GIS-BASED PRODUCTION OF DIGITAL SOIL MAP FOR NIGERIA

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Abstract

Soil, a valuable natural resource can be said to play a part across the range of human existence and its knowledge is fundamental to its utilization and management. Soil maps provide a means of gaining understanding about the soil, but limitations in accuracy, revision and mode of presentation–relating to graphics or digits–of such maps seem to stimulate lack of soil data in many places. However, much of the human activity has been treated with significant uncertainties, and many environmental processes relating to soil are poorly understood. Digital soil mapping seems to hold a strong prospect for addressing these challenges, with an interesting flexibility for utilizing many recent technologies. The present study proposes a digital soil map for Nigeria, and other thematic maps based on soil properties, using geographic information system (GIS) technology. Existing graphical soil maps are the primary data sources. Although, the study is specific to making improved soil data available for the study area, the results tend to support the assumption that significant prospects are held by digital soil mapping in enhancing the knowledge of soil and its provision for a range of human activities.

Key words: *Soil, Soil maps, Digital soil map, GIS, Soil Database, Soil thematic maps, Query.*

Introduction

Soil, a valuable natural resource has been fundamental to human existence and can be said to play a part across the range of human activities such as housing, industrialization, economic activities, mining, fishery, and transportation. Plants depend on it for survival, as it provides physical support and nutrients. All activities that constitute the cycle of life including procreation and extinction, and adverse environmental events one way or the other relate to it. Knowledge about soil is fundamental to its utilization and management and therefore to the ecology and economy as a whole.

Knowing the soil can be said to involve obtaining information about it and describing its varied features. Traditionally, describing the soil often starts with measurements and analysis by experts. Information such as, drainage, ecology, mapping units, classification type, texture, pH values, unique locations, landscape, possible uses and other characteristics particular to a soil distribution is usually provided and represented as spatial features in maps and other supporting documents by a qualitative method. Although, several soil maps have been produced (FDALR 1990) using this qualitative approach, which have assisted in providing adequate data to support several agro-based and scientific projects, the accuracy and reliability of supporting data remains questionable. The methodology has been considered to be slow, time consuming and expensive (Lark, 2007) and the resulting soil maps often suffer from dimensional instability, with highly generalized legend, non-flexibility of scale (Okeke and Nkwunonwo, 2007) and tend not to be suitable for quantitative purposes (Zhu *et al.,* 1997) Thus, the need for quick, quantitative, up-to-date, high resolution and more accurate soil data seems to overwhelm the qualitative soil maps.

Digital soil mapping is a task towards optimizing the usefulness of soils in many places. Several studies (Hengl *et al*., 2003; Kempen *et al*., 2012) have shown that such operations are effective ways of ensuring steady availability of soil data. Moreover, they tend to guarantee regular update of soil data and remove limitations in their uses. Such operations offer significant supports to solving a myriad of environmental and geographical problems (Platou *et al.,* 1989 and Jamagne *et al.,* 1995) that spread across local, national and regional levels. New sets of data often result from further analysis of data obtained by such operations (Zhu *et al.,* 1997 and Zhu *et al.,* 2001), and they tend to help overcome the limitations placed by traditional soil maps. With these benefits associated with such soil mapping technology,

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its implementation remains unaccomplished in many places and much environmental issues are still unresolved. A number of questions are yet to be answered, and the gap between the use of existing hardcopy soil maps of various places and provision of suitable soil data for a range of human activities increases.

Nigeria is one of the places where these challenges could easily be thought of to have raised a number of serious concerns. First, aside lack of accurate, up-to-date and quantitative soil data, there have been compelling needs to investigate other problems associated with the hardcopy soil map on the country. Second, how these graphical soil maps can be improved upon, to provide more acceptable soil data has not received much attention. The other concerns address prompt availability of soil data to end users as it involves providing other thematic maps based on soil characteristics.

Such concerns have received considerable attention. For example Zhu *et al.,* 1997 and Zhu *et al.,* 2001 proposed a digital soil model–SoLIM–which integrates GIS and remote sensing technologies, to overcome limitations imposed by conventional soil maps in a number of Asian countries. Digital soil mapping in Minnesota (Hengl, *et al.,* 2003 and Jamagne *et al.,* 1995), soil geographical database of Europe (Platou *et al.,* 1989) and S-map of New Zealand (Lilburne, 2004), have been proposed. With such increasing transformation in soil mapping, many places such as Nigeria still maintains the conventional soil maps, and serious attempts have not been made at reverting to digital soil mapping. Moreover, the use of GIS and remote sensing technologies for understanding and improving soil data in such places remains speculative.

In view of the above, the present study is aimed at producing a digital version of the hardcopy soil maps of Nigeria to enable users to derive maximum benefit from using such map. Our objectives were, to investigate the problems associated with the existing graphical soil map of the country, to create a soil database for updating soil data, and to produce digital soil map and other thematic maps based on soil characteristics. This paper describes how GIS has been used to achieve the aim and objectives. Sections two and three of this paper highlight the area of study and methodology respectively while section four concerns results and discussion. Section five concludes the study.

Area of Study

Geographically, Nigeria lies in the tropical zone of West Africa between latitudes 4° N and 14° N of the equator and between longitudes 2° E and 14° E, of the Greenwich Meridian (Figure 1). It has a total area of 923,770 km square (NPC, 2007) with maximum North-South and East-West extent of about 1, 050 km and 1, 150 km respectively. The country is bordered in the West by Republic Du Benin, in the Northwest and in the North by Niger, in the Northeast by Chad and in the East by Cameroon, while the Atlantic Ocean forms the Southern limits of Nigerian territory.

Much of the soil data used in the country are sourced from the traditional soil mapping, undertaken between 1985 and 1990 (FDALR 1990). The project resulted initially to the production of 39 map sheets each at a scale of 1:250,000 with 178 soil mapping units and finally to 8 sheets (Figure 2) each at a scale of 1: 650000 with 58 soil mapping units (Table 1). The final outputs describe the distribution of soil within the land area of the country, and have been useful over the years for a range of agricultural, environmental and socio-economic activities. However, Okeke and Nkwunonwo (2007) have argued that the data have a number of weaknesses and the need for quantitative, up-to-date and accurate soil data has remained active.

Methodology

Table 2 gives a summary of study requirements including data and their sources, and software used for the study. The main data for the project were sheets 1 to 8 existing hardcopy soil maps of Nigeria each at a displayable scale of 1: 650,000, acquired from Federal Department of Agricultural Land Resources (FDALR), Abuja and four sheets of the political map of Nigeria acquired from office of the surveyor general of Federation, Abuja, Nigeria. Leica Geosystem ERDAS IMAGINE 9.1 and ESRI ArcGIS 9.3 were both used to carry out GIS operations.

First, these data were studied with view to identifying their weaknesses. Then, they were scanned and spatially referenced to WGS 1984 UTM geographic coordinate system. In a GIS, the resulting raster images were subset, mosaicked (Figure 3 below) and vectorized on-screen. A non-spatial database using soil properties, for example; geology, slope, topography, drainage, and soil pH values, etc.,

(Table 3) was created and linked to the vectorized data. Queries (Figure 4), written in structured query language (SQL) were built into the database, to reduce to bare bones extraction of soil information to users of the digital soil map. Other thematic maps based on soil properties were produced.

Results and Discussion

The results of this research are Digital Soil Map of Nigeria (figure 5) and other derived thematic maps of different soil properties such as soil suitability for mechanized farming (figure 6), soil drainage (figure 7), soil texture (figure 8) and soil ecological zones (figure 9). Statistical presentation (figures 10 and 11) (Pie Chart, Histogram and Bar Chart) of degrees of soil suitability for mechanized farming and of distribution of soil mapping units in Nigeria is shown. This will enable easy identification and description of the behavior of the various soil mapping units in at various levels

From the point of view of soil suitability to mechanized farming, the results tends to show that 27.51 hectares (32%), 17.38 hectares (20%), 14.03 hectares (16%) and 27.51 hectares (32%) of the total area of Nigeria are fairly highly suitable, moderately suitable, marginally suitable and currently not suitable respectively to mechanized farming, Moreover, soil mapping units 15g appeared to be the most distributed in the country, occupying about 18.18% of the total land area. The soils are very deep, sandy-clay in texture, imperfectly drained, slightly acidic, and fairly highly suitable for mechanized farming. The effects of these attributes to the socio-economic status of the country are yet to be investigated.

Conclusion

The present study has attempted to propose a digital soil map of Nigeria using a GIS technology. The result is believed to assist in better understanding of the distribution of soil types and behavior of their components at different levels. A significant contribution has been made towards solving the problem of paucity of quantitative, up-to-date and accurate soil data. Thus, the results tend to serve as facilitator towards research in social, economic and environmental issues.

We have only attempted production of digital soil map using GIS technique. No attempt has been made to evaluate the accuracy of the generated soil maps, so as to know the extent to which the results can be relied upon. Hence, further study is recommended, which can take advantage of remote sensing technology and high computing facilities to assess the reliability of the study outputs, and investigate how the component of the soils interact with one another to impact the social, environmental and economic status of the country at large.

Acknowledgement

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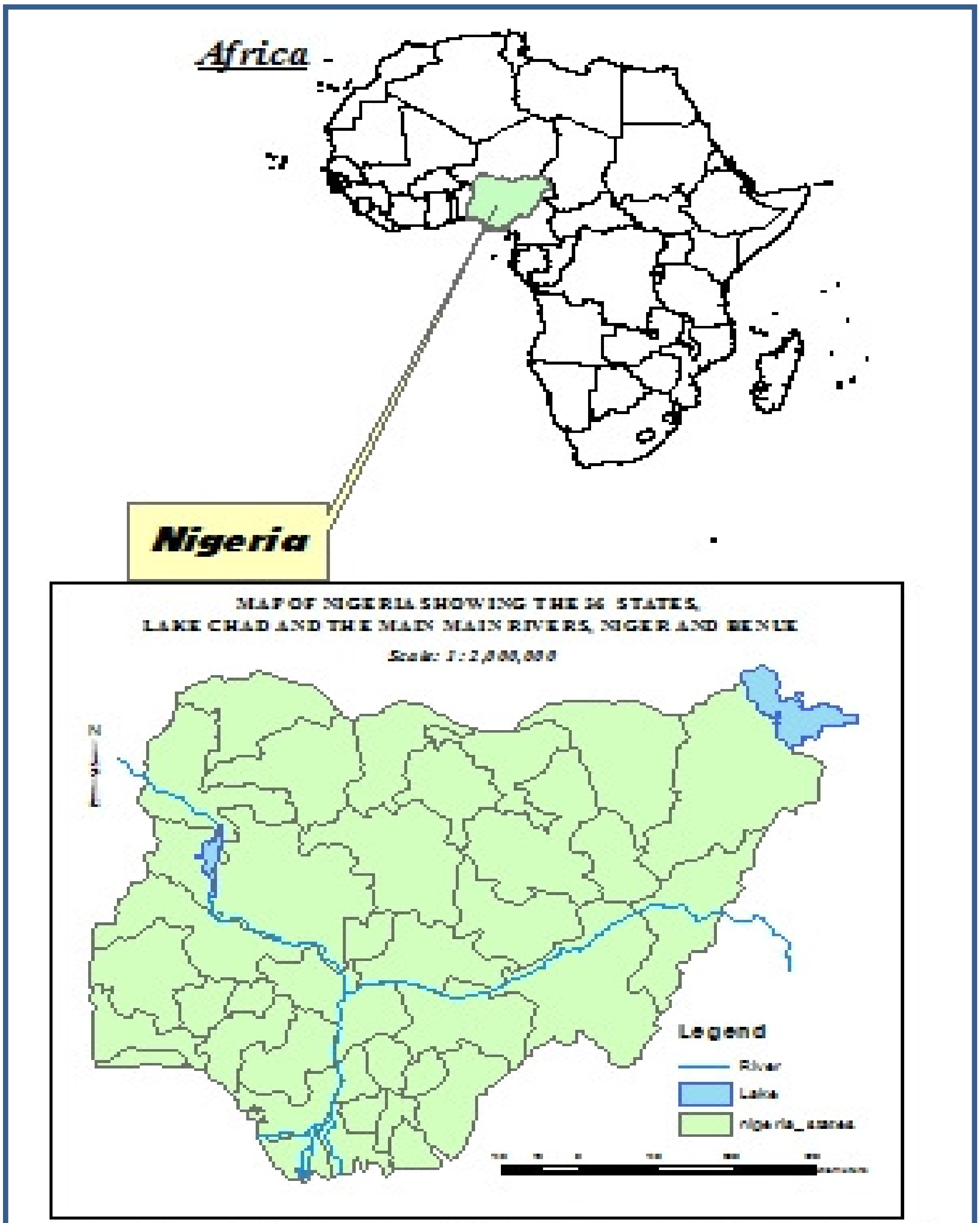

Fig 1: Area of study. Map of Nigeria showing its place in Africa

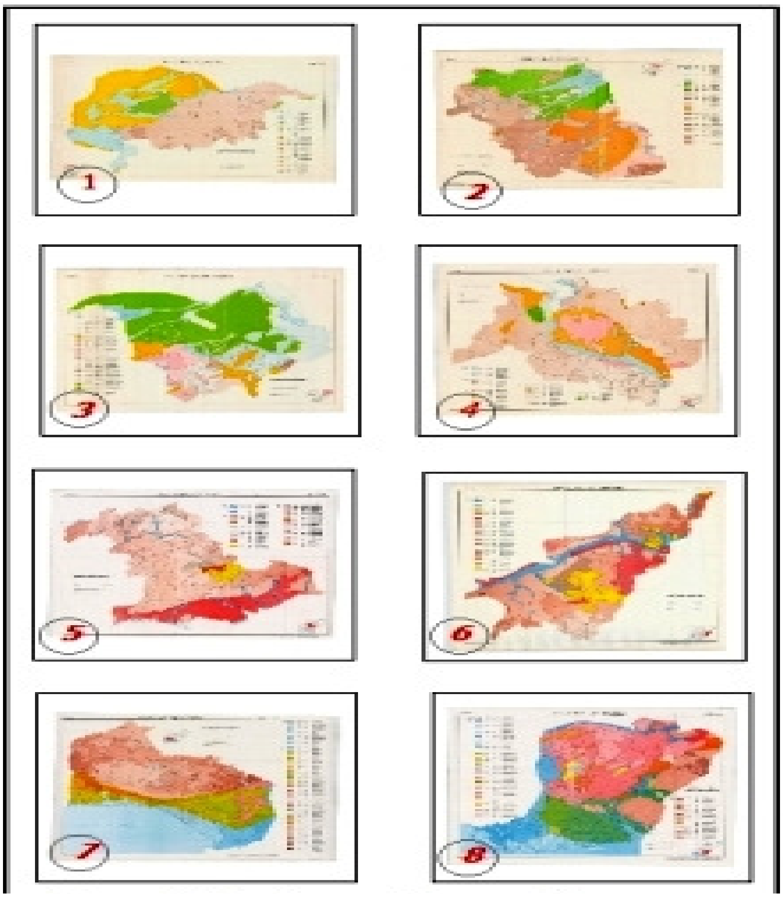

Figure 2 Hardcopy soil maps of Nigeria (Sheets 1 to 8)

Table 1 Fifty- eight Soil Mapping Units

1a	1b	1c	1d	2a	2b	2c	3a	4a	5a
5b	5c	5d	5e	5f	6a	6b	7a	7b	7c
8a	8b	9a	10a	11a	12a	13a	14a	14b	15a
15b	15c	15d	15e	15f	15g	16a	16b	17a	17b
18a	18b	18c	18d	19a	19b	19c	20a	20b	21a
21b	21c	22a	22b	22c	23a	24a	24b		

Table 2 Study Requirements

S/No.	Software	Data and sources
1.	ERDAS Imagine 9.1	Hardcopy soil map of Nigeria acquired from FDALR, Abuja
2.	ESRI ARCGIS 9.3	Four sheets of Political Map of Nigeria each at a scale of 1:250,000 acquired from OSGof, Abuja
3.	Microsoft Excel 2007	Reconnaissance soil survey report prepared of 1990 (FDALR, 1990)

Table 3 Soil properties and their descriptions

S/No	SOIL CHARACTERISTICS	DESCRIPTION
1.	Mapping Unit	58 mapping units from 1a-24b
2.	Geology	The forming background like Basement complex
3.	Slope	Differential topographies in Percentages
4.	Ecological Zone	Mostly Savanna and Wetlands
5.	Drainage	From poorly drained, moderately and highly drained
6.	Soil pH	Scales ranges from 3.0 – 8.0
7.	pH Description	Acidic, Basic or spectrum of either basic or acidic
8.	Suitability to mechanized farming	Moderately, Fairly, Marginally suitable or unsuitable
9.	Soil Texture	Sandy clay, Sandy Loam, clay loam, etc.
10.	Soil Classification	USDA or FAO classification categories
11.	Vegetation cover	Fallow, woodland, Grassland, etc.
12.	Depth	Deep, Most deep, Shallow, etc.
13.	Percentage Distribution	Distribution of mapping units around the country
14.	Major Crops	Particular crops supported majorly like yam, cassava, grains, etc.

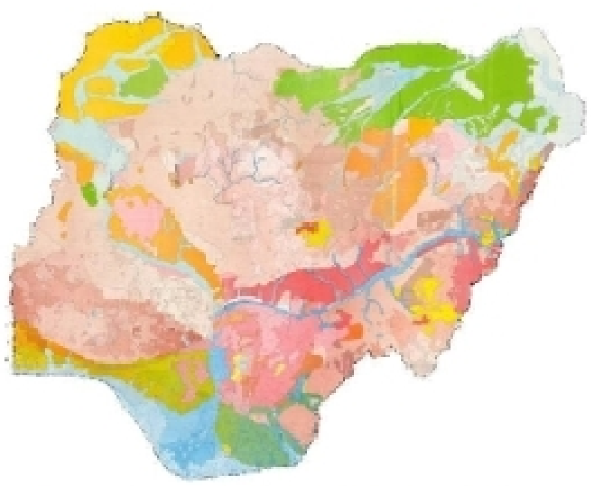

Fig 3: Mosaicked sheet soil map of Nigeria

Query 1: `[Geology] = 'Undifferentiated Basement Complex' AND [Suitability for mechanized farming] = 'Moderately Suitable'`

Query 2: `[Drainage] = 'Poorly Drained' = 'Poorly Drained'`

Query 3: `[pH Description] = 'Very Strongly Acidic' = 'Very Strongly Acidic'`

Query 4: `[Texture] = 'Clay Loam' = 'Clay Loam'`

Query 5: `[Ecology] = 'Rain Forest Soils' = 'Rain Forest Soils'`

Query 6: `[Crops] = 'Yam and Cassava' = 'Yam and Cassava'`

Fig 4: Common SQL queries for Digital Soil map of Nigeria

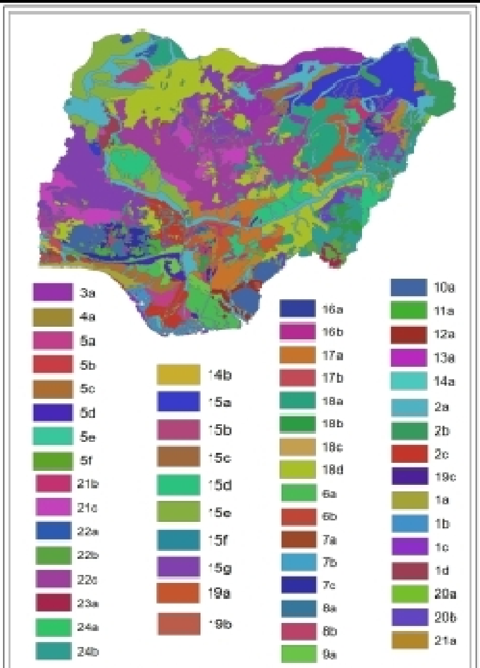

Fig 5: Digital soil map of Nigeria

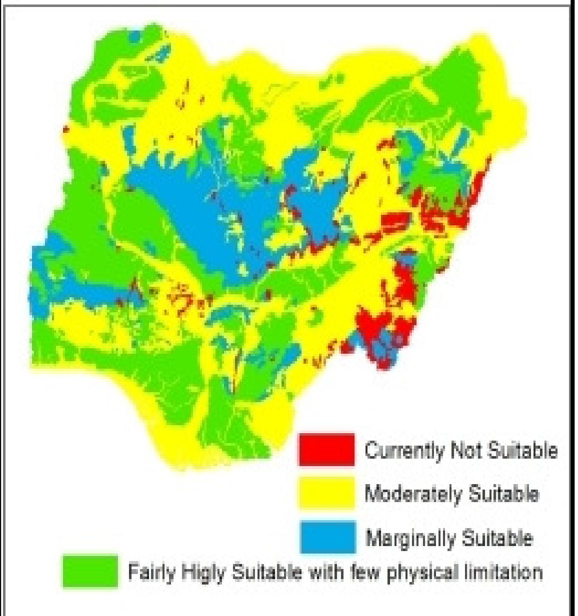

Fig 6: Map of soil suitability for mechanized farming

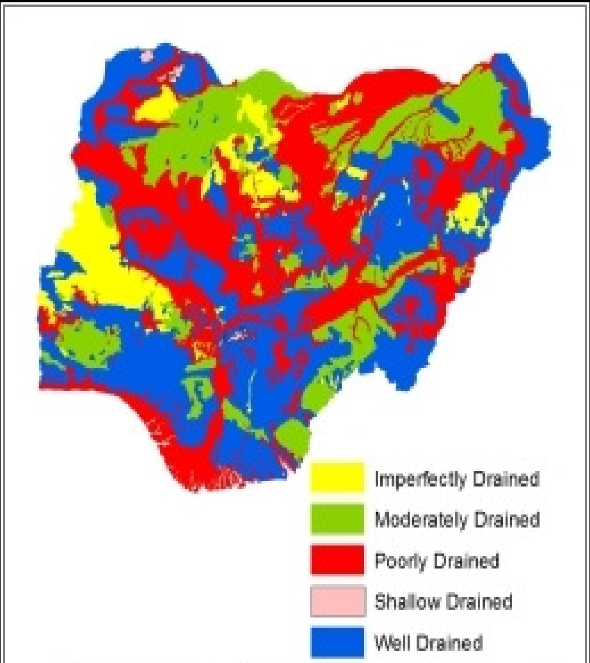

Fig 7: Digital soil drainage map of Nigeria

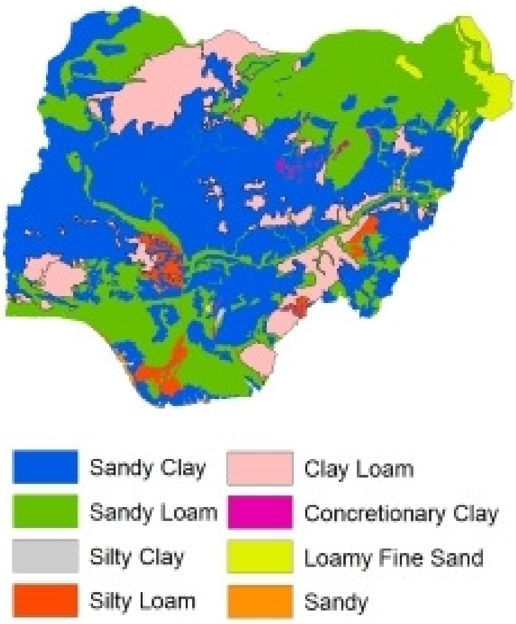

Fig 8: Digital Soil Texture map of Nigeria

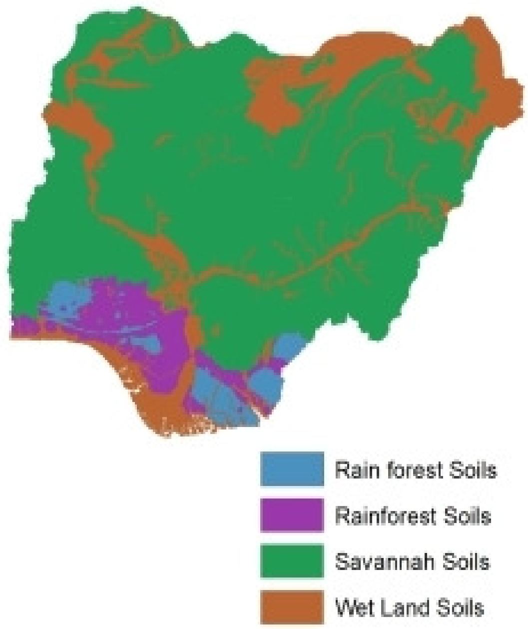

Fig 9: Digital soil Ecological zones map of Nigeria

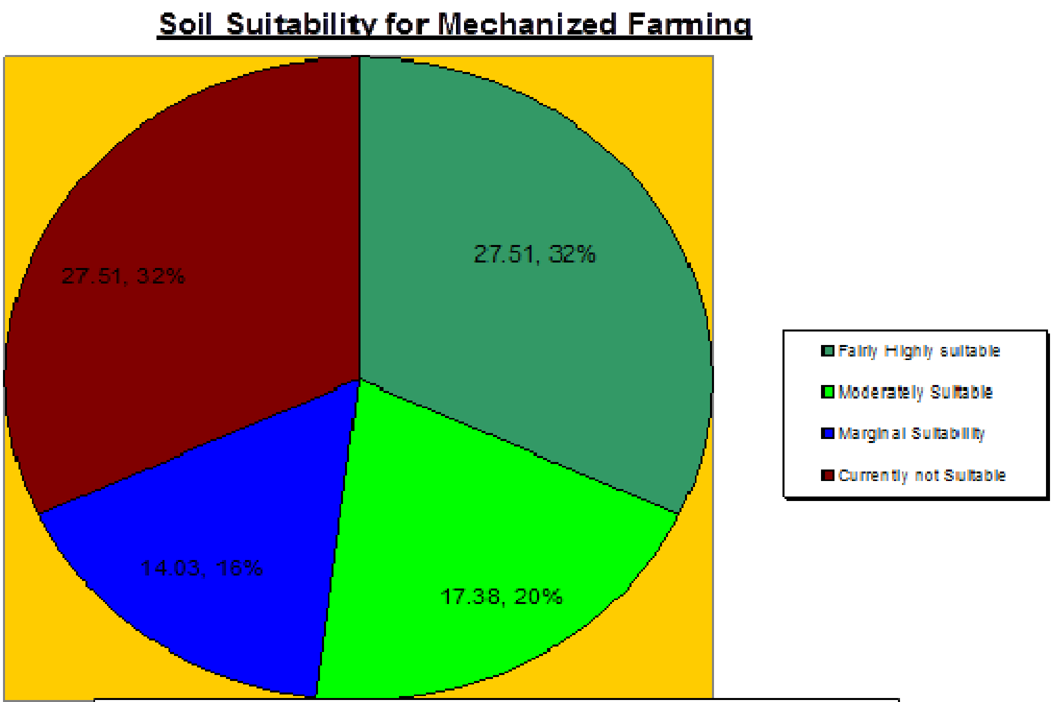

Fig 10: Pie Chart showing soil suitability to Mechanized Farming

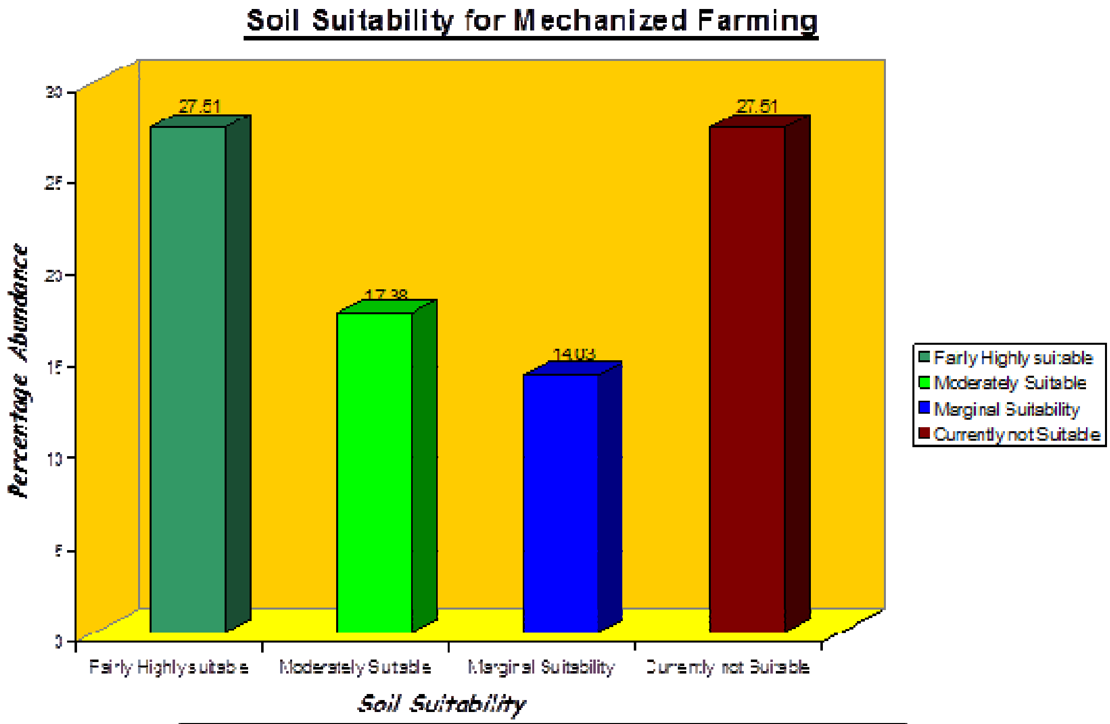

Fig 11: Bar Chart showing soil suitability to Mechanized Farming