Original Research Article

Geotechnical investigation using Engineering Geological and Mapping techniques in the Niger Delta Sub-region, Nigeria

ABSTRACT

Aim: The study was carried out with the purpose of producing an engineering geological parameters for development planning and control.

Study Design: The study was designed to use the various parameter values to produce Iso-contour maps using Surfer II Computer software.

Place and Duration of Study: The research was conducted in two locations along the Borokiri axis of Port Harcourt (the eastern Niger Delta) between February and June 2020.

Method: The study involved both field sampling and laboratory analysis using boring, particle analysis, Oedometer and triaxial tests. In-situ field results were integrated in laboratory analysis.

Results: The strength parameter revealed that clays are very cohesive (38 kPa to 90 kPa), with friction angles ranging between 4 and 5, and settlement values ranging between 18 mm and 84 mm.

Conclusion: The various engineering parameters converted into iso-contour maps are useful for reconnaissance studies as they give a regional view of an area, which is excellent for development planning.

Keywords: Engineering geological mapping, bearing capacity, settlement, development planning.

Introduction

The Niger Delta is a vast geographical area spanning about 36260 cm^2 which is about 4% of Nigeria, and is presumed to be the third largest delta in the world [1]. The Niger Delta, due to its environmental and metro-hydrological processes, faces some environmental and geological challenges. Among the challenges identified by various authors are uneven subsoil settlement, an abundance of organic and highly compressible clays, poor drainage systems, erosion, and flooding [4] [1] [13] [12].

These problems are highly complicated and connected to other problems in the area, such as environmental sustainability, poverty, climate change, portable water availability, and infrastructural development, among others. These problems, coupled with the lack of scientific data on the superficial soil for development planning and control, have in various ways hampered or threatened the development of the Niger delta, especially infrastructural development, which is a key to industrial and economic development [3]. The Global Competitive Index 2017-2018 listed underdeveloped infrastructure as the most problematic factor for doing business in Nigeria.

Much has not been done, by various bodies, to address the problems that may be attributed to its complexity and the enormous cost involved. The efforts of individuals and organizations could not yield the required results because their efforts were based on isolated cases geared toward the development of personal estates. There is therefore a need for a holistic and integrated approach to solving the environmental and geologic problems in the Niger Delta. Engineering geological mapping comes into play here.

Engineering geology is the application of geological sciences in engineering practice for the purpose of ensuring that the geologic factors affecting the location, design, construction, operation, and maintenance of engineering works are recognized and adequately provided for [6].

The International Association of Engineering Geology and the Environment defines engineering geology as:

> *"Engineering Geology is the science diverted to the investigation, study and solution of engineering and environmental problems which may arise as a result of the interaction geology and the works or activities of man, as well as the prediction and development of measures for the prevention on remediation of geological hazards"*[11].

There has been a new focus on applying geologic knowledge and skills to broad-ranging engineering, environmental, and socio-economic issues, which requires integrated earth-science knowledge [4]. The traditional examination of separate, independent components must be replaced with the idea of an integrated, holistic approach. This concept emphasizes interactions and linkages rather than components and trends, rather than engineering geological mapping, and provides a new paradigm shift toward an integrated and holistic approach to solving geological and environmental problems. It emphasizes interactions, linkages, and trends.

For proper understanding of the environmental and geological problems in the Niger Delta, a detailed engineering and geological mapping of the superficial soils of the Niger Delta becomes necessary. This has been emphasized by [4][2].

The aim of this study was to prepare a set of engineering geological parameter maps primarily to guide decision-making in environmental developmental planning, control, and management. It involved a detailed soil investigation in accordance with approved scientific standards.

Mapping is very important in synthesizing field data in engineering geology, especially subsurface geotechnical investigations. With the application of GIS, engineering geological mapping for environmental management and planning has become more common. GIS has become a handy tool in the preparation of more accurate and detailed maps for engineering and geoscience planning. [6][10]. Literature on the subject [8] [7][11].

1.1 Study Location

The study was carried out in South-East part of Port Harcourt, Rivers State, Nigeria in the Southern Niger Delta. Its environment, geology, climate and hydrogeology are as of the Niger Delta.

Geographically, the study location is between latitude 4.43.1N and 4.46.8N of the Equator and Longitude 7.15.9E and 7.17.3E of the Meridian. The site is a mangrove tidal flat with the Bonny River as shore-line. The Niger Delta has a cris-cross of rivers pall emptying into the Atlantic Ocean with several morphological units such as meander belt, coastal plain sentiments beaches, fresh water swamp deposits, mangrove swamp among others [2][5]. The area has two districts climatic season the raining season from April to October and the dry season from November to March. The annual mean rainfall is very high, averaging 4000mm [11].

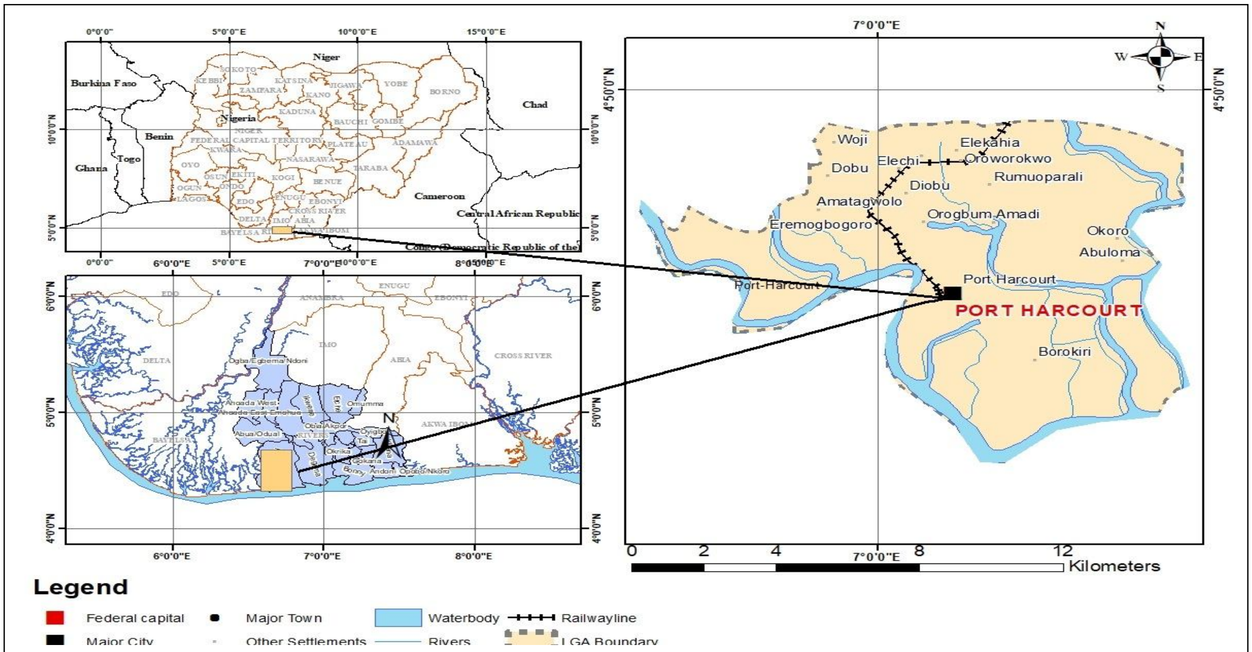

Figure 1: Location Map of the Study Area

2.0 Materials and Methods

The study involved both field and laboratory analysis using boreholes, particle size analysis, oedometer tests, and the triaxial test. In-situ results were compared and integrated with laboratory engineering and geological properties. Sample locations were referenced using Meller GPS. In all, about 18 locations were sampled.

Borings were carried out with a shell and hang auger rig. The bore positions are shown on the site plan. Boring was up to 30 meters, although this study was limited to 7 meters. During this operation, both disturbed and undisturbed samples were collected. Disturbed samples were collected at regular intervals of 0.75 m and when a change in soil type was noticed for laboratory analysis. Undisturbed, cohesive soil samples were retrieved with a conventional open-tube sampler, 100 mm in diameter and 450 mm in length. All samples recovered from the boreholes were examined, identified, and roughly classified in the field.

2.1 Laboratory Tests

A series of classification tests were carried out on the disturbed samples in accordance with the British Standard (BS 1377 of 1990). Classified tests were done to verify and improve the field identification and classification of the samples.

- The test included natural grain size distribution, moisture content, unit weight and soil consistencies (Atterberg limits).
- The relatively undisturbed samples were analyzed to determine the design/strength parameters, such as consolidation and compressibility.
- Undrained triaxial tests were performed with the objective of determining their undrained cohesion (Cu) and the angle of internal friction (θ).

3. Results

This section presents and discusses the test results and their application in engineering geological parameter mapping of the locations.

3.1 Subsurface Lithology Characteristics

The soil stratigraphy as determined from the results of borings, in situ penetration, and laboratory testing is as follows:

- Dark Organic Peaty Clay (DOPC)
- Dark Grayish Silty Clay (DGMC)
- Dark Grayish Sandy Clay (DGSC)

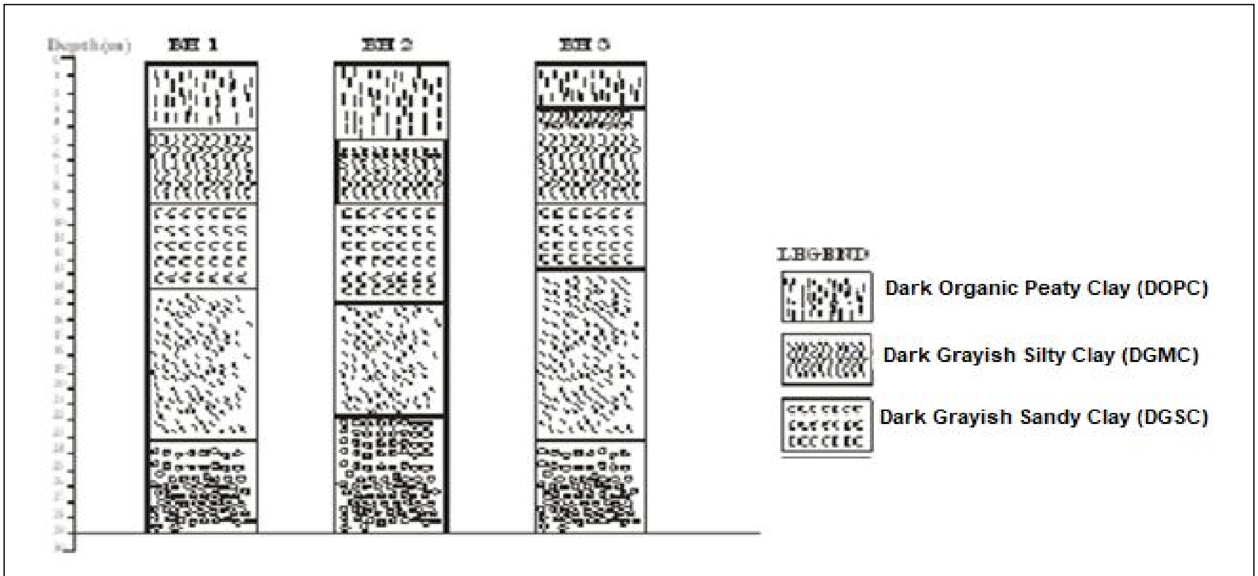

Figure 2: Representative Stratalog of Study Area

Table 1. Characteristics of the various Lithological Types

S/N	Soil Type	Depth (m)	Engineering Geological Characteristics
1	Dark Organic Peaty Clay (DOPC)	0.0-1.0	• Dark brown in colour • High Organic content • Fair to poor compaction characteristics • Medium to high compressibility • Ability to swell and shrink • Sensitive to water • Poor drainage characteristics • Belongs to CL group in the USCS classification
2	Dark Grayish Silty Clay (DGMC)	1.0-5.0	• Dark and grayish in colour • Some Organic matter • Poor to fair compaction characteristics • Highly compressible • Swelling and expansion abilities • Low hydraulic conductivity • Impervious and difficult to drain water • Belongs to OH group
3	Dark Grayish Sandy Clay (DGSC)	5.0-13.0	• Dark clay with fine sand • Fair to good compaction characteristics • Limited compressibility • Poor drainage characteristics

			• Fairly stable as fill material • Belongs to SC.

The stratigraphic sequence is consistent, but variations in the thickness of the layers were observed. Organic clay on top followed by silty/sanding clay with medium plastic to firm clay at the base.

The dark organic silty clay is the top layer. It has a depth range of 0.0 to 1.0 m and an average thickness of 1.0. It is classified as OL under the Unified Soil Classification System (USCS). The second stratigraphic layer is the dark grayish silty clay with an average thickness of 4.0 m (ranging from about 1.0 m to 5.0 m). It is classified as "OH." It is made up of organic silty clay of moderate consistency. The third stratum encountered was the dark grayish-firm silty clay at an average depth of 6.0 m and an average thickness of 8.0 mm. It is high in consistency and belongs to the CH under the Unified Soil Classification System (USCS). Other details of the above stratigraphic layers are given in Table 1.

3.2 Grainsize Analysis

The values of the gradation pattern from the analysis are presented in Table 2. There are no significant differences in the various properties within the same major soil group; hence the ranges and sometimes average of values from different boreholes rather than typical values are used.

In all the locations 90% and above passed through 4.75mm sieve for the organic clay, 80-95% for the 4.75mm sieve, while the 2μ sieve retained between 0-18% for all soil types.

Table 2: Representative Grain Size Distribution Pattern

S/N	Soil Type		% Passing Sieve Sizes			
		Symbol	**>4.75**	**4.75m**	**75μ**	**2μ**
1.	Dark Organic softy silty clay	OH	90–98	80–95	65–76	5–9
2.	Dark sandy clay soil	SC	80–95	61–65	45	12–15
3.	Dark Medium Plastic Clay	CH	70–96	50–55	26	10–18

3.3 Consistency Indices of the Soils

Both the Atterberg limits (Liquid limit LL; Plastic Index PI) were determined in addition to the natural moisture contents (wn).

The values of the Atterberg limits were determined in accordance with ASTM D423 and AASHTO T89 and the results are presented in Table 3. The results show high values for both the liquid limit and plasticity index; ranging from 34% to 40% for LL and 7 to 25 for PI. As expected, there is a high percentage of water due to the meteorological conditions of the area and their nearness to the sea. The moisture content ranges from 20 to 70%.

Table 3: Consistency of Sub-soils in the Area

S/N	Soil Type	Symbol	Liquid Limit (%)	Plasticity Index (%)	Moisture Content
1.	Dark organic soft silty	OL	35.0-38.2	7.4-8.2	20.3-22.5
2.	Dark greyish silty clay	OH	34.0-35.8	8.2	20.3
3.	Dark firm silty clay	CH	34.0-40.0	10-12	24.8-32.6

3.4 Drainage Condition / Permeability

Generally, the water tables were encountered at shallow depths from 0.30m below ground surface during low tides to sometimes submerge during high tides. This tidal effect is a verification of the high permeability of the shallow soils, in the area. Values of Coefficient of permeability (K) obtained during consolidation tests on the top 1.50 - 3.00m soils indicate moderate permeability values.

The values of permeability and their effect on drainage and consolidation characteristics of the various soil profiles are presented in Table 4.

3.5 Consolidation Tests

The results of Consolidation tests carried out on relatively undisturbed samples using Terzaghi one-dimensional Consolidation (Oedometer) test are presented in Table 4. Two parameters; Co-efficient of Volume Compressibility (M_v) and Co-efficient of Consolidation (C_v) were determined over a pressure range of between 50 and 40kPa on cohesive samples. The values range from $0.98M^2/MN$ to $2.5m^2/MN$ for M_v and $1.32m^2/MN$ to 8.0m2/MN for C_v respectively.

Detail result shows that the coefficient of compressibility (M_v) for the organic soft clay (OL) is between 1.12 x 10^{-} m^2/MN and 1.40 x 10^{-} m^2/MN. The dark greyish silty clay (OH) below had values between 0.98 m^2/MN and $1.25m^2/MN$.

Table 4: Consolidation and Drainage Characteristics of the Various Soil Layer

Soil/Strata Type	Depth Range (m)	Co-efficient Compression (Mv(m^2/Mv)	Co-efficient Consolidation Cv(m^2/yr)	Co-efficient Permeability (k)m/s	Remarks
Dark organic soft silty clay (OL)	0.00	1.20	1.32-1.60	1.5 x 10^{-5}	Highly Compressible
	1.00	1.40		2.30 x 10^{-7}	Moderately Impermeable
Dark greyish silty clay (OH)	1.00	0.98	1.27-1.45	2.50 x 10^{-4}	Moderately Impermeable
	5.00	1.27		3.5 x 10^{-8}	Moderately Compressible
Dark greyish firm silty (CH)	5.00	1.07	1.19-1.45	2.65 x 10^{-4}	Moderately Compressible
	13.00	1.26		3.00 x 10^{-6}	Highly Impermeable

3.6 Bearing Capacity of the Sub soils

The Terzaghi formula for computing the bearing capacity of soils based in laboratory results was used in computing the bearing capacity of the sub soils at various sample points. This is given for rectangular footing as;

$$Qu = CN_c (l+O.3B/L) + YD_fN_qRw_1 + 0.5YBN_q (l-0.2B/L) Rw_2 \qquad 1$$

Where;

Qu = ultimate bearing capacity

C = undrained cohesion of the soil

B = width of footing

L = Length of footing

Y = Unit weight of soil

D_f = Dept. of footing

Q = Angle of friction as O for undrained condition of soil.

Rw_1 = reduction factor for water table above the base level of foundation

= $0.5 (1 + Dw_1/D_f$

Rw_2 = reduction factor for water table below the base level of foundation

= $0.5 (1 + Dw_2/B)$

Value of various strength Characteristics are presented in table 5.

Table 5: Strength Characteristics of the Various Soil Layers

S/N	Soil Type	Symbol	U-U Tri-axial Test	
			$\Theta_u(^0)$	C_u(kPa)
1.	Dark organic soft silty	OL	4	41.4 - 48.5
2.	Dark greyish silty clay	OH	4	56.6 - 65.6
3.	Dark firm silty clay	CH	4	73.0 – 80

Source: Survey Data

Settlement Computations

The likely settlement as a result of vertical loading was computed considering subsurface lithology and the likely land improvement method. Settlement prediction was made for a foundation depth of 2.5m.

The settlement of each layer was computed using skepton and Bieranar [9] which gives Oedometer settlement as;

$$S = M_v \cdot d_v \cdot H \qquad 2$$

Where;

Mv = Coefficient of Volume Compressibility

H = Thickness of compressible layer

d_v = average effective vertical stress imposed m the particular layer form wet foundation pressure (q_n)

4.0 Engineering Geological Parameter Mapping

Using the field and laboratory characterization results, iso-contour maps for liquid limits (LL), Cohesion, Friction angle, Bearing Capacity Settlement were produced.

The comprehensive approach emphasized by [10][7]are hereby listed;

- Acquire a rather complete set of engineering geological data
- Field map systematically layer area in different scales
- Collect the comprehensive information in special data bank
- Use GIS-based mapping technique

The Procedures include;

- Geotechnical characterization of the superficial layers within the depth of interest based on parameters selected.
- Generation of a spatial base map using Google earth with geo-referenced sample location points and the parameter values were transferred to each location point.
- The geotechnical parameters obtained during field and laboratory analysis maintained in Spreadsheet Excel 2013 noting their reference co-ordinates.
- Using a GIS technology tool Surfer II, the basic information is translated into digital topographic database which generates a new file of worksheet. The file is gridded and then plotted to create the contours.
- In the final map, parametric values, which now feature classes, are represented by shaded color codes

Table 6: Analyzed Geotechnical Data

Easting	Northing	Liquid Limit (%)	Cohesion (kPa)	Angle of Friction (θ^0)	Bearing Capacity KN/m^2	Settlement (mm)	T90 (Yrs)
278533.2	524913.2	33.6	62.3	5	189.94	82	7.42
278563.9	524870.1	32.1	68.4	6	162.35	80	4.27
278563.7	524805.5	35.8	56	4	191.67	69	2.8
278564	524900.8	26	64.4	4	135.27	352	3.69
278594.7	524863.8	24.5	75	6	155.27	168	3.65
278625.4	524820.7	29.2	79	6	201.08	70	5.69
278533.4	524993	24	80	4	172.87	332	3.92
278625.8	524952.8	26.5	64	4	175.32	172	4.81
278656.4	524863.6	31	67	6	156.81	148	4.33
278687.1	524829.8	24.5	78	4	198.1	63	4.81
278687.1	524829.8	29.8	62	6	169.07	84	5.1
278748.8	524860.3	25	58	4	202.37	96	3.86

278687.4	524943.4	37.2	43.2	6	185.62	97	4.72
278625.9	524980.5	25	59	4	172.72	128	5.06
278687.6	525023.3	29	46	6		217	4.48
278656.9	525054.1	26	53	4			
278687.7	525051	38	43.5	5			
278626	525038.9	35.8	46.3	6			

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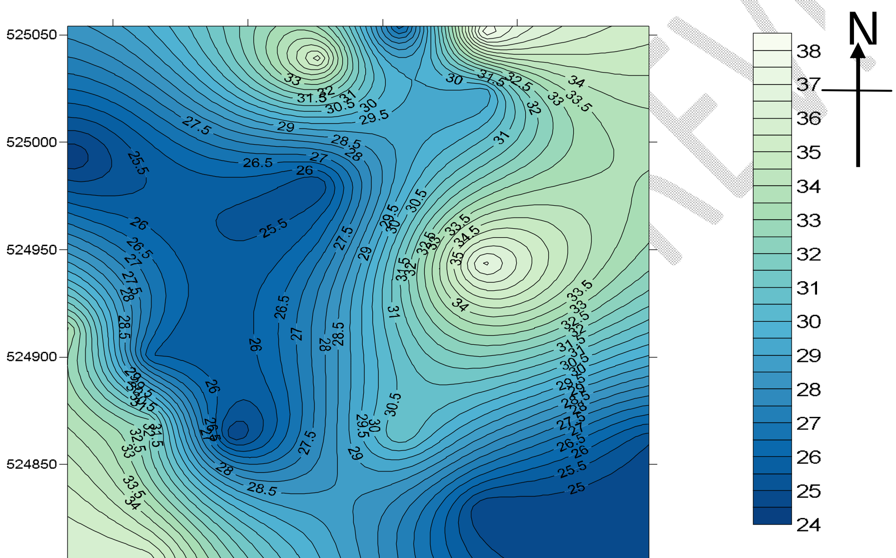

Figure 3: Liquid Limit

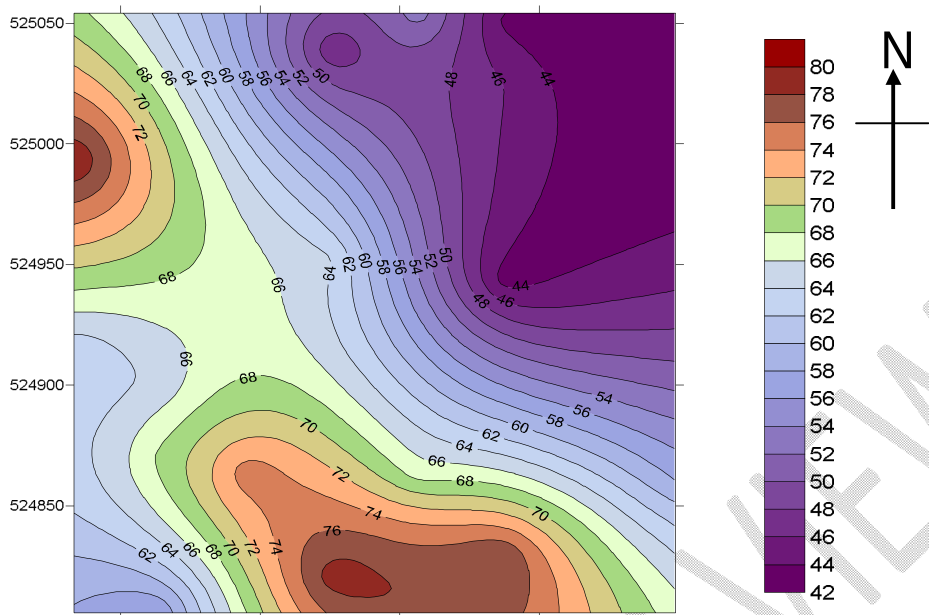

Figure 4:Cohension

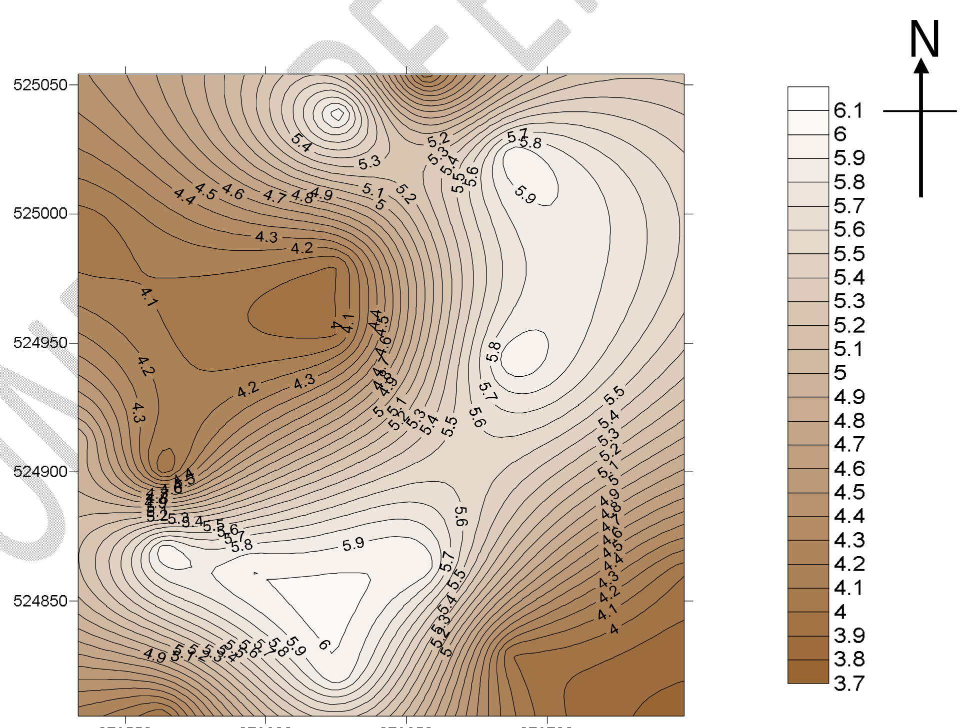

Figure 5: Angle of Internal friction

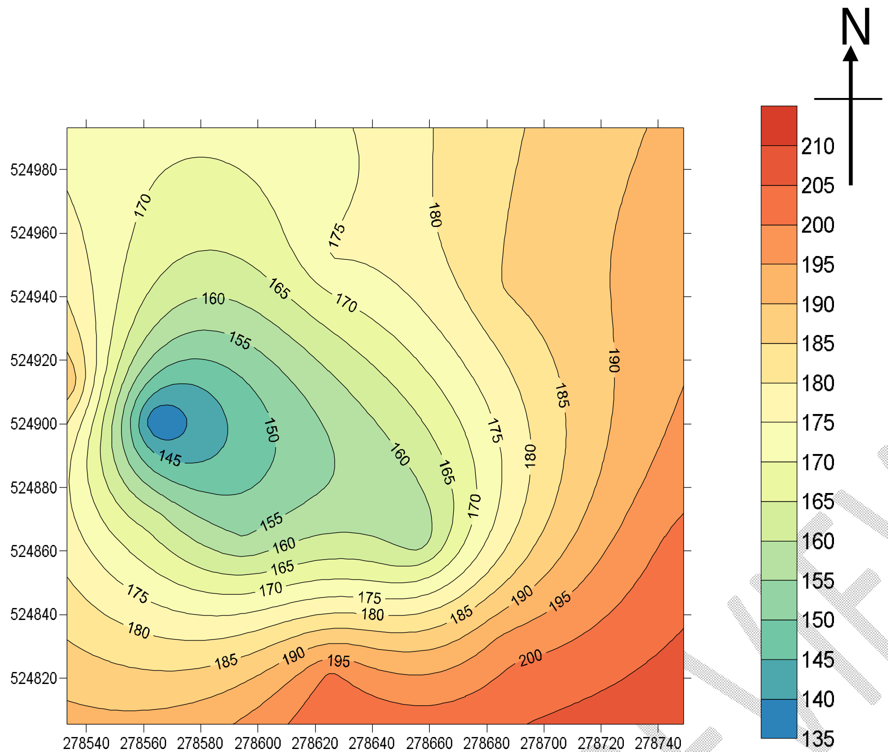

Figure 6: Bearing capacity

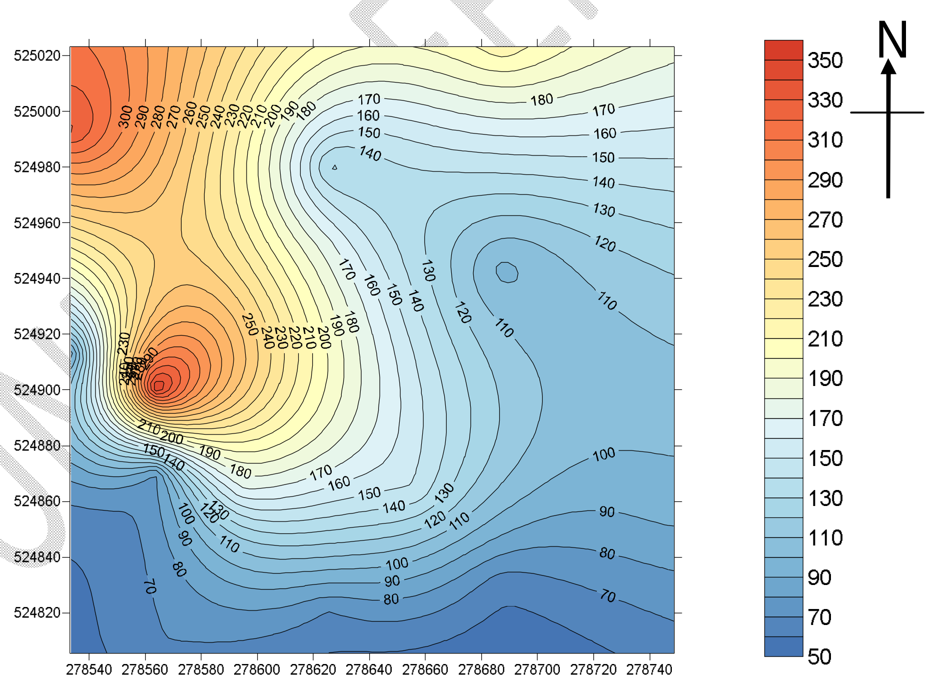

Figure 7: Settlement

4. Discussion

The range of the consistency values (LL and PI) are good indications of the likely behavior of the clayey soils in the pressure of excess water, knowing the area is a place of long and heavy rainfall. The high plastic soils will take a longer period to also dry. This is a problem in the wider Delta because of the long season of rainfall, about nine months in the year.

The moistures contents of the clays are high and this is influenced by the high rate of precipitation, the organic content and the drainage conditions. The clays, especially those at the top layers are high in organic content. The moisture content of the soils is expected to vary with the season. This will create a volume changes in the claying soils resulting to excessive swelling and shrinkage. In terms of compressibility, the clay layers have medium to high compressibility with low rate of consolidation, their values of co-efficient of compressibility and consolidation are typical characteristics of clay soils in the Niger Delta [4][13].

The generated maps are presented from Figures 3 to Figure 7 These maps cover a wider area; they give a broader overview of the engineering geological picture of the region which is important in strategic planning, development and management of the environment for sustainable development. They are also useful for reconnaissance study giving the geoscientist a general picture of the area, to prepare him for a more detailed and specific investigation, if necessary.

Conclusion

This study has demonstrated the application of engineering geological mapping in engineering geological investigations. However, there is note of caution. These maps are not intended replacement for detailed studies.

Most of what we want to know is hidden subsurface and thus very difficult to discern. Even the most thorough investigation program encounters only a small fraction of the soil below the site. We do not know what conditions exist between borings, and only rely on interpolation processes. Accordingly, in geotechnical projects, it is desirable to encounter the unexpected conditions. Adoption of the observation method becomes most cost effective approach [9].

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