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Research Article

Digital Mapping of Soil Chemical Properties for Erosion Hazard Management in Bayelsa State, Nigeria

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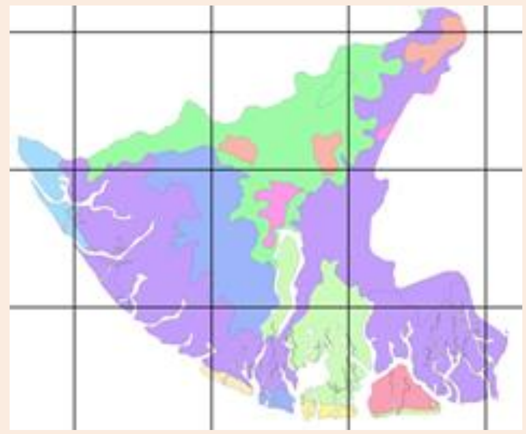
Abstract

A possible way of enhancing the accessibility of data relating to soil chemical properties such as soil pH scale for addressing the challenges of erosion hazard in Bayelsa state, Nigeria is presented in this paper. Besides flooding and rapid population growth along with climate change concerns, the environmental and socio-economic impacts of erosion hazard in Bayelsa are critical issues. The economic significance of this part of Nigeria highlighted by extensive oil exploration suggests the need to focus attention towards sustainable development. Against this background, it is important to explore the prospects of maps which delineate soil chemical properties particularly soil pH scale. How this map is derived for Bayelsa is the focus this study. Sheets 7 and 8 of hardcopy soil map of Nigeria each at a scale of 1:650,000 were scanned and spatially referenced to WGS 1984 coordinate system. In a GIS, vector form of these maps representing Bayelsa was created and linked to soil aspatial data of the area obtained from Federal Department of Agricultural Land Resources (FDALR). Then by spatial analysis of the resulting vector map, the digital soil pH scale map for the area was derived. The result of the study showed a pH scale that ranges from 4.5 to 7.3 for eleven soil mapping units including 1b, 1c, 7c, etc., Environmentalists, large-scale farmers, telecommunications operators and erosion hazards managers among other users of soil will find this result vital to reducing cost and time implications of collecting data relating to soil chemical properties.



Keywords: Soil chemical properties, Environmental challenges, Digital Soil pH scale map, Digital soil mapping, Erosion, Bayelsa state, Erosion management, GIS, Soil mapping unit

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Introduction

Concerns for erosion hazard have increased in recent times due to the range of associated environmental and socio-economic impacts which include land degradation, sedimentation of aquatic environment and air-borne dust pollution [1]. The severity of the hazard alongside rapid population growth and urbanization, as well as climate change especially in increased rainfall frequency and intensity is increasing the need for sustainable development and for assisting social systems to cope with the hazard through ensuring food security and building social capacities [2].

For Bayelsa state Nigeria, the incidences of such a hazard, attributed mainly to natural processes and anthropogenic activities as well as climate change have been traumatic, affecting large numbers of human populations, developmental infrastructure and economic activities [3-5]. Invariably, the lack of a lasting solution to the menace has subjected many victims in the area to untold hardship. Although government at various levels alongside other stakeholders has come up with various measures to address the menace, however success so far seems limited. Moreover, the economic significance of Bayelsa with respect to Nigeria's net GDP vis-a-vis widespread flooding in the area which appears to be intensifying erosion episodes suggest the need for intensified efforts and more so research towards finding a solution.

Existing knowledge regarding this situation is unsatisfactory and fails to provide lasting solution with means of reducing the socio-economic and environmental impacts of erosion. Few studies which considered erosion in the area focused attention on the causes and impacts with insufficient contribution towards remedies [1, 5, 20]. Despite such contributions, the question “what are the remedies to erosion hazard in Bayelsa state, Nigeria?” remains unanswered. Arguably, this poor attention given to erosion hazard management in the area and the limited scope and application of few studies not only create a yawning gap in knowledge in the area, but also could result in the increased social damage in the future.

At the heart of all that has been proposed as possible natural causes of the erosion hazard in Bayelsa is soil composition especially the soil pH values and this prompts the need to address the soil distribution in the area for effective erosion hazard management. Unfortunately, apparent lack of quantitative, accurate and up-to-date data relating to soil chemical properties in the study area seems to constrain such investigation. Future scientific studies requiring such data will suffer the similar fate, and thus, creating a gap between soil data and solutions to soil related issues. To fill this gap, the present study undertakes digital mapping of soil pH scale of Bayelsa state using a GIS technology.

Soil is a valuable natural resource, which provides the basis of human existence. Almost all ecological components depend on it for survival, as it provides physical support and nutrients. Housing, industrialization, economic activities, mining, fishery, transportation and all activities that constitute the circle of life such as procreation and extinction, including adverse environmental events one way or the other relate to the soil. Thus, knowledge about soil plays a significant role in its utilization and management [8].

Knowing the soil involves describing it and providing information about its abundance and spatial distribution. Conventionally, describing the soil often starts with measurements and analysis by experts. Soil information such as drainage, ecology, mapping units, classification type, texture, pH, 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 were produced using the qualitative approach, which have aided in providing adequate data to support several agro-based and scientific projects, the accuracy and reliability of such supporting data remains questionable. The methodology has been considered to be slow, time consuming and expensive [6] and whilst the resulting soil maps often suffer from dimensional instability and geometric distortion [7-8], it tends not to be suitable for quantitative purposes [9]. Thus, the need for quick, quantitative, up-to-date, high resolution and more accurate soil data seems to overwhelm the qualitative soil maps. The fulfillment of this need is undoubtedly the mission of digital soil mapping.

Digital soil mapping generally is a task towards optimizing the usefulness of soils in many places. Some studies (example [10-11]) 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 [(example [12-13]) that spread across local, national and regional levels. New sets of data often result from further analysis of data obtained by such operations [9, 14], and they tend to help overcome the limitations placed by traditional soil maps.

With all these benefits and bearing in mind the need to achieve a more substantial goal of managing erosion hazard in Bayelsa, Nigeria, the aim of this study is to derive a quantitative map of soil pH scale to support environmental scientist and erosion hazard experts in their present efforts. This will be beneficial for understanding the causes and solution of erosion hazard in the area. Moreover, future scientific studies having to do with soil can equally benefit from this. At the same time it will assist towards building food security and ensuring sustainable development.

Thus, to address the question of remedies to erosion hazard in Bayelsa, the following objectives are considered:

1. *to investigate and summarize evidence of erosion hazard in Bayelsa, Nigeria,*
2. *to produce a digital map of soil pH scale, and*
3. *to make possible recommendations to stake holders*

Bayelsa state, Nigeria and experiences of erosion hazard are considered in the next section. Then, data and methodology for producing a digital soil pH scale map of Bayelsa are presented. The study results are presented and discussed in the section thereafter, while the final section concludes the paper.

Bayelsa State and erosion hazard

Bayelsa, a coastal state located within longitudes 5^o 20' and 6^o 50'East and latitudes 4^{o}10' and 5^o 25' North is in the Niger Delta region of Nigeria, West Africa (See figure 1). The state which was created in 1996 by the then military head of states has a land area of about 21,000 km^2, most of which is in fact wetlands [15]. Its coastline stretches up to 185km through which many rivers issue into the Atlantic Ocean [16]. About 6% of the rivers, creeks and estuaries in the Niger Delta are in Bayelsa. With crude oil and natural gas deposit in large quantities, petroleum production with concomitant environmental and socio-economic impacts is extensive in Bayelsa state.

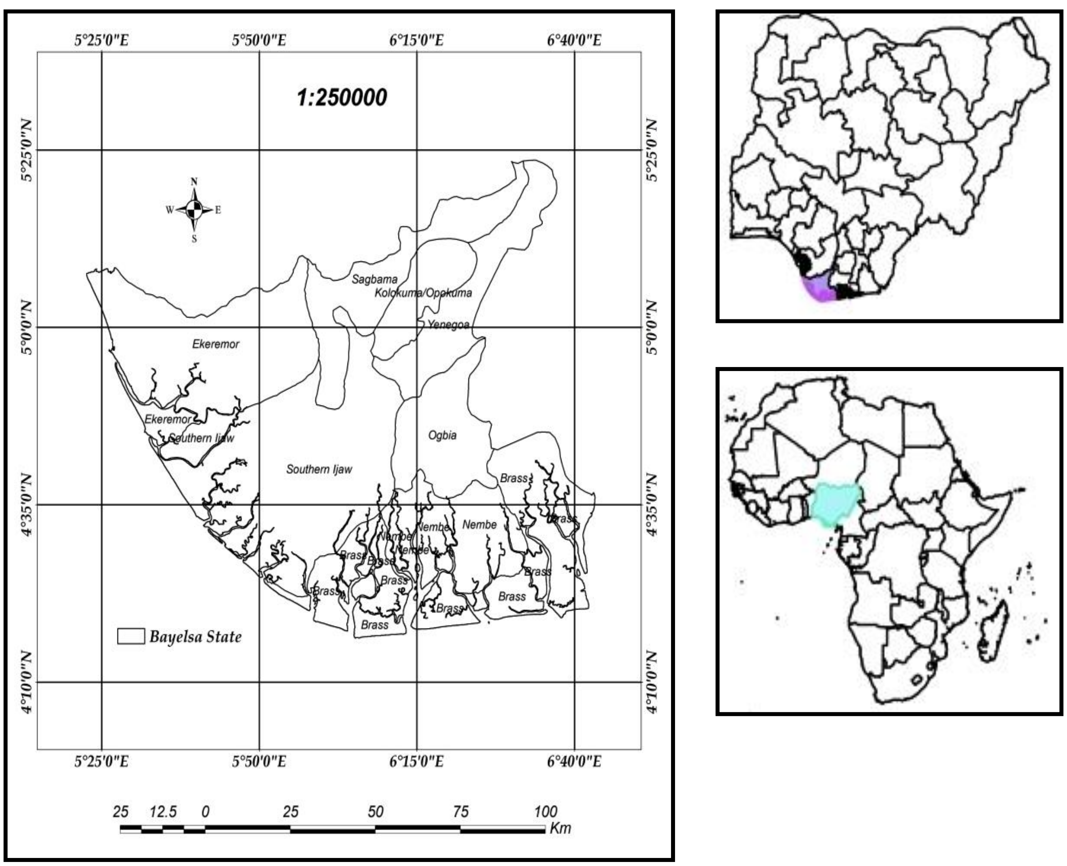

Figure 1 Map of Bayelsa state showing its location in maps of Nigeria and Africa
Source: Drafted by author

Soil is an important resource in Bayelsa due mainly to the fact that farming, hunting and fishing have been the major occupations of the original and present-day inhabitants of the area. Invariably, soil distribution in this area has attracted much attention especially with regards to its resistivity and seasonal variation [17-19]. Recent characterization of the soil distribution in Bayelsa identified important characteristics such as seasonal water logging, moderate pH value (6.1-7.3), much salt content due to the salt spray from the ocean and the subsoil water, many submerged swamps during high tide, silt sandy clayey soil and powdery white when dry and caked under intensified prolonged sun [20]. Towards the land area, the soil distribution that forms the basis of most anthropogenic activities, described as coastal soil, occupied about 50% of the total land area [20].

The nature of this soil distribution in Bayelsa generally appears to predispose it to be affected easily by flood and erosion hazards. With regards to erosion, significant impacts which are arguably overwhelming affect both rural and urban areas in the area [21]. Damage to road network and urban infrastructure by erosion hazard seems to undermine the access many communities have to market and sources of drinking water and electricity (See figures 2(a-d)). However, land degradation which invariably leads to food insecurity and resources mismanagement is critical. As observed in [1], the World Bank estimates that soil degradation affects over 50 million people in Nigeria and accounts for the loss of resources amounting to USD 3000 million per year.

Figure 2 The impacts of erosion on: (a) urban drainage infrastructure and underground utility, (b) ongong urban development project, (c) road network, and (d) causing land degradation.
Source: Author's field work and online images of ersion hazards in Bayelsa, Nigeria.

Method and Data

The main data required for this study are sheets 7 and 8 of the existing hardcopy soil maps of Nigeria each at a displayable scale of 1: 650,000, vector map of Bayelsa state and soil metadata contained in the reconnaissance soil survey report of 1990. The soil datasets and their metadata were acquired from Federal Department of Agricultural

Land Resources (FDALR) [22] Abuja, while the vector map of Bayelsa state was digitized from existing South Eastern political map of Nigeria at a scale of 1:250,000 acquired from Office of the Surveyor General of the Federation (OSGof), Abuja, Nigeria.

Sheets 7 and 8 (figure 3) of the hardcopy soil map of Nigeria were prepared by electronic scanning and referenced spatially to WGS 84 UTM coordinate system using ESRI ArcGIS 10.2 version GIS software. Image mosaicking and sub-setting operation were subsequently performed on the resulting raster layer in order to create a seamless raster layer and then to extract the area of interest - Bayelsa state. Both operations were done in Hexagon Geospatial ERDAS IMAGINE 2013 version.

In ArcGIS 10.2, the raster subset layer was vectorised into polygons of various soil mapping units delineated in Bayelsa state Nigeria. Soil metadata for the study area contained in the FDALR soil survey report were used to create and populate the attribute table which was then linked to the vector polygon layer (spatial data). Finally, the soil database (consisting of the spatial data and attribute table) were spatially analyzed by means of *"symbology"* tool in ArcGIS to derive the digital soil pH scale map (figure 4). Queries were written in structured query language (SQL) (figure 5), and built into the database for easy access of the map to end users.

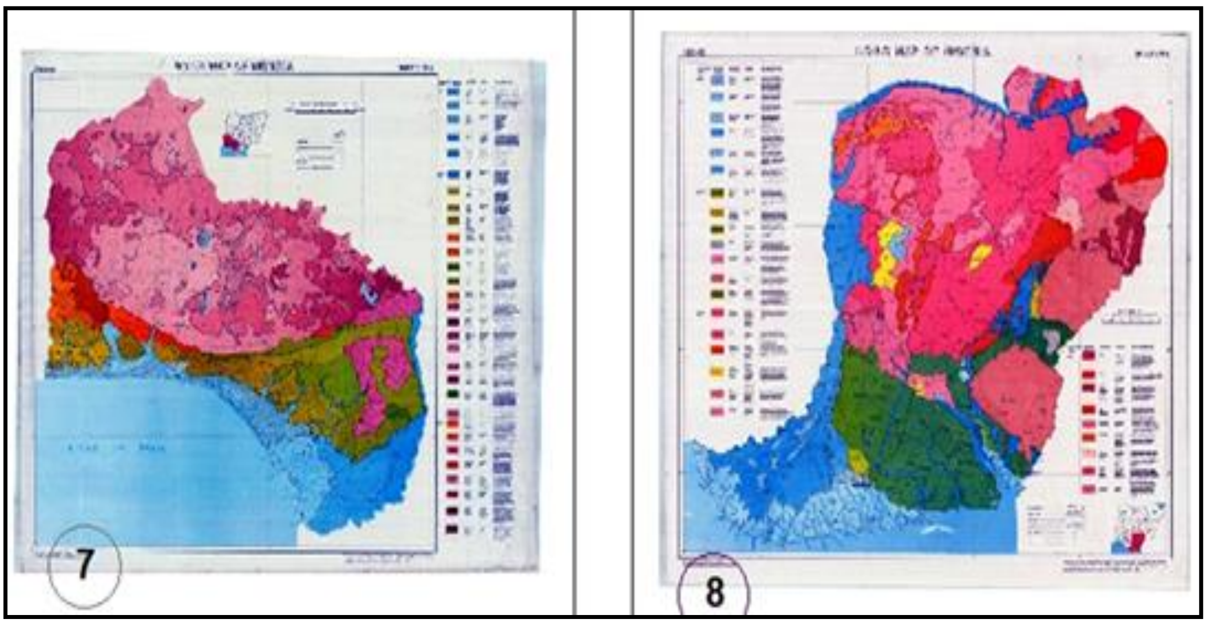

Figure 3 Sheets 7 and 8 of the hardcopy soil map of Nigeria each at a scale of 1: 650,000
Source: Federal Department of Agricultural Land Resources (FDALR, 1990)

Results and Discussions

The major result of this study is the digital soil pH scale map of Bayelsa state, Nigeria (figure 4) which demonstrates how a digital technology such as GIS can support easy access to data relating to soil chemical properties such as soil pH scale. From this map, eleven soil mapping units (1b, 1c, 7c, 8a, 13a, 15c, 15g, 17a, 18d, 22c and 24b) were identified which describes the range of soil pH scale in the study area. Soil mapping unit 24b, 18d and 7c with pH scales 5.1- 6.6, 5.5 – 6.3 and 5.6 – 6.5 and their percentage distributions in the study area 45.12 %, 21.62% and 19.13% respectively appear to be more dominant in the area. (See table 1 for a summary of these findings).

Many studies regarding erosion hazard in Bayelsa has implicated soil pH [1, 20] but none has undertaken a more critical investigation into these soil components. It is important to note that although the chemical characteristics (soil pH in particular) of such soil mapping units predispose the soil distribution of Bayelsa to susceptibility to erosion hazard, however, such characteristics equally have relative merits that can be put to good effects towards enhancing food security in the area. In view of this assumption the study strongly recommends a 'consideration of soil suitability' concept in the use of soils. This concept originated in this study seeks to take advantage of soil distribution in an area by prioritizing their specific merits whilst at the same time exploring ways of addressing their specific limitations. Investigations should be carried out towards what each soil is most suited for and concentrating soil usage on such activities. However, such investigations are adequately enhanced by the availability of digital soil data, which this study has attempted to derive in terms of soil pH scale. Although, GIS technology has been applied, a number of other techniques are available in the literature. For example, in developed countries, the use of mathematical modeling is underlined [23]. With the production of a digital soil pH scale map, it can be argued that accessibility of soil quantitative data for Bayelsa which yields easily to such scientific investigations has been enhanced.

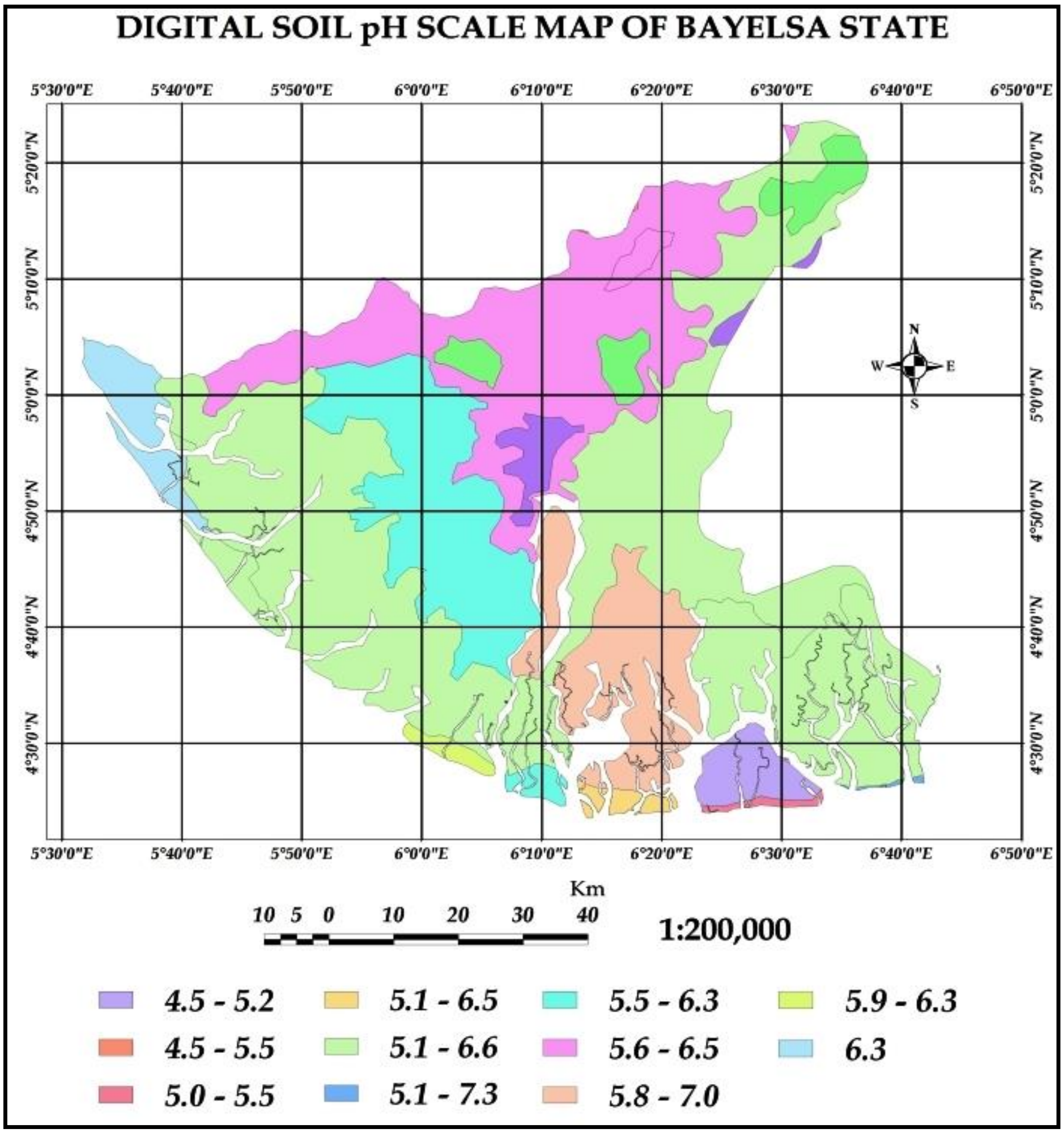

Figure 4 Digital soil pH map of Bayelsa state showing the pH scale of various soil mapping units that predominate in the area. An important feature of this map is that the scale can vary according to the users' needs

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Query 1: [pH Description] =     'Very Strongly Acidic' = 'Very
                                Strongly Acidic'

Query 2: [pH]             =     '5.1 -6.5' = '8a'
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Figure 5 SQL for extracting soil information from the digital soil pH scale map of Bayelsa state

Table 1 Summary of research findings which include soil mapping units and their percentage distribution across Bayelsa state, pH scale and descriptions

S/No.	Soil Mapping Unit	% Distribution	Soil pH range	Soil pH description
1.	1b	2.01	*4.5 - 5.2*	Very strongly to generally acidic
2.	1c	0.27	*5.0 - 5.5*	Acidic
3.	7c	19.13	*5.6 - 6.5*	Moderately to slightly acidic
4.	8a	0.56	*5.1 - 6.5*	Strongly to slightly acidic
5.	13a	0.07	*5.1 - 7.3*	Strongly acidic to slightly basic
6.	15c	0.53	*5.9 - 6.3*	Moderately to slightly acidic
7.	15g	2.56	*6.3*	Slightly acidic
8.	17a	0.02	*4.5 - 5.5*	Very strongly to generally acidic
9.	18d	21.62	*5.5 - 6.3*	Very strongly to slightly acidic
10.	22c	8.12	*5.8 - 7.0*	Slightly acidic to neutral
11.	24b	45.12	*5.1 - 6.6*	Strongly to slightly acidic

Conclusion

The challenges of erosion hazard in Bayelsa state of Nigeria requires attention with regards to sustainable development, capacity building (especially for local communities towards food security and improved means of livelihood) and improved efforts of various stake holders for better management of the hazard. The present study has demonstrated how to produce a digital soil pH scale map of Bayelsa state Nigeria using a GIS technology. This map is believed to assist in understanding the dynamics of erosion hazards in the area and providing solutions to the same. A significant contribution is made towards solving the problem of paucity of quantitative and accurate soil data. Thus, it tends to serve as facilitator towards research in food security for Nigeria and other social and environmental issues such as environmental sustainability, wealth creation and poverty alleviation.

The study is limited to production of such soil pH scale map using GIS technique as that is the only available hardcopy information to the researcher at the time of the study. Although, besides such a map, there are other chemical properties that soil is made of, the study concentrates on soil pH values. However, it is recommended for future study to investigate and digitally map other possible chemical constituents of the soil of Bayelsa state. No attempt has been made to evaluate the accuracy of the generated soil pH scale map, so as to know the extent to which the results can be relied upon, Further study is therefore recommended, which can take advantage of remote sensing technology to assess the reliability of the study outputs, as well as verify the assumption that possible solution to erosion hazard in the study area largely depends on investigation of soil pH scale, which the present study has attempted to simplify its access by a creating a digital version of the existing hardcopy soil map.

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