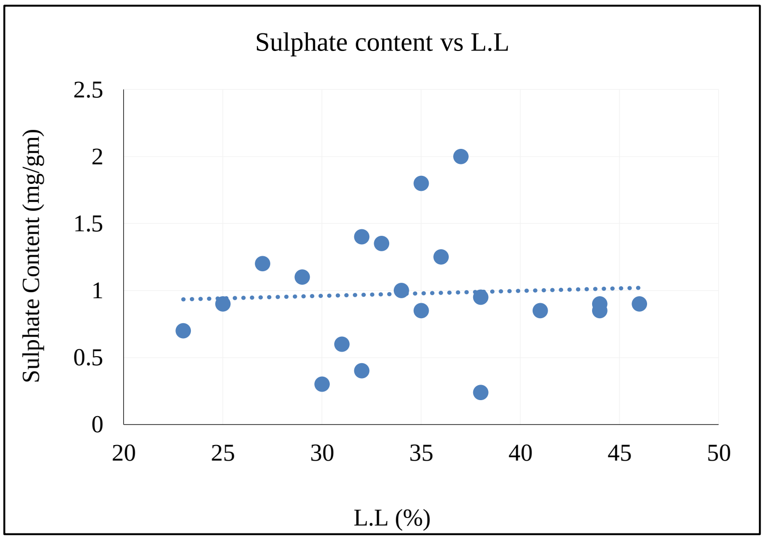

Figure 7. Relationship of Sulphate Content with Liquid limit

5.1.7. Model-7: Correlation of Sulphate Content with Plastic Limit

Figure 8 represents a graph, which shows a correlation between sulphate content and PL of soil samples. The mathematical relation between the two parameters is shown in Equation 7. It can be seen that the reliability factor R^2 obtained from this equation is only 0.074**.** Following equation shows only linear equation other power, exponential and logarithmic equations are shown in Table 3.

$$\text{Sulphate Content} = 0.0439(PL) + 0.0432 \quad R^2 = 0.074 \tag{7}$$

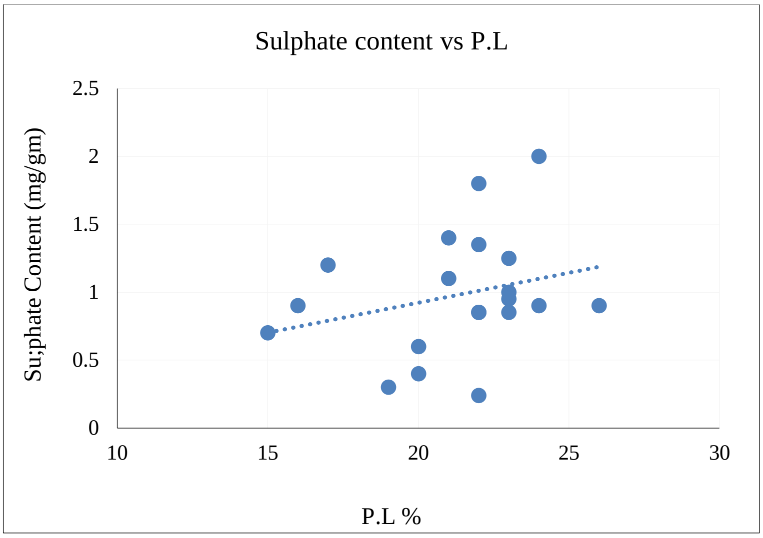

Figure 8. Relationship of Sulphate Content with Plastic Limit

5.1.8. Model-8: Correlation of Sulphate Content with Plasticity Index

Figure 9 represents a graph, which shows a correlation between sulphate content and PI of soil samples. The mathematical relation between the two parameters is shown in Equation 8. It can be seen that the reliability factor R^2 obtained from this equation is only 0.0027. Following equation shows only linear equation other power, exponential and logarithmic equations are shown in Table 3.

$$\text{Sulphate Content} = 0.0037(LL) + 0.8501 \quad R^2 = 0.0027 \tag{8}$$

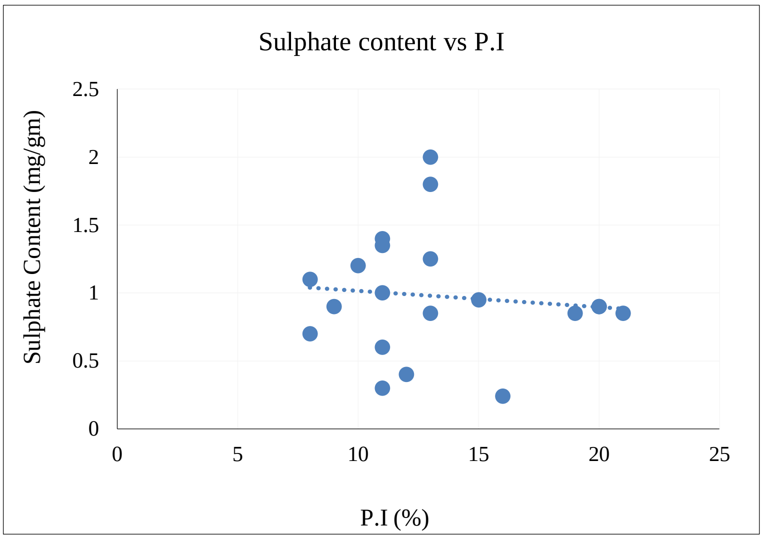

Figure 9. Relationship of Sulphate Content with Plasticity Index

5.1.9. Model-9: Correlation of PH with Liquid Limit

Figure 10 represents a graph, which shows a correlation between PH and liquid limit of soil samples. The mathematical relation between the two parameters is shown in Equation 9. It can be seen that the reliability factor R^2 obtained from this equation is only 0.0136. Following equation shows only linear equation other power, exponential and logarithmic equations are shown in Table 3.

$$PH = 0.0021(LL) + 7.6412 \quad R^2 = 0.0136 \tag{9}$$

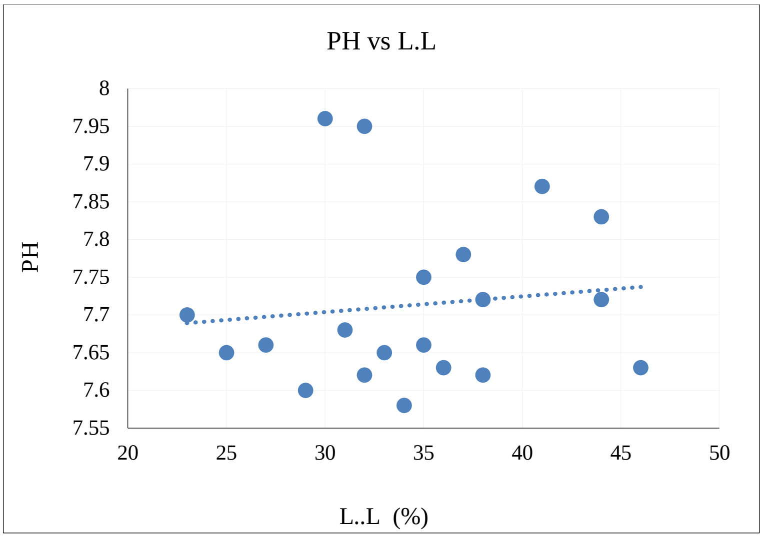

Figure 10. Relationship of PH with Liquid limit

5.1.10. Model-10: Correlation of PH with Plastic Limit

Figure 11 represents a graph, which shows a correlation between PH and Plastic limit of soil samples. The mathematical relation between the two parameters is shown in Equation 10. It can be seen that the reliability factor R^2 obtained from this equation is only 0.0099. Following equation shows only linear equation other power, exponential and logarithmic equations are shown in Table 3.

$$PH = -0.004(PL) + 7.7983 \quad R^2 = 0.0099 \tag{10}$$

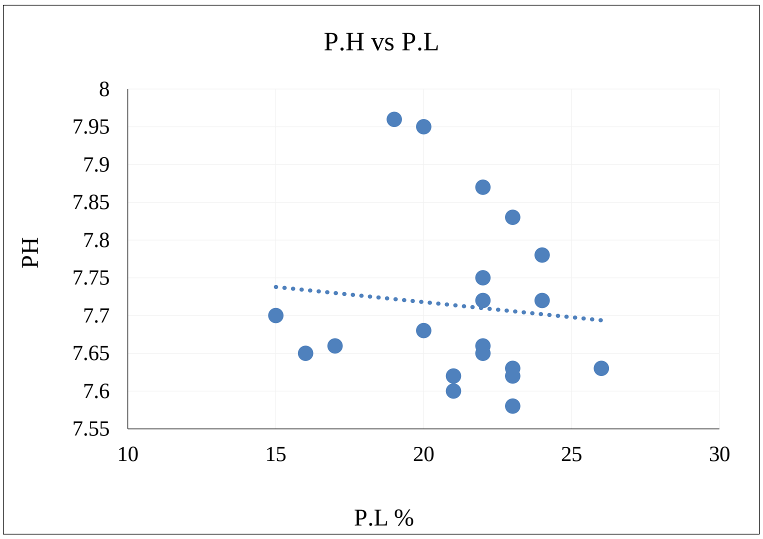

Figure 11. Relationship of PH with Plastic limit

5.1.11. Model-11: Correlation of PH with Plasticity Index

Figure 12 represents a graph, which shows a correlation between PH and Plasticity Index of soil samples. The mathematical relation between the two parameters is shown in Equation 11. It can be seen that the reliability factor R^2 obtained from this equation is only 0.0627. Following equation shows only linear equation other power, exponential and logarithmic equations are shown in Table 3.

$$PH = -0.007(PI) + 7.6205 \quad R^2 = 0.0627 \tag{11}$$

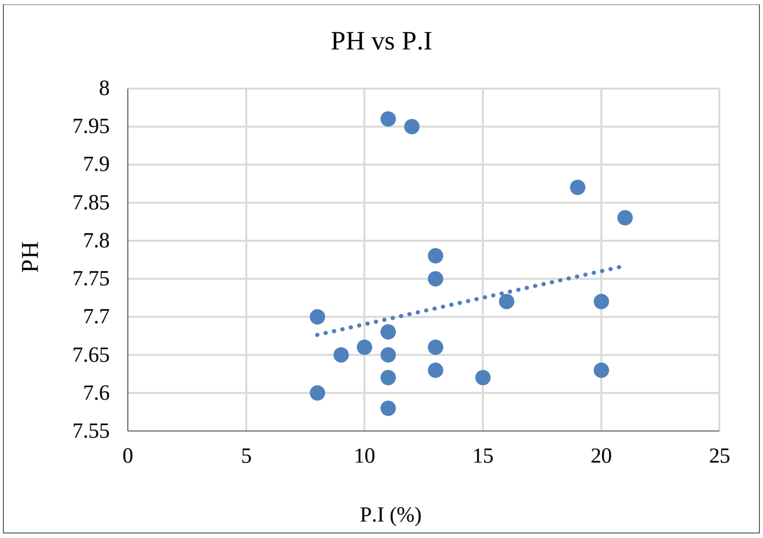

Figure 12. Relationship of PH with Plasticity Index

5.1.12. Model-12: Correlation of PH with % Finer Passing from #200 Sieve (% Finer)

Figure 13 represents a graph, which shows a correlation between PH and % Finer of soil samples. The mathematical relation between the two parameters is shown in Equation 12. It can be seen that the reliability factor R^2 obtained from this equation is only 0.0441. Following equation shows only linear equation other power, exponential and logarithmic equations are shown in table 3.

$$PH = - 0.0021(\% F) + 7.5313 \quad R^2 = 0.0441 \qquad (1۲)$$

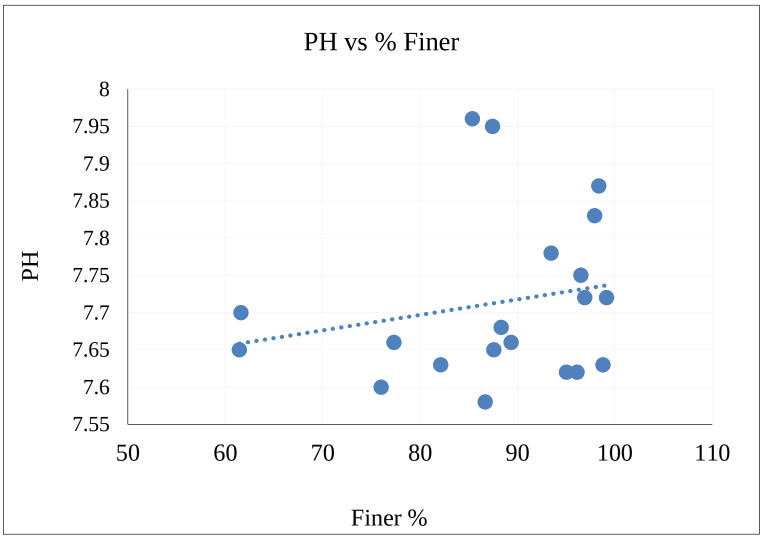

Figure 13. Relationship of PH with % Finer

5.1.13. Model-13: Correlation of E. Conductivity with Liquid Limit

Figure 14 represents a graph, which shows a correlation between E. conductivity and liquid limit of soil samples. The mathematical relation between the two parameters is shown in Equation 13. It can be seen that the reliability factor R^2 obtained from this equation is only 2E-05. From figure it can be seen that there are many regression lines because we have made linear, power, exponential and logarithmic equations. From figure it can be seen that there are many regression lines because we have made linear, power, exponential and logarithmic equations. Following equation shows only linear equation other power, exponential and logarithmic equations are shown in Table 3.

$$E. Conductivity = 0.0005(LL) + 1.8934 \quad R^2 = 2E\text{-}05 \qquad (13)$$

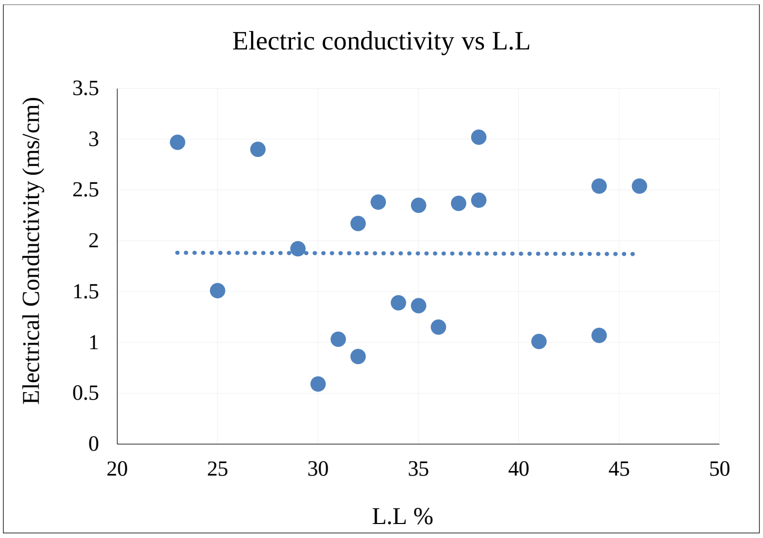

Figure 14. Relationship of E. Conductivity with Liquid limit

5.1.14. Model-14: Correlation of E. Conductivity with Plastic Limit

Figure 15 represents a graph, which shows a correlation between E. conductivity and Plastic limit of soil samples. The mathematical relation between the two parameters is shown in Equation 14. It can be seen that the reliability factor R^2 obtained from this equation is only 1E-05. From figure it can be seen that there are many regression lines because we have made linear, power, exponential and logarithmic equations. Following equation shows only linear equation other power, exponential and logarithmic equations are shown in Table 3.

$$\text{E. Conductivity} = 0.001(PL) + 1.855 \qquad R^2 = 1E\text{-}05 \tag{14}$$

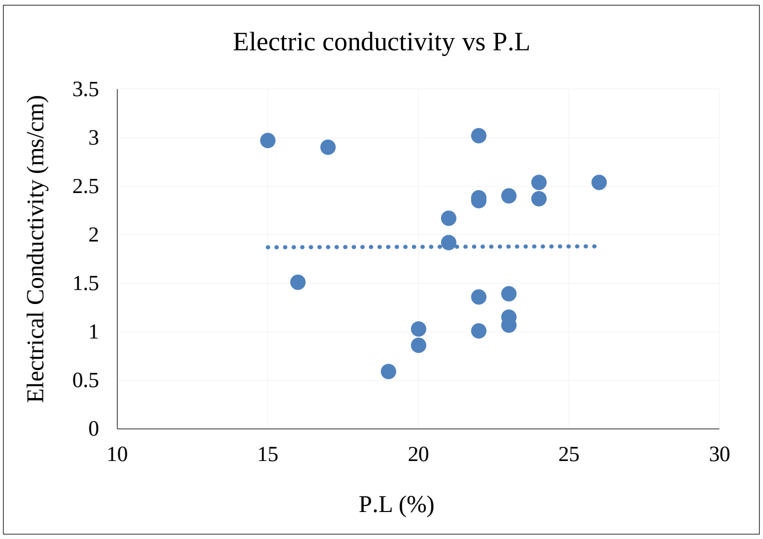

Figure 15. Relationship of E. Conductivity with Plastic limit

5.1.15. Model-15: Correlation of E. Conductivity with Plasticity Index

Figure 16 represents a graph, which shows a correlation between E. conductivity and Plasticity index of soil samples. The mathematical relation between the two parameters is shown in Equation 15. It can be seen that the reliability factor R^2 obtained from this equation is only 7E-05. From figure it can be seen that there are many regression lines because we have made linear, power, exponential and logarithmic equations. Following equation shows only linear equation other power, exponential and logarithmic equations are shown in Table 3.

$$\text{E. Conductivity} = -0.0017(PI) + 1.8987 \qquad R^2 = 7E\text{-}05 \tag{15}$$

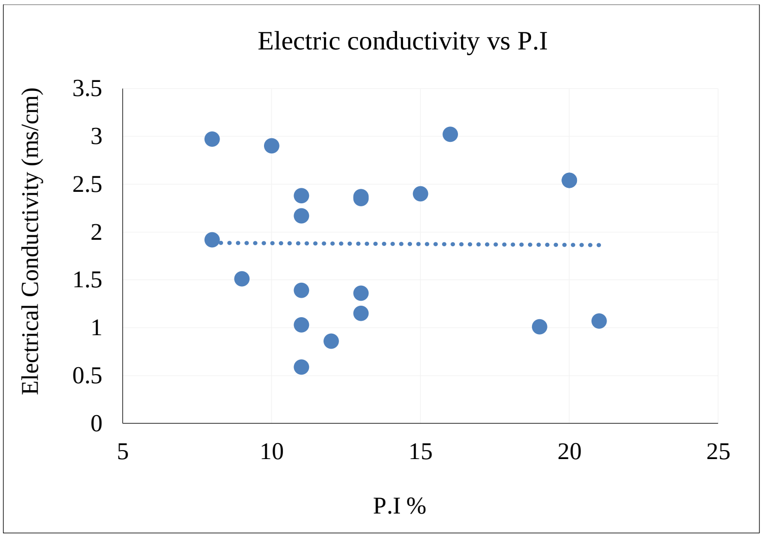

Figure 16. Relationship of Electric Conductivity with Plasticity Index

5.1.16. Model-16: Correlation of E. Conductivity with % Finer passing from # 200 Sieve (%F)

Figure 17 represents a graph, which shows a correlation between E. conductivity and % Finer of soil samples. The mathematical relation between the two parameters is shown in Equation 16. It can be seen that the reliability factor R^2 obtained from this equation is only 0.0032. From figure it can be seen that there are many regression lines because we have made linear, power, exponential and logarithmic equations. Following equation shows only linear equation other power, exponential and logarithmic equations are shown in Table 3.

$$\text{E. Conductivity} = -0.0039(\%\ F) + 2.2147 \qquad R^2 = 0.0032 \tag{16}$$

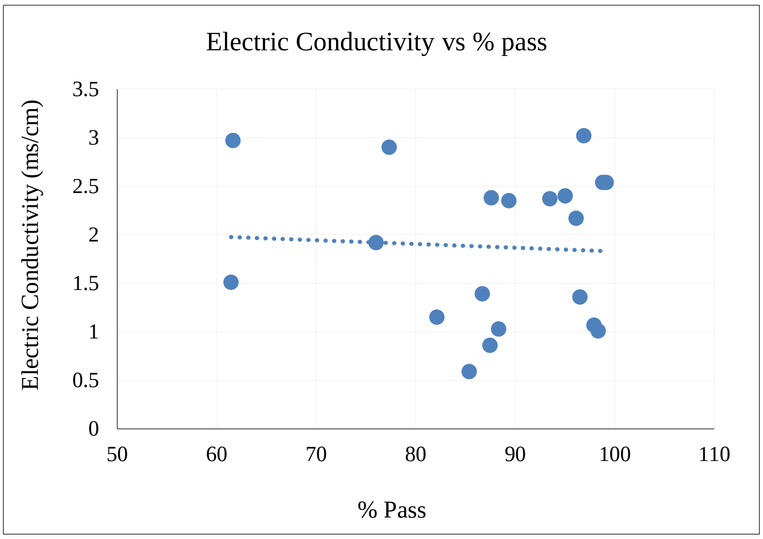

Figure 17. Relationship of Electric Conductivity with % Finer

5.1.17. Model-17: Correlation of Chloride Content with Liquid Limit

Figure 18 represents a graph, which shows a correlation between Chloride Content and Liquid limit of soil samples. The mathematical relation between the two parameters is shown in Equation 17. It can be seen that the reliability factor R^2 obtained from this equation is only 0.1436. From figure it can be seen that there are many regression lines because we have made linear, power, exponential and logarithmic equations. Following equation shows only linear equation other power, exponential and logarithmic equations are shown in Table 3.

$$\text{Chloride Content} = 0.167(LL) - 1.7334 \qquad R^2 = 0.1436 \tag{17}$$

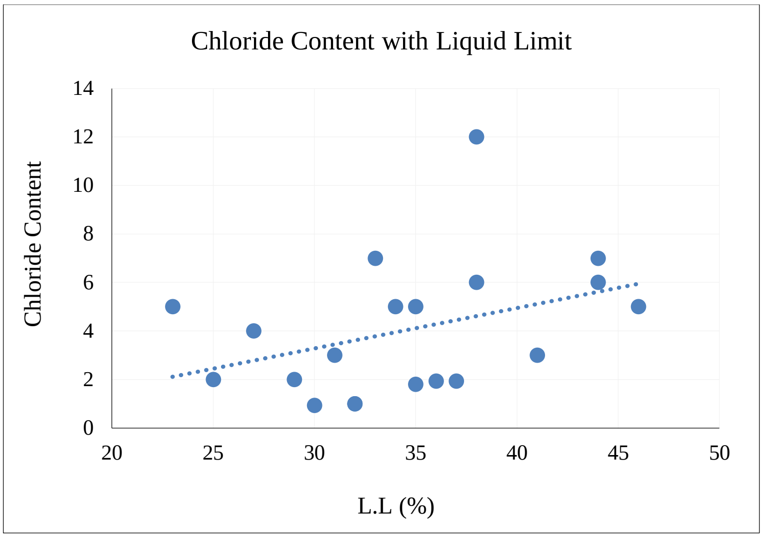

Figure 18. Relationship of Chloride Content with Liquid limit

5.1.18. Model-18: Correlation of Chloride Content with Plastic Limit

Figure 19 represents a graph, which shows a correlation between chloride content and Plastic limit of soil samples. The mathematical relation between the two parameters is shown in Equation 18. It can be seen that the reliability factor R^2 obtained from this equation is only 0.0629. From figure it can be seen that there are many regression lines because we have made linear, power, exponential and logarithmic equations. Following equation shows only linear equation other power, exponential and logarithmic equations are shown in Table 3.

$$\text{Chloride Content} = 0.25(PL) - 1.2832 \quad R^2 = 0.0629 \tag{18}$$

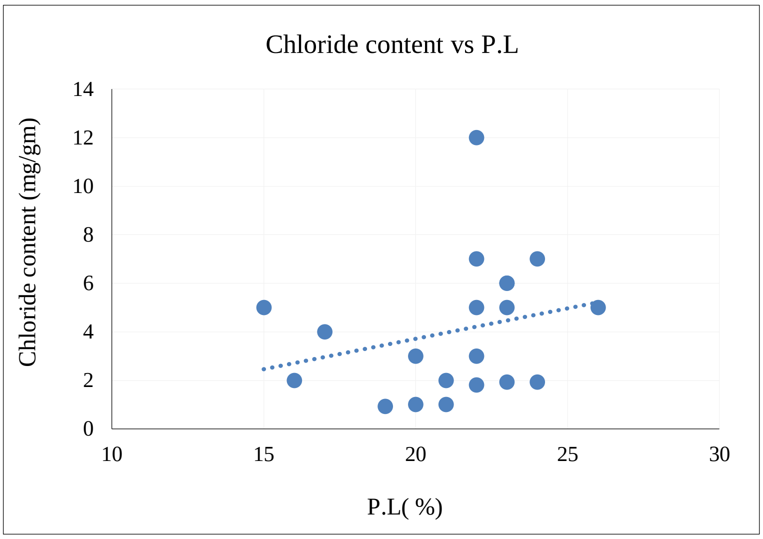

Figure 19. Relationship of Chloride Content with Plastic limit

5.1.19. Model-19: Correlation of Chloride Content with Plasticity Index

Figure 20 represents a graph, which shows a correlation between Chloride Content and Plasticity index of soil samples. The mathematical relation between the two parameters is shown in Equation 19. It can be seen that the reliability factor R^2 obtained from this equation is only 0.1749. From figure it can be seen that there are many regression lines because we have made linear, power, exponential and logarithmic equations. Following equation shows only linear equation other power, exponential and logarithmic equations are shown in Table 3.

$$\text{Chloride Content} = 0.2878(PI) + 0.2157 \quad R^2 = 0.1749 \tag{19}$$

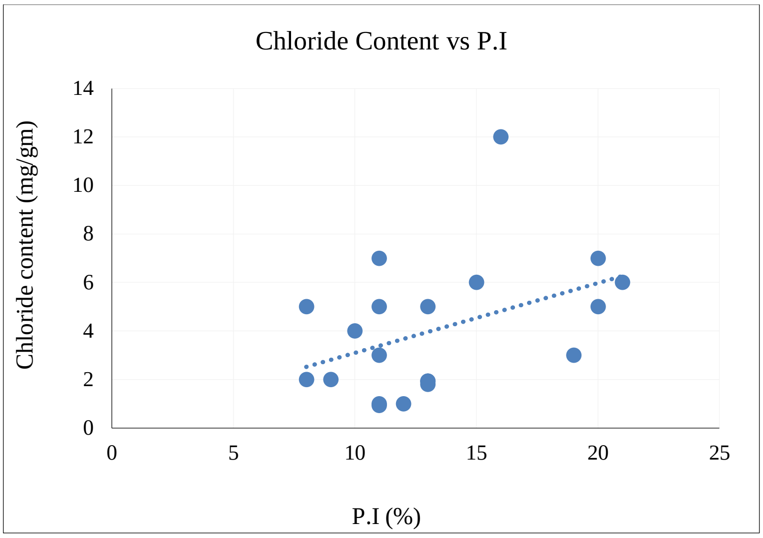

Figure 20. Relationship of Chloride Content with Plasticity Index

5.1.20. Model-20: Correlation of Chloride Content with % Finer passing from #200 sieve (%F)

Figure 21 represents a graph, which shows a correlation between Chloride Content and % Finer of soil samples. The mathematical relation between the two parameters is shown in Equation 20. It can be seen that the reliability factor R^2 obtained from this equation is only 0.1749. From figure it can be seen that there are many regression lines because we have made linear, power, exponential and logarithmic equations. Following equation shows only linear equation other power, exponential and logarithmic equations are shown in Table 3.

$$\text{Chloride Content} = 0.0637(\%\ F) - 1.5618 \quad R^2 = 0.1749 \tag{20}$$

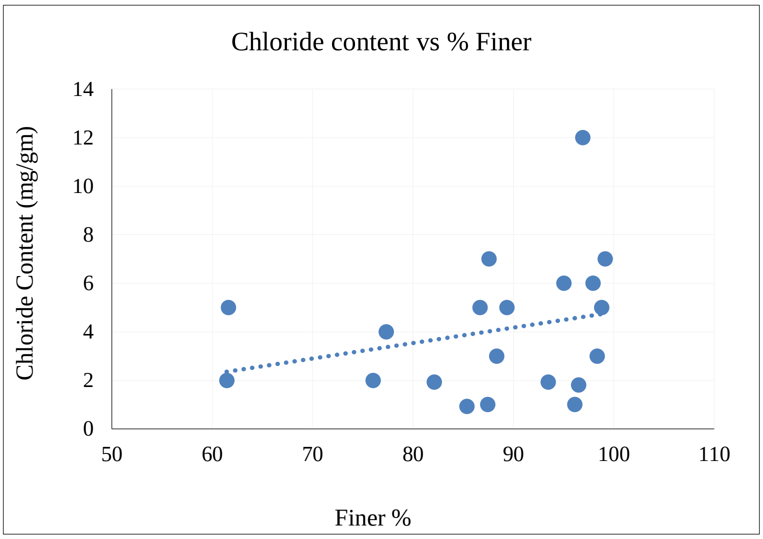

Figure 21. Relationship of Chloride Content with % Finer

5.2. Correlations by Multiple Linear Regression Analysis

This analysis has been performed by taking chemical property as function of more than one independent variables. Now, the equations which have been obtained through MLRA by adopting Microsoft Excel solution are given in Table 4 along with their model number. From the above developed MLRA models for chemical properties, based on the values of coefficient of determination (R2), it has been noted that Model -29 provides a better correlation with LL, PI and % Finer with value of R2 = 0.9886.

Table 3. Developed Correlations for Chemical Properties Values (SLRA)

Model No.	Correlation	Equation Type							
		Linear	Linear R^2	Logarithmic	R^2	Power	R^2	Exponential	R^2
1	Chloride vs. L.L	y = 0.167x - 1.7334	R^2 = 0.1436	y = 5.3221ln(x) - 14.73	R^2 = 0.128	$y = 0.025x^{1.3754}$	R^2 = 0.1222	$y = 0.6819e^{0.0447x}$	R^2 = 0.147
2	Chloride vs P.L	y = 0.25x - 1.2832	R^2 = 0.0629	y = 4.6328ln(x) - 10.089	R^2 = 0.0551	$y = 0.0834x^{1.1959}$	R^2 = 0.0524	$y = 0.7573e^{0.0677x}$	R^2 = 0.0659
3	Chloride vs P.I	y = 0.2878x + 0.2157	R^2 = 0.1749	y = 3.8504ln(x) - 5.7608	R^2 = 0.1659	$y = 0.2609x^{0.9845}$	R^2 = 0.155	$y = 1.1544e^{0.0767x}$	R^2 = 0.1775
4	Chloride vs % Finer	y = 0.0637x - 1.5618	R^2 = 0.0685	y = 4.7039ln(x) - 16.976	R^2 = 0.0587	$y = 0.0777x^{0.8318}$	R^2 = 0.0262	$y = 1.1392e^{0.0117x}$	R^2 = 0.0332
5	Organic vs L.L	**y = 0**.1582x + 0.0769	R^2 = 0.4198	y = 5.3001ln(x) - 13.149	R^2 = 0.4141	$y = 0.1651x^{0.9851}$	R^2 = 0.3779	$y = 1.9343e^{0.0293x}$	R^2 = 0.3809
6	Organic vs P.L	**y = 0**.3378x - 1.6457	R^2 = 0.3747	y = 6.5189ln(x) - 14.333	R^2 = 0.3557	$y = 0.137x^{1.2006}$	R^2 = 0.3188	$y = 1.4235e^{0.062x}$	R^2 = 0.3336
7	Organic vs P.I	y = 0.2243x + 2.5611	R^2 = 0.3466	y = 3.1799ln(x) - 2.5521	R^2 = 0.369	$y = 1.1726x^{0.5945}$	R^2 = 0.3409	$y = 3.0537e^{0.0419x}$	R^2 = 0.3188
8	Organic vs % Finer	y = 0.09x - 2.3611	R^2 = 0.4458	y = 6.8983ln(x) - 25.272	R^2 = 0.4119	$y = 0.0156x^{1.3055}$	R^2 = 0.3897	$y = 1.1904e^{0.0171x}$	R^2 = 0.4233
9	E.conductivity vs L.L	y = -0.0005x + 1.8934	R^2 = 2E-05	y = -0.158ln(x) + 2.4352	R^2 = 0.0014	$y = 1.7942x^{-0.015}$	R^2 = 3E-05	$y = 1.5943e^{0.0019x}$	R^2 = 0.0006
10	E.conductivity vs P.L	y = 0.001x + 1.855	R^2 = 1E-05	y = -0.19ln(x) + 2.4544	R^2 = 0.0012	$y = 1.2542x^{0.1}$	R^2 = 0.0009	$y = 1.331e^{0.0116x}$	R^2 = 0.0045
11	E.Conductivity vs P.I	y = -0.0017x + 1.8987	R^2 = 7E-05	y = -0.081ln(x) + 2.083	R^2 = 0.0009	$y = 1.9273x^{-0.049}$	R^2 = 0.0009	$y = 1.7221e^{-9E-04x}$	R^2 = 6E-05
12	E. Conductivity vs % pass	y = -0.0039x + 2.2147	R^2 = 0.0032	y = -0.417ln(x) + 3.7403	R^2 = 0.0058	$y = 4.5784x^{-0.222}$	R^2 = 0.0043	$y = 2.0069e^{-0.002x}$	R^2 = 0.002
13	PH vs L.L	y = 0.0021x + 7.6412	R^2 = 0.0136	y = 5.3001ln(x) - 13.149	R^2 = 0.0143	$y = 7.4616x^{0.0094}$	R^2 = 0.0146	$y = 7.6403e^{0.0003x}$	R^2 = 0.0139
14	PH vs P.L	y = -0.004x + 7.7983	R^2 = 0.0099	y = 6.5189ln(x) - 14.333	R^2 = 0.0062	$y = 7.9041x^{-0.008}$	R^2 = 0.0061	$y = 7.7971e^{-5E-04x}$	R^2 = 0.0098
15	PH vs P.I	y = 0.007x + 7.6205	R^2 = 0.0627	y = 3.1799ln(x) - 2.5521	R^2 = 0.0689	$y = 7.4605x^{0.0131}$	R^2 = 0.07	$y = 7.6201e^{0.0009x}$	R^2 = 0.0638
16	PH vs % Finer	y = 0.0021x + 7.5313	R^2 = 0.0441	y = 6.8983ln(x) - 25.272	R^2 = 0.0431	$y = 7.0187x^{0.0211}$	R^2 = 0.0434	$y = 7.533e^{0.0003x}$	R^2 = 0.0445
17	Sulphate vs L.L	y = 0.0037x + 0.8501	R^2 = 0.0027	y = -0.158ln(x) + 2.4352	R^2 = 0.0054	$y = 0.4484x^{0.1871}$	R^2 = 0.0041	$y = 0.7303e^{0.005x}$	R^2 = 0.0033
18	Sulphate vs P.L	y = 0.0439x + 0.0432	R^2 = 0.074	y = -0.19ln(x) + 2.4544	R^2 = 0.0696	$y = 0.0601x^{0.8757}$	R^2 = 0.0514	$y = 0.3182e^{0.0472x}$	R^2 = 0.0585
19	Sulphate vs P.I	y = -0.012x + 1.1358	R^2 = 0.0116	y = -0.081ln(x) + 2.083	R^2 = 0.0066	$y = 1.2367x^{-0.14}$	R^2 = 0.0057	$y = 0.9947e^{-0.01x}$	R^2 = 0.0059
20	Sulphate vs % Finer	y = 0.0043x + 0.5992	R^2 = 0.0119	y = -0.417ln(x) + 3.7403	R^2 = 0.0126	$y = 0.5464x^{0.1034}$	R^2 = 0.0007	$y = 0.7733e^{0.0013x}$	R^2 = 0.0008

Table 4. Developed Correlations for Chemical Properties Values (MLRA)

Model No.	Correlation / Model	R^2
1	Chloride = - 0.0015 (L.L) - 0.306 (P.I)	0.7453
2	Chloride = 0305 (L.L) - 0.306 (P.L)	0.7453
3	Chloride = - 0.250 (L.L) - 0.052 (%Pass)	0.7401
4	Organic = 0.129 (L.L) + 0.0498 (P.L)	0.9610
5	Organic = 0.179 (L.L) - 0.0498 (P.I)	0.9610
6	Organic = 0.088 (L.L) + 0.028 (%Pass)	0.9624
7	Electric Conductivity = - 0.0304 (L.L) + 0.136 (P.L)	0.84846
8	Electric Conductivity = 0.106 (L.L) - 0.136 (P.I)	0.84846
9	Electric Conductivity = -0.003 (L.L) + 0.0221 (%Pass)	0.84152
10	PH = - 0.097 (L.L) + 0.515 (P.L)	0.985
11	PH = 0.418 (L.L) - 0.515 (P.I)	0.985
12	PH = -0.077 (L.L) + 0.117 (%Pass)	0.98602
13	Sulphate = - 0.057 (L.L) + 0.139 (P.L)	0.8717
14	Sulphate = 0.0818 (L.L) - 0.139 (P.I)	0.8717
15	Sulphate = - 0.016 (L.L) + 0.0173 (%Pass)	0.83346
16	Chloride= - 0.0015 (L.L) + 0.306 (P.I)	0.74539
17	Chloride= - 0.314 (L.L) - 0.263 (P.L) - 0.0142 (%Pass)	0.74573
18	Organic = 0.179 (L.L) - 0.049 (P.I)	0.96103
19	Organic = 0.104 (L.L) - 0.063 (P.L) + 0.0377 (%Pass)	0.96272
20	E. Conductivity= - 0.0333 (L.L) + 0.124 (P.L) + 0.004 (%Pass)	0.84862
21	E. Conductivity= 0.106 (L.L) - 0.136 (P.I)	0.84846
22	PH= 0.418 (L.L) - 0.515 (P.I)	0.985
23	PH = - 0.148 (L.L) + 0.290 (P.L) + 0.075 (%pass)	0.98869
24	Sulphate content = - 0.081 (L.L) - 0.139 (P.I)	0.8717
25	Chloride= 0.0508 (L.L) + 0.263 (P.I) - 0.014 (%pass)	0.74573
26	Sulphate content= - 0.053 (L.L) + 0.154 (P.L) - 0.005 (%Pass)	0.87255
27	Organic content = 0.040 (L.L) + 0.063 (P.I) + 0.0377 (%pass)	0.96272
28	E. Conductivity = 0.0908 (L.L) - 0.124 (P.I) + 0.004 (%pass)	0.84862
29	PH = 0.141 (L.L) - 0.290 (P.I) + 0.075 (%pass)	0.98869
30	Sulphate content = 0.10 (L.L) - 0.154 (P.I) - 0.005 (%pass)	0.87255

6. Conclusions

From the results of the research, the following conclusions can be drawn:

- The characteristics of soils such as moisture content were very important in order to classify the type of soil that represent the sample. Table 1 and 2 shows the summary of test results for all sample tested. According to the table moisture content ranges from 2.08% to 30.57%, Liquid limit between 23 to 46% and plasticity index value ranges from 8 to 21%.
- This paper has represented Regression equations for the estimation of chemical properties from index properties.
- Based on the above laboratory results, no any reliable SLRA relationship exists for predicting chemical properties value from index properties.
- The highest coefficient of determination obtained from organic content VS liquid limit is 0.4198.
- The correlation of PH with L.L, P.I and % Finer by utilizing MLRA approach gives a good relationship with R^2 = 0.9886 which is PH = 0.141(L.L) – 0.290(P.I) +0.075 (% F).
- The correlation of organic content with L.L, P.L and % Finer by utilizing MLRA approach gives a good relationship with R^2 = 0.96272 which is Organic content = 0.104 (L.L) – 0.063 (P.L) + 0.0377 (% F).
- In light of the above, in case of MLRA a combination of soil index properties correlates better with chemical property than individual soil properties.
- Relatively an improved correlation than the SLRA is obtained when MLRA is used.

7. Acknowledgement

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8. Conflicts of Interest

The authors declare no conflict of interest.

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