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Mapping of Soil Properties Using Geographical Information System (GIS): A Case Study of Hassan Usman Katsina Polytechnic

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Abstract

GIS relates and integrates spatial data from various sources, for storage, retrieval, analyses and display. This paper presents the analysis and mapping of Geotechnical data using natural neighbour interpolation tool of GIS. The Campus of Hassan Usman Katsina Polytechnic Nigeria was as the study area, and Arc GIS 10.2.1 was used to perform the analyses. The study used soils samples from ten trial pit distributed within the study area and subjected to various laboratory tests. Index and engineering properties of the samples were determined. Map database developed in a GIS environment and the result of the laboratory tests stored, were analysed and displayed using GIS. The research results show maps of various soil properties. The research result provides estimated data for preliminary designing of engineering infrastructures in the area.

Keywords

Geographic Information System, Soil Properties and Hassan Usman Katsina Polytechnic

1. Introduction

Index and engineering properties of soil, for example, specific gravity, moisture content, dry density, bulk density, permeability, compressibility, and shear strength are among the geotechnical parameters. The said parameters may change between places. Civil engineers need to know about the variation of the index and engineering properties of soil before carrying out design and con-

struction of an engineering structure. Field or laboratory soil testing will provide a result which is too specific for a particular location to generalise over an extended area. Geotechnical engineers investigate the behaviour of soils under different conditions. The duties of geotechnical engineers also include but not limited to assessing and designing of slopes, excavations and foundations [1].

Engineering data especially that used by geotechnical engineers are costly, and difficult to obtain and analyse. It is difficult to determine the soil types and change of layers at every point on the site. Engineers depend on information from representative samples to estimate the soil properties. In this regards, a method of analysing and mapping soil properties using GIS and GPS in the study area (Hassan Usman Katsina Polytechnic Katsina State Nigeria) attempted in the paper. The following objectives achieved the aim of the paper:

1) Obtaining soil samples from the representative trial pits, and testing the soil properties for each location chosen.

2) Digitizing and developing the study area map.

3) Developing the map database of soil test results and analysis of result using Arc GIS 10.2.1 software.

2. Literature Review

Application of GIS in Civil and Geotechnical Engineering is receiving much interest in the current literature. Hallowell *et al.* (2012) [2] highlighted the GIS application by reviewing case studies. The three GIS components identified by the authors are databases, graphics interfaces and data analysis. A method of mapping the swelling potential of soil was developed using GIS by [3]. The research used a digital map of a region, data from the area and GIS to propose zoning of maps, evaluate various mechanisms that caused soil swelling and indicate an area with high and low-risk of soil swelling. The maps are used in the development planning and in reducing the risk of damage caused by soil swelling. The cost of constructing projects also reduces by permitting designers to avoid places with dangers for soils swelling.

Player [4] as cited by [5] introduced applications of GIS technology in geological hazards identification. The research planned and tracked field work. Communication improved by creating figures and maps. Foyer *et al.* [6] estimated recharge using GIS that identifying possible combinations of soil type and vegetation. In Athens of Greece, [7] reported the application of GIS to produce thematic maps of the geotechnical, geological, seismological and geomorphological data of the area. In Brazil, [8] used GIS for geotechnical and environmental risk management of oil pipeline. Thiesen [9] conducted GIS Mapping of geotechnical data of Blumenaui city in Brazil using a digital terrain model. The result provided information on the geographic features and urban growth.

Furthermore, [10] reviewed the application of GIS in Geotechnical Engineering. The review covered the capabilities and uses of the technology of GIS in Civil Engineering. Other similar researches were carried out using numerous

applications of GIS like those by [11]-[21]. However, application GIS for mapping soil properties for use in preliminary design is limited in the literature. Given that, an effort is made here, to conduct Mapping of Soil Properties using natural neighbour interpolation tool of GIS in the case study of Hassan Usman Katsina Polytechnic Nigeria.

3. Methodology

The methodology used in this study was in three phases. The first stage was the field exploration and laboratory test. This involved activities like site exploration, feasibility survey of the study area, obtaining the samples and performing the prescribed tests in a laboratory. Ten numbers of trials pits were collected within the study area and tested for index and engineering properties as per standard procedures of [22]-[28]. The trial pits were distributed correctly within the study area in order to obtain a representative cross-section of the area. The depths of the trial pits were made more than the depth of foundation most existing building in the study area. The second stage was the digitisation and development of the study area map in ArcGIS. Satellite image of the area obtained from google earth digitised and geo-referenced in Arc map. Coordinates of some control points were obtained using handheld GPS and used to geo-referenced the map.

The last stage of the research was database creation and analysis of results. Map database was created using arc catalogue and uploading the tested results of the borrow pits in the database. Other spatial and non-spatial attributes of the study area also recorded, and the map was updated accordingly. Natural neighbour interpolation tool was used in performing the analyses that resulted in obtaining maps of various properties of soil. The natural neighbor interpolation tool is also called "Sibson" or "area-stealing". The procedure of using the tool involves catching the nearby subcategory of input models to the point of enquiry and putting weights to them based on comparable areas to incorporate a value [29]. In other words, the closest subset of input samples of a point in question are defined, and weights are applied to them based on proportionate areas, and their values are interpolated. The properties of natural neighbor interpolation tool are local because it only uses a subset of samples that border the inquiry point, and the interpolated heights are within the range of the models used. Natural neighbor interpolation tool neither deduces trends nor yield peaks not embodied by the input samples. The result is uniform all over the place except at positions of the input samples. The weights assigned to the input point are scores comparative to the significance of each input samples.

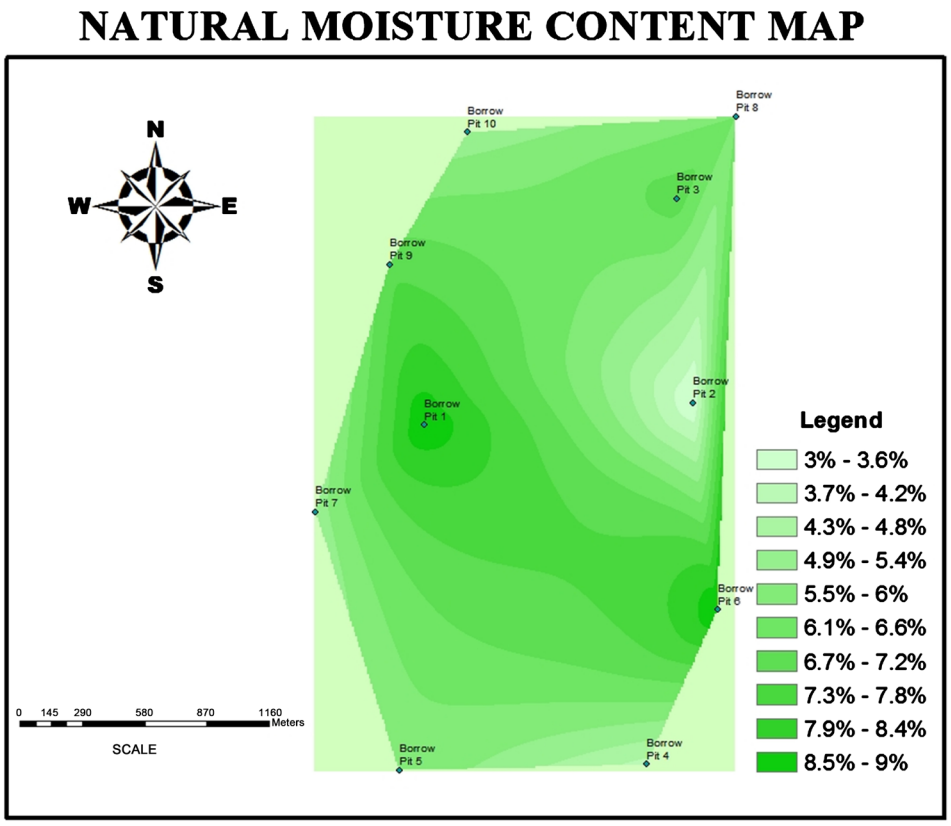
4. Results and Discussions

Taking samples at every position in the study area for investigation of soil property could be very expensive. As a substitute, a measure of the soil properties of the representative sample at selected locations and then predicting other values

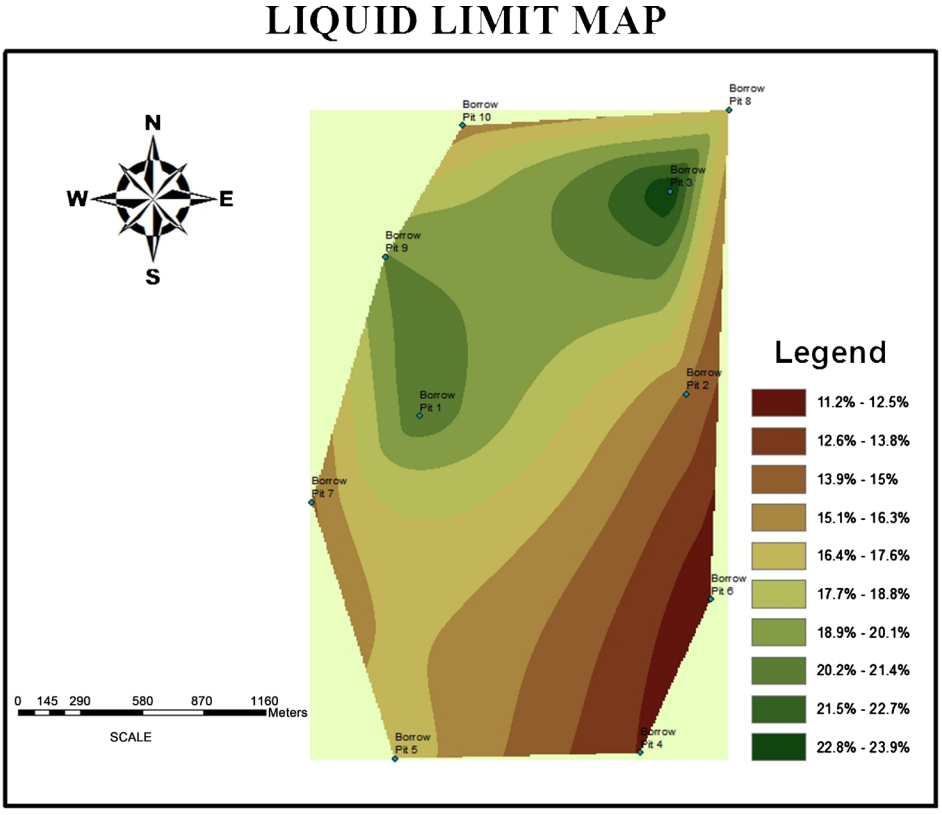
in all other locations using the natural neighbour interpolation tool of GIS can save cost and time. Input points (trial pits) were spaced correctly based on a sampling scheme. The properties of soils at the sample points uploaded in the map database then analysed and presented in results (**Figures 1(a)-(j)**).

Figure 1(a) shows the distribution of natural moisture content over the study area. Colours variation denoted the result; each colour layer indicates range per cent of moisture content; the darker the colour, the higher the moisture content in the area. Similarly, **Figure 1(b)** shows the distribution of the liquid limit over the study area. The various colours ranges indicate the amount of moisture content present in the area. The variation in the moisture content was due to the variation in the soil type. The area with loose soils showed lower natural moisture content as well as and lower values of liquid limit, plastic limit, linear shrinkage and CBR as shown in **Figures 1(b)-(d)** and **Figure 1(j)** respectively. Borrow Pit no 3 with lighter colour has lower moisture content about 3% while Borrow pit no 8 and 9 have higher moisture content about 9%.

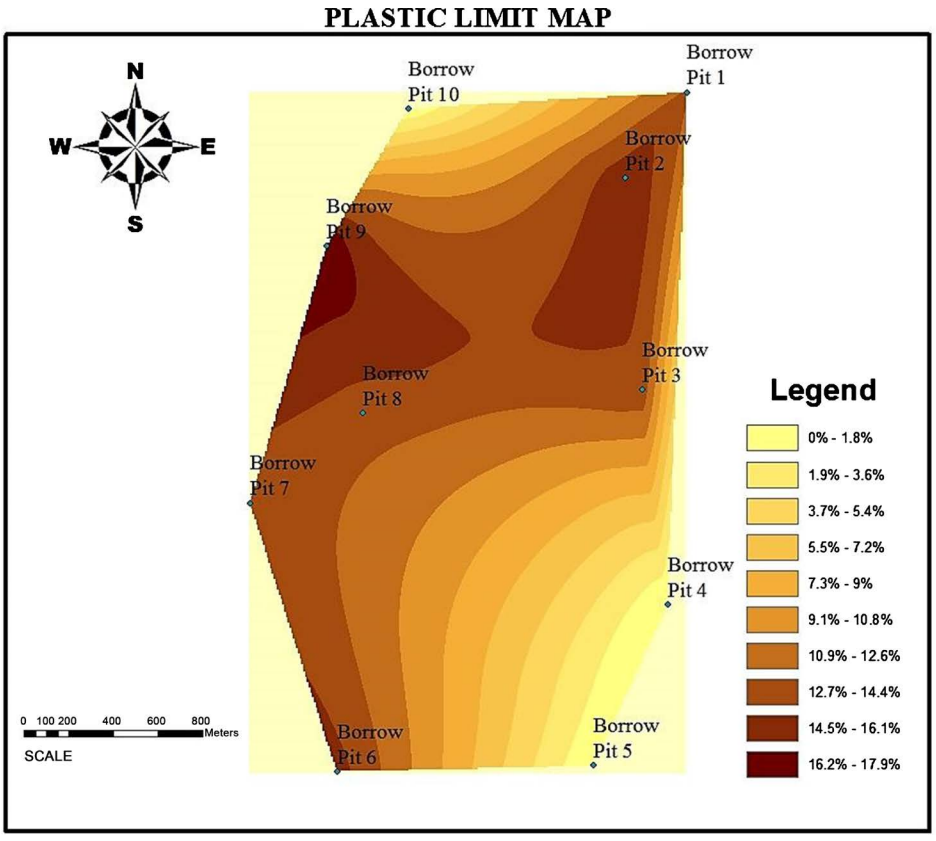
The distribution of the amount of fine-grained particles (smaller the 0.075 mm) existing in the samples is shown in **Figure 1(e)**. Area near Borrow Pit 9 and 10 contain about 5% of fine grain particles and that was due to the presence of residual soils in those areas that can be confirmed by the higher CBR value of about 50% as shown in **Figure 1(j)**. Furthermore, **Figure 1(g)** and **Figure 1(h)** show the distribution of compaction characteristics (maximum dry density,



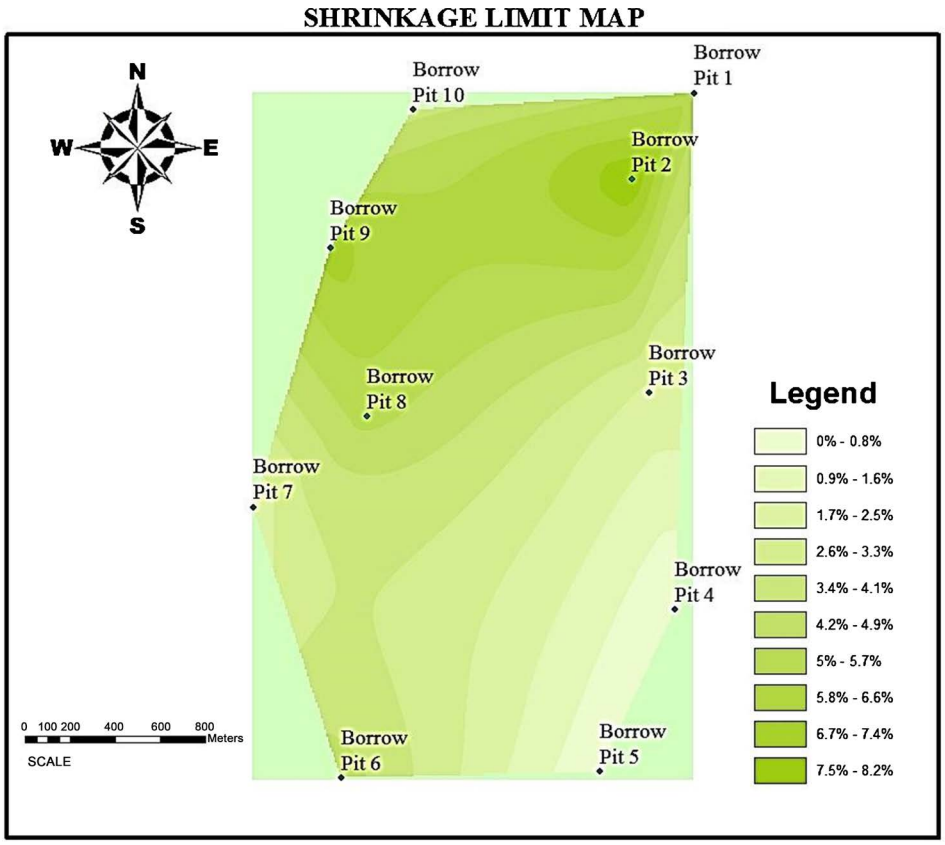
(a)


LIQUID LIMIT MAP
N
W
E
S
Borrow Pit 10
Borrow Pit 8
Borrow Pit 3
Borrow Pit 9
Borrow Pit 2
Borrow Pit 1
Borrow Pit 7
Borrow Pit 6
Borrow Pit 5
Borrow Pit 4
0 145 290 580 870 1160
Meters
SCALE
Legend
11.2% - 12.5%
12.6% - 13.8%
13.9% - 15%
15.1% - 16.3%
16.4% - 17.6%
17.7% - 18.8%
18.9% - 20.1%
20.2% - 21.4%
21.5% - 22.7%
22.8% - 23.9%

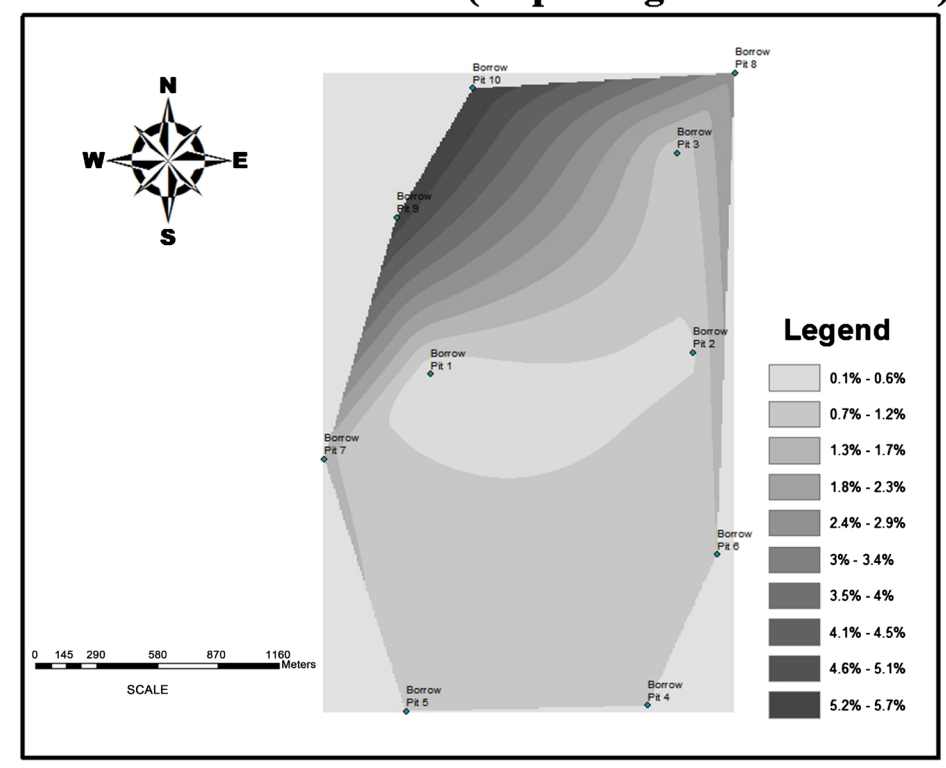
(b)


PLASTIC LIMIT MAP
N
W
E
S
Borrow Pit 10
Borrow Pit 1
Borrow Pit 2
Borrow Pit 9
Borrow Pit 3
Borrow Pit 8
Borrow Pit 7
Borrow Pit 4
Borrow Pit 6
Borrow Pit 5
0 100 200 400 600 800
Meters
SCALE
Legend
0% - 1.8%
1.9% - 3.6%
3.7% - 5.4%
5.5% - 7.2%
7.3% - 9%
9.1% - 10.8%
10.9% - 12.6%
12.7% - 14.4%
14.5% - 16.1%
16.2% - 17.9%

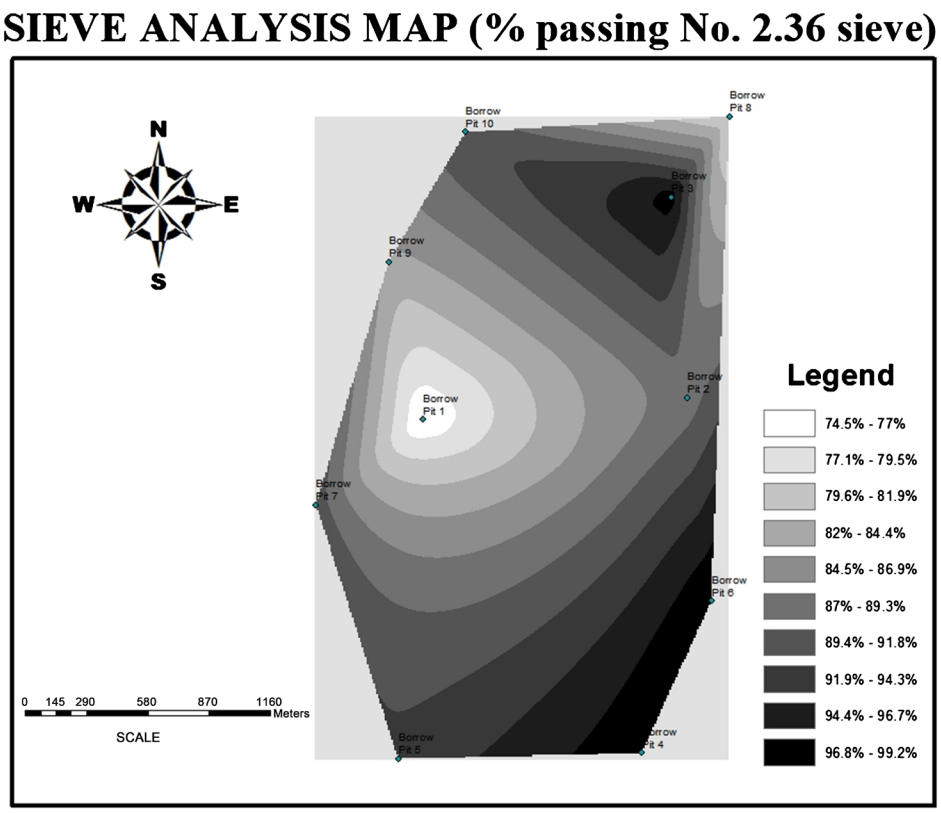
(c)


SHRINKAGE LIMIT MAP
N
W
E
S
Borrow Pit 10
Borrow Pit 1
Borrow Pit 2
Borrow Pit 9
Borrow Pit 3
Borrow Pit 8
Borrow Pit 7
Borrow Pit 4
Borrow Pit 6
Borrow Pit 5
0 100 200 400 600 800 Meters
SCALE
Legend
0% - 0.8%
0.9% - 1.6%
1.7% - 2.5%
2.6% - 3.3%
3.4% - 4.1%
4.2% - 4.9%
5% - 5.7%
5.8% - 6.6%
6.7% - 7.4%
7.5% - 8.2%

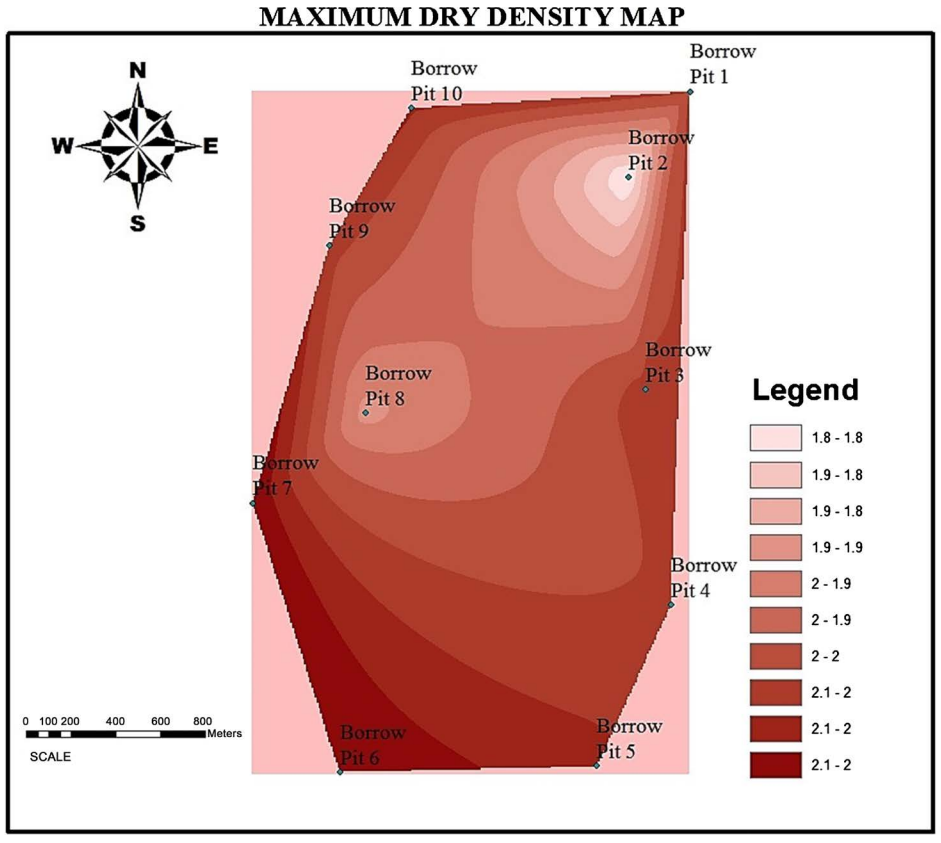
(d)


SIEVE ANALYSIS MAP (% passing No. 0.075 sieve)
N
W
E
S
Borrow Pit 10
Borrow Pit 8
Borrow Pit 3
Borrow Pit 9
Borrow Pit 2
Borrow Pit 1
Borrow Pit 7
Borrow Pit 6
Borrow Pit 5
Borrow Pit 4
0 145 290 580 870 1160 Meters
SCALE
Legend
0.1% - 0.6%
0.7% - 1.2%
1.3% - 1.7%
1.8% - 2.3%
2.4% - 2.9%
3% - 3.4%
3.5% - 4%
4.1% - 4.5%
4.6% - 5.1%
5.2% - 5.7%

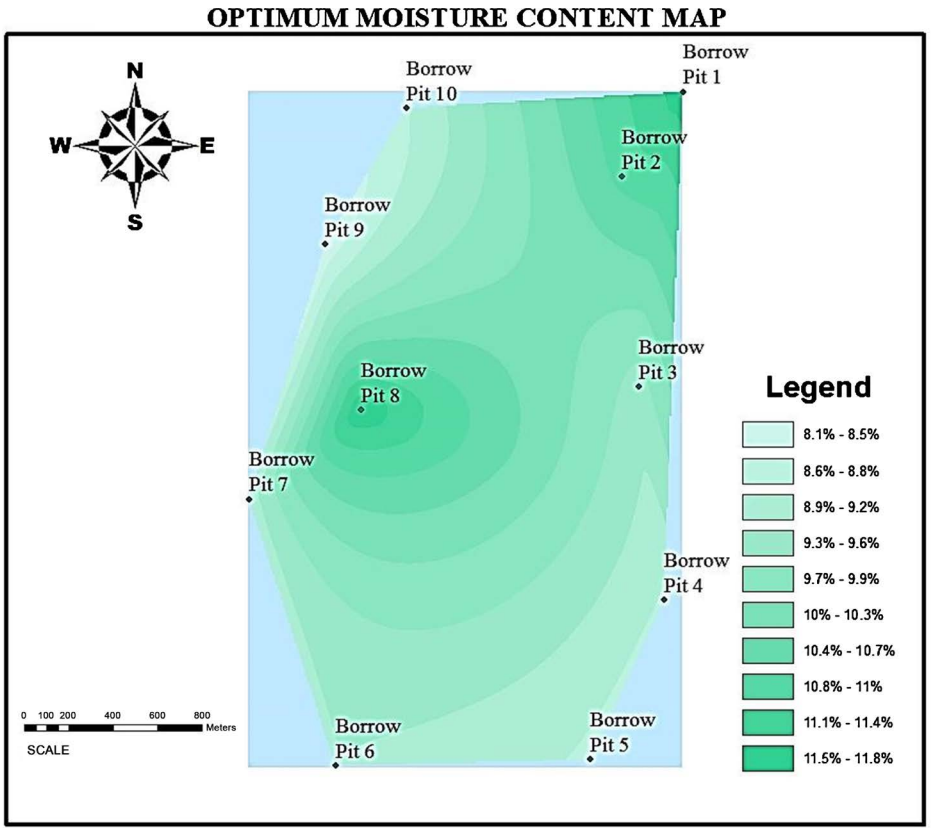
(e)


SIEVE ANALYSIS MAP (% passing No. 2.36 sieve)
N
W
E
S
Borrow Pit 10
Borrow Pit 8
Borrow Pit 3
Borrow Pit 9
Borrow Pit 2
Borrow Pit 1
Borrow Pit 7
Borrow Pit 6
Borrow Pit 5
Borrow Pit 4
0 145 290 580 870 1160
Meters
SCALE
Legend
74.5% - 77%
77.1% - 79.5%
79.6% - 81.9%
82% - 84.4%
84.5% - 86.9%
87% - 89.3%
89.4% - 91.8%
91.9% - 94.3%
94.4% - 96.7%
96.8% - 99.2%

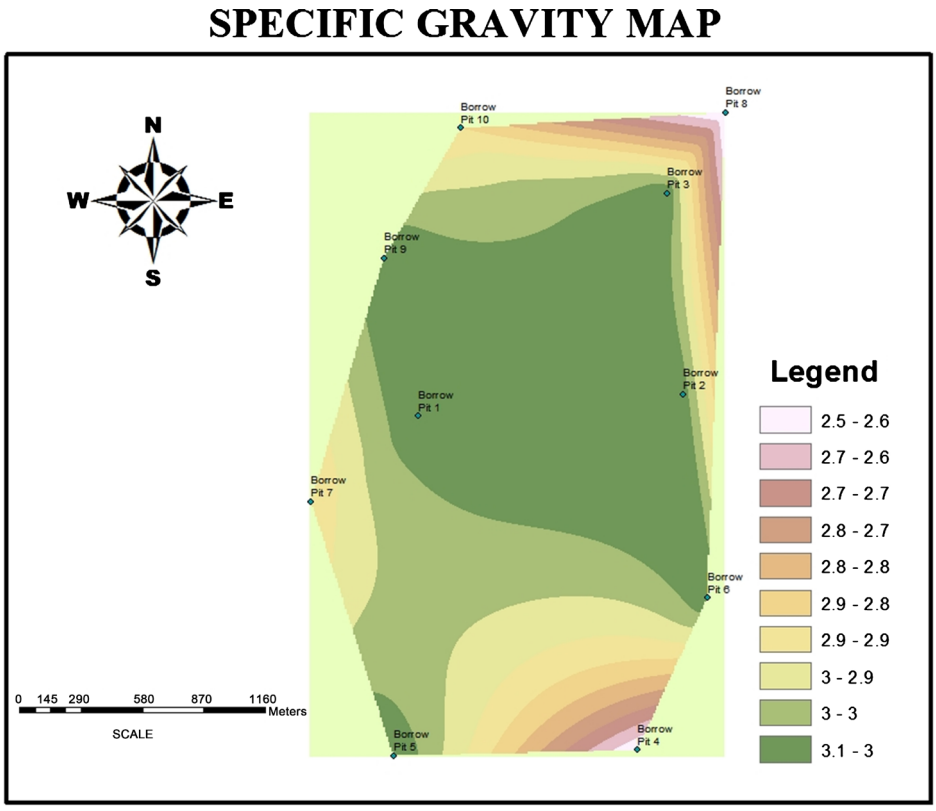
(f)


MAXIMUM DRY DENSITY MAP
N
W
E
S
Borrow Pit 10
Borrow Pit 1
Borrow Pit 2
Borrow Pit 9
Borrow Pit 3
Borrow Pit 8
Borrow Pit 7
Borrow Pit 4
Borrow Pit 6
Borrow Pit 5
0 100 200 400 600 800
Meters
SCALE
Legend
1.8 - 1.8
1.9 - 1.8
1.9 - 1.8
1.9 - 1.9
2 - 1.9
2 - 1.9
2 - 2
2.1 - 2
2.1 - 2
2.1 - 2

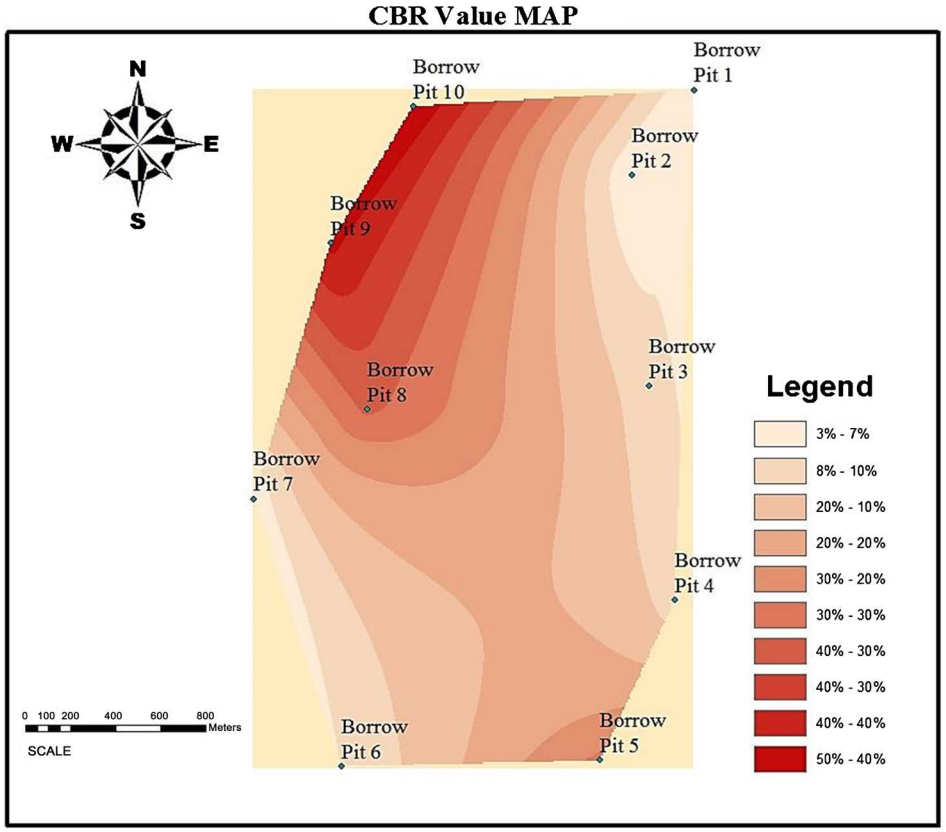
(g)


OPTIMUM MOISTURE CONTENT MAP
N
W
E
S
Borrow Pit 10
Borrow Pit 1
Borrow Pit 2
Borrow Pit 9
Borrow Pit 3
Borrow Pit 8
Borrow Pit 7
Borrow Pit 4
Borrow Pit 6
Borrow Pit 5
0 100 200 400 600 800
Meters
SCALE
Legend
8.1% - 8.5%
8.6% - 8.8%
8.9% - 9.2%
9.3% - 9.6%
9.7% - 9.9%
10% - 10.3%
10.4% - 10.7%
10.8% - 11%
11.1% - 11.4%
11.5% - 11.8%

(h)


SPECIFIC GRAVITY MAP
N
W
E
S
Borrow Pit 10
Borrow Pit 8
Borrow Pit 3
Borrow Pit 9
Borrow Pit 2
Borrow Pit 1
Borrow Pit 7
Borrow Pit 6
Borrow Pit 5
Borrow Pit 4
0 145 290 580 870 1160
Meters
SCALE
Legend
2.5 - 2.6
2.7 - 2.6
2.7 - 2.7
2.8 - 2.7
2.8 - 2.8
2.9 - 2.8
2.9 - 2.9
3 - 2.9
3 - 3
3.1 - 3

(i)



(j)

Figure 1. Distributions of the soil properties over the study area. (a) Natural moisture content; (b) Liquid limit; (c) Plastic limit test; (d) Linear shrinkage; (e) Percent finer than sieve No 200 (size 0.075 mm); (f) Percent finer than sieve no 10 (size 2.00 mm); (g) Maximum dry density; (h) Optimum moisture content; (i) Result of specific gravity test; (j) CBR test result.

MDD and optimum moisture content, OMC) in the study area. The area near Borrow Pits 10, 9, 7, 6, 5 and 4 have soil type with higher MDD values and lower OMC value. While area near Borrow Pits 2 and 8 contain is materials with low MMD values and high OMC value. Thus, area near Borrow Pit 10, 9 and 5 contain soil type that is more suitable for construction purposes and are not likely to give trouble to shallow foundation due the high strength symbolized by high CBR and MDD values and lower OMC values about 50%, 2 Mg/m^3 and 8.8% respectively as shown in **Figure 1(j)**, **Figure 1(g)** and **Figure 1(h)**.

5. Conclusions

This research work on Mapping of Soil Properties using Geographic Information System (GIS) (A Case Study of Hassan Usman Katsina Polytechnic) was successfully implemented with the following conclusion:

A GIS-based user-friendly system developed using application of Natural Neighbor Interpolation Tool can assist to easily and quickly produce the maps of different themes based on soil properties. The valuable information about soil properties within the study area obtained is suitable preliminary designs pur-

pose.

The system can provide a means of identifying areas with suitable construction material in the study area. Furthermore, areas with potential foundation problem within the study area can also be easily identified and avoided during the feasibility studies of future development.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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