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Physico-chemical Properties of Expansive Soils from Sudan and their Effects on Intrinsic Swelling and Shrinkage

Ahmed M Elsharief [1] and Suhad E. Moustafa [2]

[1] *Associate Professor, Building and Road Research Institute, University of Khartoum, Sudan (Email: aelsharief@yahoo.com)*
[2] *Senior Engineer, Civil aviation Authority, Sudan*

Abstract: Intrinsic swelling was evaluated for seventeen potentially expansive clay samples obtained from different parts of Sudan. A swell percent test, where the test samples were statically compacted at air dry temperature to the same dry density (1.35 g/cm3) and allowed to swell was used as a measure for intrinsic swelling. Physico-chemical properties were measured for all the samples to assess the effect of these properties on intrinsic swelling. The physical properties included, gradation (clay, silt and sand contents), Atterberg limits (LL, PL and SL), linear shrinkage and free swell whereas the chemical properties included cation exchange capacity CEC, exchangeable sodium percent ESP and sodium absorption ratio SAR. The investigation has shown that intrinsic expansiveness is well related to linear shrinkage and that linear shrinkage alone is a good candidate for assessing both the swelling and shrinkage potential of clay soils. However, clay activity is found to be a poor indicator of intrinsic expansiveness if the well known evaluation standards are adopted. Intrinsic expansiveness is well related to LL, PI and SI and these parameters could be used for its assessment. The CEC showed poor relationship whereas ESP and SAR showed no relationship with intrinsic expansiveness.

Keywords: *Swelling Soils; Intrinsic Swelling; Lineal Shrinkage; Free Swell; Physico-chemical Properties.*

1. INTRODUCTION

Large areas of Sudan and Southern Sudan are known to be covered by potentially expansive clay soils. These areas include the area between the White Nile and Blue Nile (central clay plains), east of the Blue Nile towards the boundaries with Ethiopia and Eriteria (eastern clay plains) and in eastern part of South Sudan, Swelling soils are also found in scattered areas north and west of the country (Figure 1). Most of the development projects in Sudan are found in the areas covered with expansive soils and serious damages to important structures were caused by these soils [1].

The swelling phenomenon is known to be a function of two basic variables; the intrinsic soil properties and the placement and environmental factors. The intrinsic soil properties are those related to the mineralogical composition of the clay fraction, soil gradation and its pore water chemistry. The placement factors are the density, water content and loading, whereas the environmental factors are related to the increase or loss of water. Intrinsic swelling therefore is the inherent expansiveness resulting from the intrinsic properties of a soil. The potential of a soil for swelling is caused by combination of the intrinsic soil properties and its placement and environmental conditions. An intrinsically high potential expansive soil would not swell if it is found below the ground water level, is fully saturated or subjected to loads greater than or equal to its swelling pressure.

Several researches over the past six or seven decades were carried out to classify expansive soils based on their potential for swelling. However, there is no a unified or universal method for their classification. The reader may refer to the proceedings of the international conferences on expansive / unsaturated soils. Schriener and Habte [2] presented a method which they consider as universal for assessing the intrinsic expansiveness of a soil. One dimensional swelling and unconfined shrinkage were measured for soil samples of identical stress history and stable micro-fabric. Three models based on combination of index tests were reported for prediction of the intrinsic swell potential. It was found that intrinsic expansiveness can be obtained based on liquid and plastic limit tests and hydrometer analysis test results (i.e. clay content).

Extensive research on swelling soils was carried out in Sudan since early 1970's mainly focusing on the swelling potential and foundation alternatives on these soils [3]. Efforts were made to identify the factors affecting the potential of soils to swelling. Few researches were carried out on the distribution and properties of swelling soils in Sudan [4] [5]. Important aspects in dealing with expansive soils are their identification and classification by simple and practically applicable methods. In practice, physical soil properties are often used by engineers for the identification and classification of expansive soils.

This paper summarizes the data gained on the physico-chemical properties of the swelling soils of the vast clay plains of Sudan and attempts to relate these properties to their intrinsic swelling potential. A simple test was suggested for quantifying intrinsic swelling.

2. Intrinsic Swelling Test

The studied samples have been obtained from different areas within the central, eastern and southern clay plains of Sudan. They are of different origin, formed or deposited in different environments and found in differing climatic conditions. To compare the intrinsic expansiveness of these soils the tested samples should have initially the same dry unit mass and the same reference initial water content and subjected to the same loading conditions. This reference water content is chosen here to be equal to the air dry water content. The air dry water content is the lowest moisture content under natural conditions since the soil was allowed to dry in the laboratory for more than one week. The intrinsic expansiveness was therefore measured by statically compacting the air-dried soil samples to the same dry density (1.35 gram/cm^3 was used) in an oedometer ring and cell which allow one dimensional swelling. The compacted sample was covered with a light plastic cap, i.e. subjected to negligible load, and distilled water was added. It was left to swell until the vertical swelling practically ceased. The swell percent SW% is the vertical swelling divided by the original height and multiplied by 100. Contribution to swelling could therefore be attributed to the mass constituents of the statically compacted samples rather than the environmental and placement factors; consequently the measured swell percent (SW%) is considered as an expression of the intrinsic soil swelling potential. The swell percent (SW) test results are given in Table 1.

3. The Physical Soil Properties

Seventeen soil samples were collected from various locations in the clay plains of Sudan and tested for the following: Liquid Limit (L.L), Plastic Limit (P.L), Shrinkage Limit (S.L) and grain size analysis and hydrometer tests. Two simple tests namely the free swell (F.S) and linear shrinkage (L.S), often performed in the laboratory to assess the swelling and shrinkage potentials, were also performed on the samples. The free swell test consisted of placing a known volume of oven dried soil passing No. 40 sieve into a granulated cylinder filled with distilled water and measuring the swelled volume after the soil has completely settled. The free swell is the ratio of the change in volume to the initial volume expressed as percentage. All the tests were carried out following British Standards procedures (B.S. 1377-1990). The test results are summarized in Table 1. The plasticity index PI, shrinkage index SI (L.L-S.L) and activity AC (PI/C%) were computed from the tests data and reported in Table 1. Mineralogical examination on samples from the clay plains of Sudan has shown that the dominant clay mineral is montmorillonite. Kaolinite, illite and chlorite were also present [6].

4. The Chemical Soil Properties

The chemical tests were performed in the Agricultural Research Center of Sudan in Wadmedani. The Cation Exchange Capacity (CEC), Sodium Absorption Ratio (SAR), Exchangeable Sodium Percent (ESP) and Electrical Conductivity (EC) were determined for the 17 samples. The results are presented in Table 2. The given properties are known to govern the aggregation, chemistry and moisture potential of clay soils [7]. Salinity and sodicity are measured by the electrical conductivity ECe expressed in decisiemens per meter (dS m^{-1}) of the extract of the saturated soil paste. Typical values for Sudanese soils are less than 20 dS m^{-1} [8].

5. Analysis and Discussion

Tables 1 shows the measured physical soil properties of interest. It shows that the tested samples are highly plastic CH silty or sandy silty clays except for two soils (soils listed 8 and 9) which are low plastic. The plasticity index is greater than 30 whereas the liquid limit is greater than 60 for the CH soils. The clay content varies between 20 and 60% and the sand content is generally less than 20%. The shrinkage limit is generally less than 10% . The variation in the free swell values is more noticed than the variation in the linear shrinkage values which cover relatively narrow range.

The chemical test results (Table 2) show the presence of dissolved salts (cations) in the pore water as depicted by the ESP and SAR results. The electrical conductivity which is an indirect measure of salinity/sodicity of the tested soil indicates low salinity for almost all the samples except soils 3 dS m^{-1} and 11 dS m^{-1}. The ESP values show large variation (5% to 186%). The cation exchange capacity CEC ranges between about 20 meq./gram to 67 meq./gram. The soil from Fao (Soil 1 in list) measured the highest CEC value and is known to be highly expansive and to cause severe damages to structures founded on it.

The swell percent (SW) is considered here as reliable comparative measure of the intrinsic swelling of the tested soils since the initial moisture and density conditions for the test are kept the same. The measured values of SW range between19% to 60%. Intrinsic swelling potential (SW%) is related to several index and physical soil properties namely liquid limit LL, plasticity index PI, shrinkage index SI, sand content S% and clay content C% (Figures 5 to 9). Good linear relationship was found between SW and LL, PI and SI. The latter gave the best linear relationship. Based on the relationships obtained, the given index parameters may be equally used for the assessment of intrinsic swelling. The sand content or amount of sand seems to affect intrinsic swelling. Figure 8 shows a remarkable trend of decrease in

SW with increase in sand content although the samples were obtained from different sources. This shows that the sand content is essentially important in controlling swelling. Figure 9 shows poor relationship between SW and clay content. This shows that the clay content alone is not usable for assessing the intrinsic swell potential; this may be due to the mixed mineral constituents of the clay fraction of the tested soils. The above findings suggest the use of any of the index tests (L.L, PI and SI) for assessing the swell potential of swelling clays from Sudan.

The Swell Percent is related to the activity (AC) which is the ratio of plasticity index to the percentage clay fraction (see Figure 10). The figure does not show any relationship between SW and AC. According to Nelson and Miller [7] in-active clays have AC values less than 0.75, whereas normal clays have AC values between 0.75 and 1.25 and active clays have AC values higher than 1.25. The measured AC values for the tested samples range between 0.56 and 1.8 and most of the samples are rated as having normal activity and few are in-active. Relating the measured values of activity to the reported damages from sites in the study areas, the reported activity measure [7] is not considered hers as a good indicator for assessment of the swelling potential of soils from Sudan. For example the sample from Malakal is rated as in-active (AC = 0.56), although the same soil has caused extensive damages to the airport runway and several buildings in the town. The sites with normal activity ratings (e.g. Al Fao, Al Manshia) have records of severe damages to many structures erected on them.

Swell percent was plotted against cation exchange capacity CEC, Sodium absorption ratio SAR and exchangeable sodium percent ESP (Figures 11, 12 and 13). Poor relationship is noticed between SW and CEC whereas there is no noticeable relationship between SW and SAR and/or ESP. The cation exchange capacity is known to have relationship with the clay activity [7] and therefore could affect intrinsic swelling. It is clear from this investigation that none of the mentioned chemical pore water properties seem to have, individually, direct link with intrinsic swelling.

5.1 Alternative Assessment of Intrinsic Swelling Potential

The free swell and linear shrinkage are simple tests to perform and may be attempted for assessment of the swelling potential of soils. They are carried on samples which have been crushed and oven dried. The swell percent is related to the linear shrinkage (L.S) and free swell (F.S) as shown in Figures 2 and Figure 3 in an attempt to evaluate the two test parameters as alternative indicators of the intrinsic swell and shrinkage potentials. Figure 2 shows good agreement or relationship between SW and L.S whereas Figure 3 shows fair to poor relationship between SW and F.S. This is an indication that L.S, although it is a shrinkage test, is superior to F.S for assessing the intrinsic swelling potential of the soils obtained from the vast clay plains of Sudan. The free swell is rather a sedimentation test and results may be affected by the presence of sand and silt in the soils. More research may be needed to assess the L.S as an indirect indicator of intrinsic swell potential. It is interesting to note that L.S has good relationship with PI (Figure 4) for the tested soils. Similar finding was reported for Sudanese soils by Omer [5].

6. Conclusions

This paper presented the results of a research aimed at studying the effect of physico-chemical soil properties on the intrinsic swelling and shrinkage potential of clay soils from the vast clay plains of Sudan. Seventeen soil samples were collected from different parts of the country covering different climatic conditions. An intrinsic swell parameter was deduced from a swell percent test in the oedometer cell. In this test, air dried clay samples were statically compacted to the same dry unit mass (1.35 g/cm), covered with a light plastic cover, submerged with distilled water and allowed to swell until the swelling practically ceased. The percent swell (SW%) based on the original sample height was considered as a comparative measure of intrinsic swelling. Mineralogical examination of the samples was done using the X-ray diffraction technique. The physical, index and chemical properties which are thought to affect swelling were measured. The measured physical properties included grain size analysis (sand, silt and clay contents), Atterberg limits, linear shrinkage and free swell whereas the chemical properties included cation exchange capacity, sodium absorption ratio and exchangeable sodium percent.

The results obtained from the above investigation were analyzed to find out the parameters which affect intrinsic swelling. It was found that the linear shrinkage test correlates very well with the swell percent and could be used for assessing intrinsic expansiveness. The plasticity index, liquid limit and shrinkage index have good correlation with swell percent and may equally be used for assessing intrinsic swelling. Activity, which is well known as a good indicator of swell potential, failed to correlate with swell percent. The investigated chemical properties of the pore water (CEC, SAR and ESP) showed poor or no correlation with the intrinsic swell parameter SW.

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Figure (1). Samples location

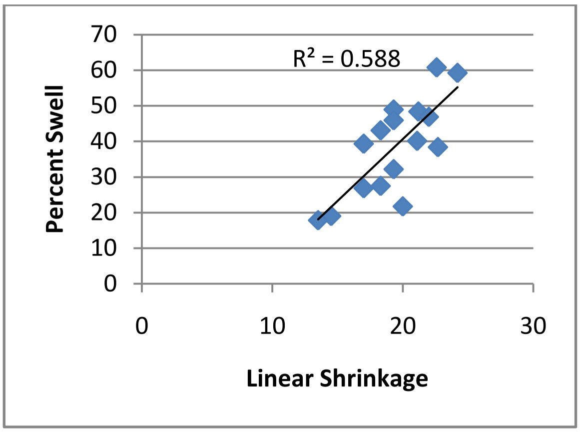

Figure (2). Swell Percent versus L.S

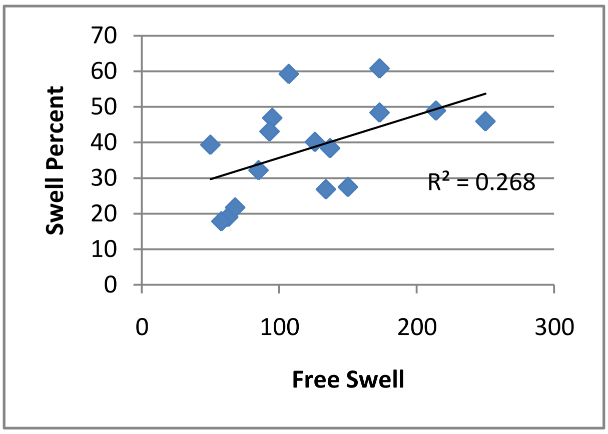

Figure (3). Swell Percent versus F.S

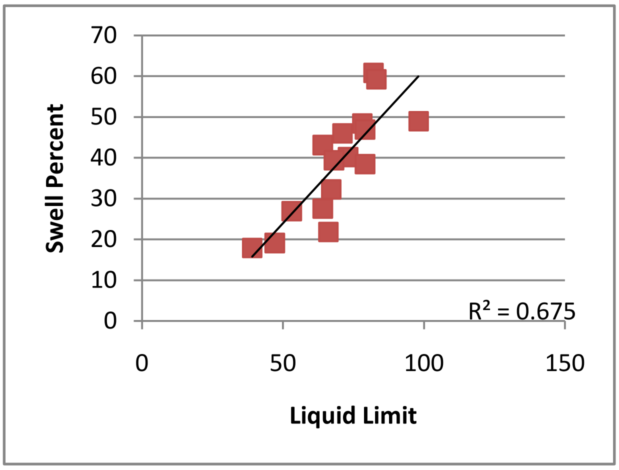

Figure (4). Linear Shrinkage versus L.L

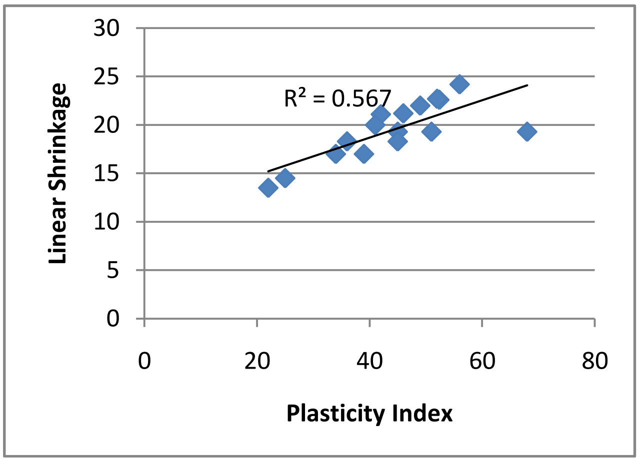

Figure (5). Linear Shrinkage versus P.I

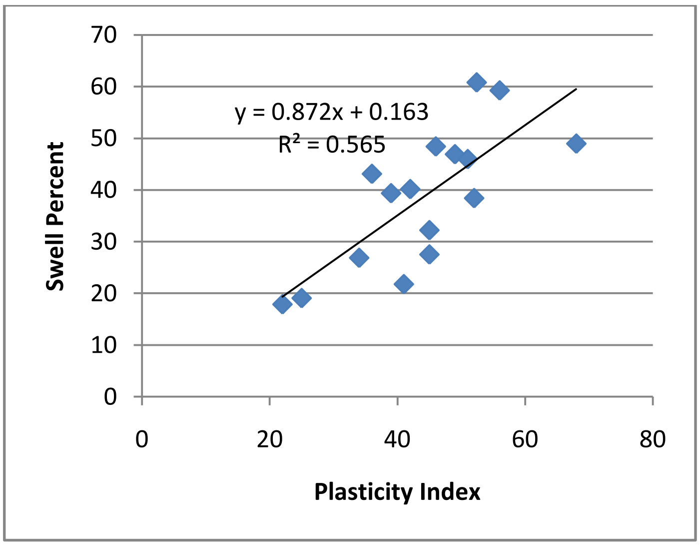

Figure (6). Swell Percent versus P.I

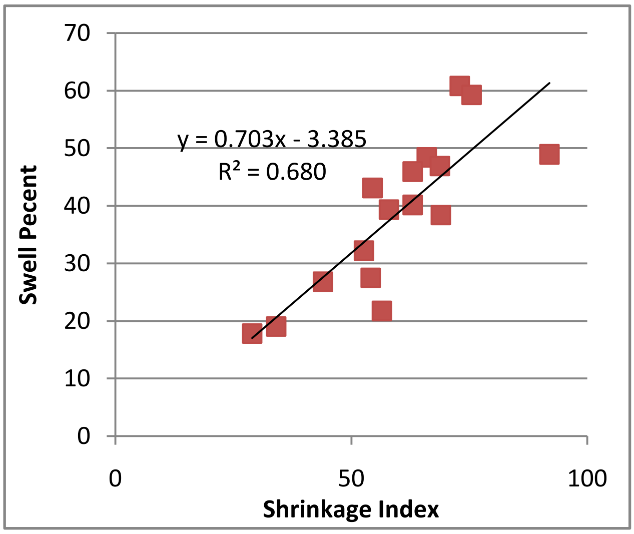

Figure (7). Swell Percent versus S.I

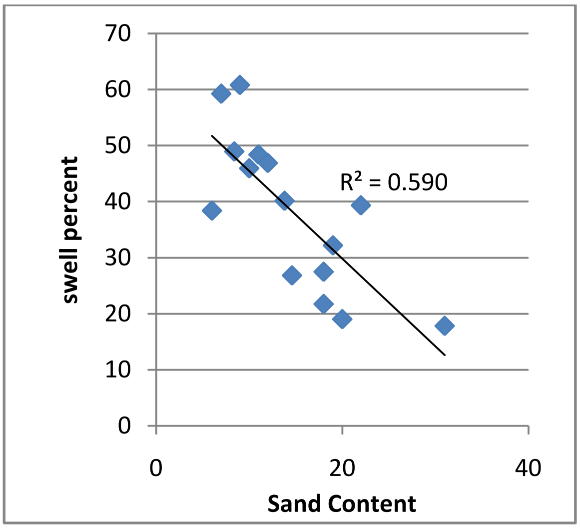

Figure (8). Swell Percent versus Sand Content

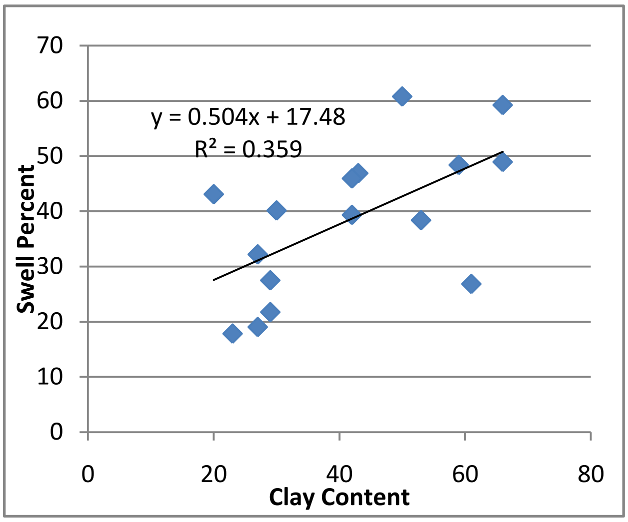

Figure (9). Swell Percent versus Clay Content

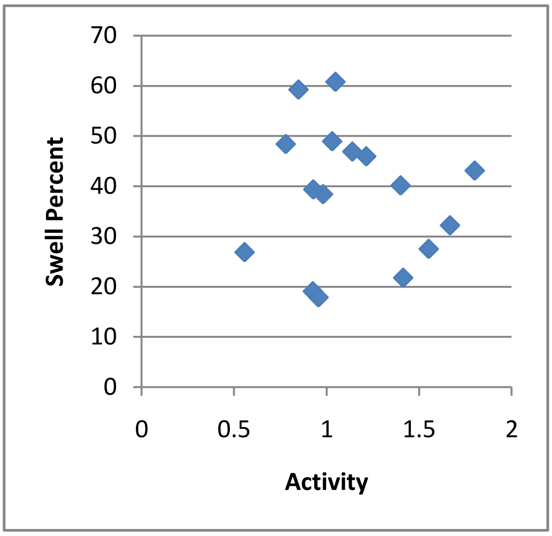

Figure (10). Swell Percent versus Activity

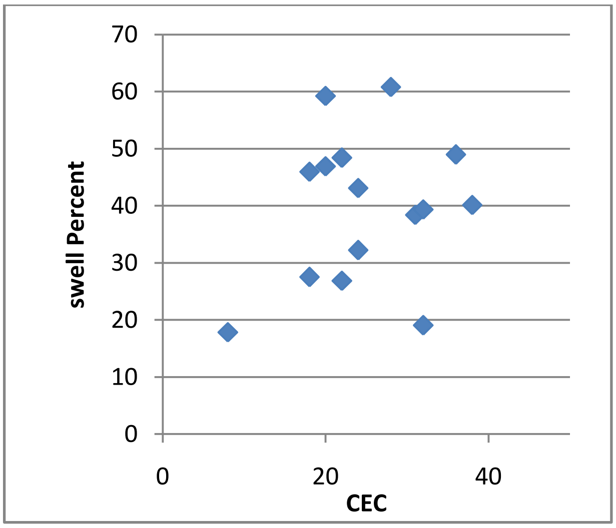

Figure (11). Swell Percent versus CEC

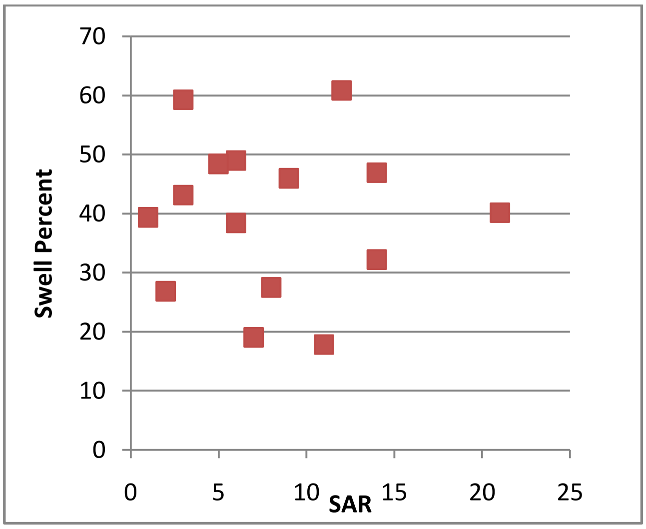

Figure (12). Swell Percent versus SAR

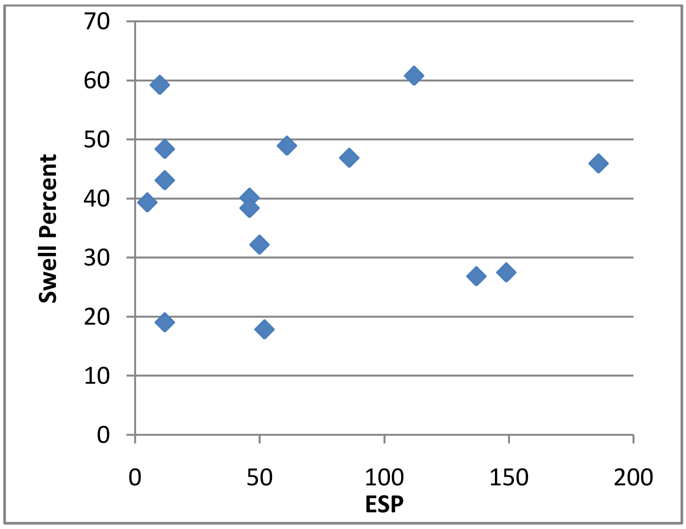

Figure (13). Swell Percent versus ESP

Sample Number	Sample Location	F.S	L.S	L.L	P.I	S.L	C%	S%	M%	SW	SI	AC
1	Al Fao		20	70	41	8.5	45	12	43		61.5	0.91
2	Manshia	173	22.6	82	52.4	9	50	9	31	60.8	73	1.05
3	Nisheshiba	126	21.1	73	42	10	30	13.8	56.2	40.2	63	1.4
4	White Nile1	214	19.3	98	68	6	66	8.4	25.6	49	92	1.03
5	Dinder-Sinja	137	22.7	79	52	10	53	6	41	38.4	69	0.98
6	Malkal	134	17	53	34	9	61	14.6	24.4	27	44	0.56
7	Bahary	173	21.2	78	46	12	59	11	30	48.4	66	0.78
8	Omdorman	63	14.5	47	25	12.9	27	20	53	19	34.1	0.93
9	Kosti	58	13.5	39	22	10	23	31	46	17.9	29	0.96
10	Altor	107	24.2	83	56	7.5	66	7	27	59.3	75.5	0.85
11	Wad Madani	85	19.3	67	45	14.3	27	19	54	32.2	52.7	1.67
12	Al Soki	95	22	79	49	10.2	43	12	45	47	68.8	1.14
13	Unity State	68	20	66	41	9.5	29	18	53	21.8	56.5	1.41
14	Gadarif	93	18.3	64	36	9.5	20	59	21	43.1	54.5	1.8
15	Khartoum Air Port	150	18.3	64	45	9.9	29	18	53	27.5	54.1	1.55
16	White Nile2	250	19.3	71	51	8	42	10	48	46	63	1.21
17	Damazeen	50	17	68	39	10	42	22	35.2	39.4	58	0.93

Table(1). physical Soil Properties

Table (2). Chemical Soil Properties

Sample Number	Sample Location	AC %	Ec	SAR	CEC	ESP
1	Al Fao	0.911	0.5	3	67	7
2	Manshia	1.05	1.6	12	28	112
3	Nisheshiba	1.42	7.4	21	38	46
4	White Nile1	1.02	1.1	6	36	61
5	Dinder-Sinja	0.99	0.88	6	31	46
6	Malkal	0.56	0.46	2	22	137
7	Bahary	0.78	1	5	22	12
8	Omdorman	0.94	1.3	7	32	12
9	Kosti	0.95	2.8	11	8	52
10	Altor	0.85	0.5	3	20	10
11	Wad Madani	1.66	5	14	24	50
12	Al Soki	1.13	2.2	14	20	86
13	Unity State	1.43	-	-	-	-
14	Gadarif	1.8	1.9	3	24	12
15	Khartoum Air Port	1.53	1.3	8	18	149
16	White Nile2	1.21	1.6	9	18	186
17	Damazeen	0.93	0.38	1	32	5