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GEOTECHNICAL MODELING OF LANDSCAPE SENSITIVITY TO SOIL EROSION IN PARTS OF EBONYI AND CROSS RIVER STATES NIGERIA

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ABSTRACT

A study was carried out to determine the susceptibility of soils in some parts of Eastern Nigeria to erosion. This is with a view to developing regional scale maps and identifying combinations of soils, landforms and land cover that may respond to climate variability. The Revised Universal Soil Loss Equation and Geographic Information System were used to model the landscape sensitivity of the area. The results obtained from the field and laboratory investigations, aerial photographic survey, land use and land cover classifications as well as topographical maps were digitized to determine the soil losses. The results suggest that a total of 56.07% (1829.72km^2) is potentially endangered while actually, 7.48% (243.04km^2) is endangered, thus soil erosion is not ravaging this part of eastern Nigeria as widely reported for other areas. The cover practice significantly reduced the high risk of erosion to moderate and perhaps manageable level. Adequate precaution is therefore necessary if the vegetation is to be disturbed for any form of development. An important feature of the model is a development of zoning map that shows developable areas and associated geotechnical/geological hazard and risk.

1.0 INTRODUCTION

1.1 Preamble

It is estimated that one sixth of the world's soils are affected by water erosion [1]. The long term impact of gully erosion on the sustainable net National product of Nigeria was estimated at about US$ 100 million per year by the World Bank in its 1990 environmental action plan [2]. Report [3] showed that Anambra and Enugu States have over 500 active gully complexes, with some extending over 100m long, 20m wide and 15m deep.

The changes in Eastern Nigeria landscape will continue for quite some time, as a result of a variety of social and economic forces, including food production, housing needs, transport issues, and energy requirements.

The ecosystem on which societies of Eastern Nigeria depend is showing many signs of stress due to over exploitation. A systematic understanding of the changes in the land use and land cover is critical to the understanding of the ecosystem functioning and services, and human welfare. The areas already suffering from erosion damage require remedial measures and readily attract the attention of the public and government. It thus becomes necessary to identify areas of serious erosion risks in order to take preventive measures. Such preventive measures become more and more important as more lands are being cleared for various infrastructural developments.

The main aim of this study thus is to develop regional scale maps and identify combinations of soil, landforms and land cover that may respond to climatic variability and change with changes in the rates of earth surface process from which action plan can be created using the geo-data base and total support system that may be informed by this study to control/minimize soil erosion in the study area.

The first types of erosion survey were essentially static in concept and consisted of mapping, often from aerial photographs and concentrated on eroded area. Erosion hazard was estimated by calculating simple indices such as gully density. No attempt was made to map the factors that influence erosion and which could therefore provide the basis for predicting change [4]. More recently, the need for dynamic approach in which both erosion features and the factors influencing them are mapped and the relationships sought has become apparent. Regional scales soil erosion research is a general evaluation of the landscape and its susceptibility to erosion, taking into account only the main factors (rainfall, vegetation, topography/slope and soil type) influencing the process. The main factors, rainfall [5], [6], [7], vegetation [8], [9], [10], soil properties [11], [12] and topography have been described in details. The erosion assessment at regional scale is based on empirical models or expert evaluation, resulting in map (GIS database) consisting of regions with different susceptibility to soil erosion [13].

1.2 The Study Area

The study area (figure 1) covered by topographic sheet 303 is located within longitude $8^{o}\ 00^{1} - 8^{o}\ 30^{1}$ and latitude $6^{o}\ 00^{1} - 6^{o}\ 30^{1}$ is also within South Eastern Nigeria. The study area covers part of the eastern flank of Ebonyi State and also part of the western flank of Cross River State with a land area of $3249km^{2}$.

The geological formation in the area is the Asu River Group, which consists mainly of shale, with siltstone and limestone horizons and with igneous bodies. The structure is controlled by the Abakaliki uplift and the Afikpo syncline. The rocks are the most deformed by the folding and faulting. The shale which cover almost all the basins have been aggregated to an almost flat topography, features have been created by sand bodies, which form occasional ridges in some parts of the project area, and by some isolated hill formed by igneous rock.

Lithologically, the study area is of poorly bedded sandy shale with fine to medium grained sandstone lenses with massively bedded, grey chalky limestone with fossils. Also, cross bedded coarse to medium grained immature sandstones with basal conglomerates and arkoses form the lithology.

1.3 Model Selection

The main guiding principle when selecting a model is availability of the data form and the reasonableness of the model. It is imperative that the selected model meet the objectives or the design requirement of the research. Physically based models are more appropriate at catchments scale while empirical models are appropriate at larger catchments (Regional) scale. Empirical models are generally applicable only to those conditions for which parameters have been calibrated [14]. On the other hand, conceptual models usually incorporate general description of catchments processes without specifying processes interactions that would require very detailed catchments information [15].

Empirical models are generally the simplest of the three model types. They are based primarily on the analyses of field experiments and seek to characterize the response from these erosion plots using statistical inference. They are particularly useful as a first step in identifying the sources of sediments. Empirical models are often criticized for employing unrealistic assumptions about the physics of the catchment system, for ignoring the heterogeneity of catchment inputs and characteristics, such as rainfall and soil types, and for ignoring inherent non linearity in a catchment system [16]. While these criticisms are valid, insufficient meteorological networks and the spatial heterogeneity of soil restrict the use of more complex models. Such models are generally based on the assumption of being stationary, which assumes that the underlying conditions remain unchanged for the duration of the study period. This assumption limits the potential of empirical models for predicting the effects of catchment change. Furthermore, empirical models tend not to be event- responsive, neglecting to model the processes of rainfall-runoff in the catchment [17]. The validity of a model is judged by how well it serves its intended purpose [18].

The Universal Soil Loss Equation (USLE) is a well known, widely used empirical model [19]. USLE was developed as a tool to predict soil erosion from crop land on a hill slope and also to assist soil conservationists in farm planning [20], [21]. USLE cannot deal with deposition; its applicability limits large areas and watersheds [19]. It was on the bases of these limitations that several other models were developed [22].

The Revised Universal Soil Loss Equation (RUSLE) which has been selected for this investigation is a review of the USLE that has been described in details by [20], [21]. RUSLE updates the information in data required after 1978 release, and incorporates several process-based erosion models [23].

RUSLE remains to be a regression equation of USLE: A=RKLSCP. Where A = Soil loss (tons/ha/yr); R = the Rainfall erosivity factor, which equals the potential energy; K =soil erodibility factor; SL = the topographic factor; C =the plant cover and farming technique and P =erosion control practices.

RUSLE/GIS interface provides such a methodology for regional level analysis of soil erosion. While it is likely that application of non complex models than RUSLE can provide more accurate estimates of soil erosion for specific sites, the data requirements of these models make them difficult to use on a regional scale [24].

2.0 METHODOLOGY

2.1 Rainfall

Average monthly rainfall data, spanning over 21 years (1980-2000) for Ikom and obtained from Federal Meteorological Centre Oshodi were used to compute Rainfall Erosivity (R) for the study area. The equation used to calculate R was (R = 3786.6 + 1.5679* (Precipitation in mm) – 1.9809* Elevation in mm).

2.2 Topography

Topographical maps of scale 1:50,000, produced in 1963 and obtained from the Federal Department of Survey were used. The topographical maps were scanned using SCAN-PLUS IV 436Cx, digitized and a Digital Elevation Model (DEM) was first created using ArcGis before the necessary computations of flow direction, cumulative and non cumulative slope length as well as slope angle that were subsequently used to obtain the Slope-Length.

It has been acknowledged [25], [20] that in using USLE, the greater challenge is generating the topography factor. Traditionally, the best estimates for slope length (L) are obtained from field measurements, but these are rarely available or practical [25]. The particular algorithms that have been developed to calculate slope length include grid-based method [26], [27]. The RUSLE equation to calculate the LS values is: $LS = (\ell/72.6)^m(65.41\sin^2\beta+4.56\sin\beta+0.065)$.

Where ℓ is the cumulative slope length (ft.), β is downhill slope angle (degrees), m is slope contingent variable.

2.3 Vegetation Classification

A Land sat Enhanced Thematic Mapper (ETM +) image covering the study area (path 202, row 055, acquisition date of December 17, 2000) was used in the analysis. The ETM+ was obtained from the United States Geological Survey (USGS). The image was obtained as geometrically and radio metrically corrected (level IG) data in digital number (DN) values. The image was rectified using 1^{st} order polynomial rectification.

The satellite image was decoded using ERDAS software. Unsupervised classification was performed on the crisped, clipped image using the ISODATA procedure. Supervised classification was performed on the same image with random training samples digitized with the AOI TOOLS features. The desired classes were assigned to the image undergoing supervised classification.

2.4 Field Survey

A comprehensive field survey was conducted during which soil samples were collected and subjected to laboratory tests to investigate their engineering properties. The sampling points were determined using hand held Global Positioning System (Garmin GPSmap 76CSx). The depth of boring was limited to 0.4m. Thomas Asworth moisture meter was used to determine the in-situ moisture content of the soil. Visual inspection was used to determine the soil colour, vegetation and land use pattern.

2.5 Laboratory Investigation

The soil samples collected during the field investigations were first air dried and laboratory tests were carried out in order to determine the soil group. These tests were carried out in accordance with the American Society for Testing of Materials [28] Standards.

3.0 RESULTS AND DISCUSSIONS

3.1 Field Investigation Results

A total of 107 soil samples (figure 2) were obtained. RUSLE only predicts the amount of soil loss that results from sheet or rill erosion on a single slope and does not account for additional soil losses that might form gully or wind tillage erosion [29]. While rill could have incision up to 0.4m, any incision above that is gully hence the study was terminated at 0.4m since any value below this limit is not covered by the RUSLE. The results of the field investigations showed that the soils in the study area are predominantly reddish brown gravelly sandy clay.

The natural moisture contents of the soil samples taken in-situ ranged between 3.2 to 19.0% with an average value of 11.91% and a standard deviation of 3.49. The soil colours were in combinations (mottled) of red, brown, grey, yellow and ash but mostly red, brown and yellow. Reddish soils are generally well drained while yellow and yellowish brown soils as well as yellow mottled soils are poorly drained. Thus, the soils in the study area range from poor to well drained but mostly poorly drained.

3.2 Rainfall Erosivity (R) Factor

The R-factors at 50m, 100m, 150m, 200m, 250m, 300m and 350 m above sea level were 413.34, 407.52, 401.70, 395.88, 390.06, 384.24 and 378.42 respectively. The R factor has a range of 378.42 to 413.34 with a mean of 395.88 and a standard deviation of 11.64. The results suggest that the R value is a function of altitude.

3.3 Slope Length (SL) Factor

The range of the elevation was 50m to 350m. The non-cumulative downhill slope length has a range of 0 to 5657m and cumulative range of 0 to 46,142m. Similarly, the slope angles have a range of 0 to 2.86.

3.4 Crop (C) and Control Practice (P)

Vegetation analysis is used to obtain Crop (C) and control Practice (P) factors. The total area investigated was 3249km^2 of which 1139.42km^2 (35.07%) was under cultivation while settlements (cities, towns and villages) making up of the built up areas covered 244.65km^2. Vegetation ranging from native forest (gallery) to light vegetation covered 1576.09 (48.51%). The area that could be subjected to erosion as at the time of investigation are the bare soil, area under cultivation and around built up areas occupying 1384.07km^2 (42.60%).

In agricultural uses of the RUSLE, P is used to describe contouring, terracing, strip cropping, ploughing and tillage practices. In construction site applications, P reflects the roughening of the soil surface by tractor treads or by rough grading and raking. Roughening the soil surface is essential before seeding because it greatly increases plant establishment and thus also reduces the C-factor. Since no conservation practice was observed during field investigation, P value of 1 was assumed.

3.6 Landscape Sensitivity Mapping

The laboratory test results have been used to classify the soils based on Textural and Unified classification. The results showed that the soil samples collected predominantly contain gravel. Sandy soil group accounted for 3.73% of the soil samples of which Gravelly Sandy Loam dominated. Similarly, the silt group constituted 74.75% of the soils and Gravelly Silt Loam accounting for 35.51% was the major soil class within the group. Within the clayey soil group that accounted for 13.08%, Gravelly Clay Loam with 6.54% occurrence dominated. Although the textural class groups showed that the soils with high silt content (74.75%) are the most erodible, the gravel content could account for the high percentage of low to moderate erodibility as observed when the sand, silt and clay contents values were factorized to account for the gravel content. Highly and very highly erodible soils constituted 7.48% and 1.88% respectively. Also, low and moderately erodible soils accounted for 58.88% and 31.78% respectively.

Generally, soils with high silt content are most erodible [30]. These are silt, silt loam, silt clay and silt clay loam. Within the study area, these soils accounted for 74.75% of the soils analysed. The intervals delineating the K erodibility value subsequently used to classify K (figure 3) have been defined [31]. In determining the soil boundaries, results from remote sensing survey were used using a mosaic prepared from panchromatic aerial photographs. The erodibility class showed that Low (0.05-0.25), Moderate (0.25-0.45), High (0.45-0.65) and Very high (>0.65) constituted 58.88%, 31.78%, 7.48% and 1.88% of the study area respectively.

It has been acknowledged that there is not yet a simple and universally accepted erodibility index for soils. Instead, various tests have been proposed for this purpose.

However, a suggested hierarchy of soil erodibility based on the Unified Soil Classification System that is widely used grouped ML, SM, and SC soils as most erodible, MH, OH, and CL as moderately erodible soils, while GM, GP and GW are the least erodible soils. Consequently, using the unified soil classification system, the soils in the study area could be said to range from least to highly erodible but mostly within moderately to highly erodible. The soils are predominantly CL that account for 38.32% of the soils analysed. The other major soil groups found in the area of study are SC, GC, CH, CL-ML, SM, MH and GM that accounted for 25.23%, 13.08%, 12.15%, 5.61%, 2.80%, 1.87% and 0.93% respectively.

The Plasticity Index that is an indication of the swell potential of any soil varies from 2.2 – 51.9 with a mean and standard deviation of 19.87 and 10.92 respectively. It is observed from the plasticity chart (i.e. plot of liquid limit versus plasticity index, figure 4) that 88% of the samples are above the A-line. In addition, the plot tends to lie parallel to the A-Line. This implies that the soils are in the same formation. In other words, these soils tend to have about the same engineering behavior.

The derived RUSLE factors were used to determine the susceptibility of the study area to soil erosion. The assessment approach for the study area involves two steps. One is the calculation of the Potential Annual soil erosion (A_p = RK (LS)) and the other Actual Annual soil erosion (A_a= A_pCP). The resulting actual and potential soil erosion data layers are presented in figures 5 and 6. The intervals delineating the soil erosion classes are as outlined [32]. Actual erosion represents the actual soil that is expected to be eroded considering all the parameters that influence or cause soil erosion as at December 2006 when the field and laboratory investigations were carried out.

Similarly, potential erosion is a situation where the study area is exposed to the eroding agents without vegetal cover and conservation practice that is when the C and P factors are equal to 1. Potential erosion suggests the worse condition and is an important tool in land use planning for sustainable development.

The potential soil eroded within the study area is 5686.05t/ha/yr. The highly and very highly erodible soil loss was 1821.72t/ha/yr that constituting 56.07% of the area investigated. The mean actual annual soil loss was 53.14 tons/ha/year and a standard deviation of 67.58. The actual soil eroded within the study area is 1725.13t/ha/yr. The highly and very highly erodible soil loss area was 243.03km^2 (7.53%). The mean actual annual soil loss was 16.12t/ha/yr with a standard deviation of 23.65. It could be observed that the very low erodible areas were in places where elevation was 100m.

A total of 56.07% (1821.72km^2) is potentially endangered which are the highly and very highly erodible soil while actually, 7.48% (243.04km^2) is endangered.

Moderately, potential erosion (32.71%) is almost the same as actual erosion (38.72%).

The cover practice significantly reduced the high risk of erosion to moderate and perhaps manageable level and thus calls for caution if the area is to be disturbed. It could also be posited that although on the average, soil erosion is significant, at the moment the study area is not under any serious erosion threat as in other parts of Eastern Nigeria as widely reported. Similarly, there were not much significant changes especially in the moderate class between the actual and potential annual soil loss. The difference between actual and potential annual soil loss is 3960.92t/ha/yr (69.99%).

5.0 CONCLUSION

The four factors of vegetation, rainfall, soil types and topography that cause or influence soil erosion were modeled using RUSLE model in a GIS environment to determine the susceptibility of some parts of Ebonyi and Cross River States to soil erosion. The investigation was carried out on the field, in the laboratory and materials obtained from literature using physical tests, topographical maps and aerial photographs to evaluate the soils in the study area.

From the investigation, a total of 56.07% (1821.72km^2) was found to be potentially endangered while actually, 7.53% (243.04km^2) is endangered. The difference between actual and potential annual soil loss is 3960.92t/ha/yr (69.99%). The cover practice (vegetation) significantly reduces the high risk or erosion to moderate and perhaps manageable level in the study area. Consequently, adequate precaution is necessary if the vegetation is to be disturbed for any form of development.

An important feature of the model is a development of zoning map that shows developable areas and associated geotechnical/geological hazard and risk. The generated information can be implemented for further planning of the urban areas. Action plan can be created using the geo-database and total decision support system can be developed to depict location and type of action/control measures recommended for sustainable development plan for natural resources.

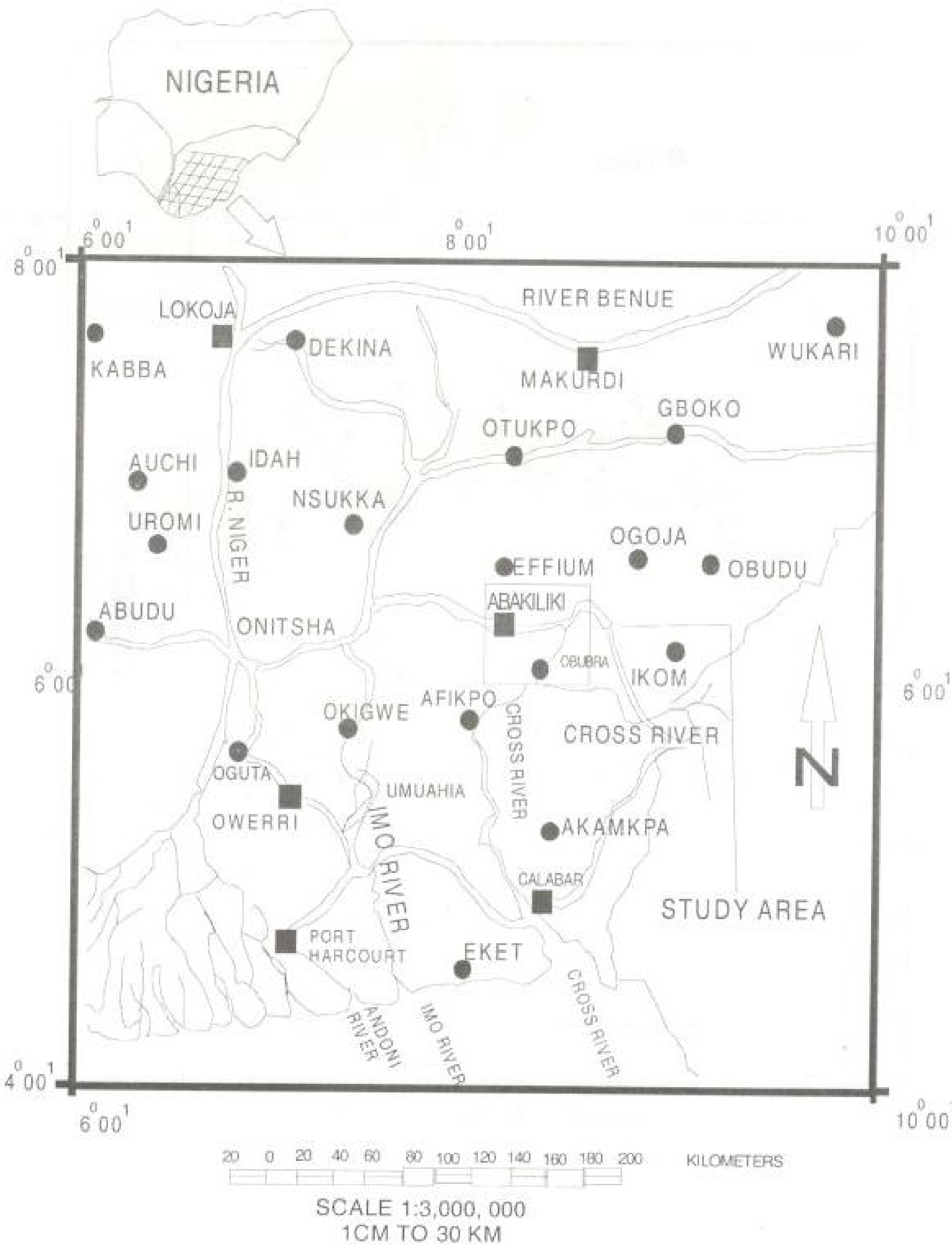


Figure 1 : Map of South Eastern Nigeria showing the Study Area

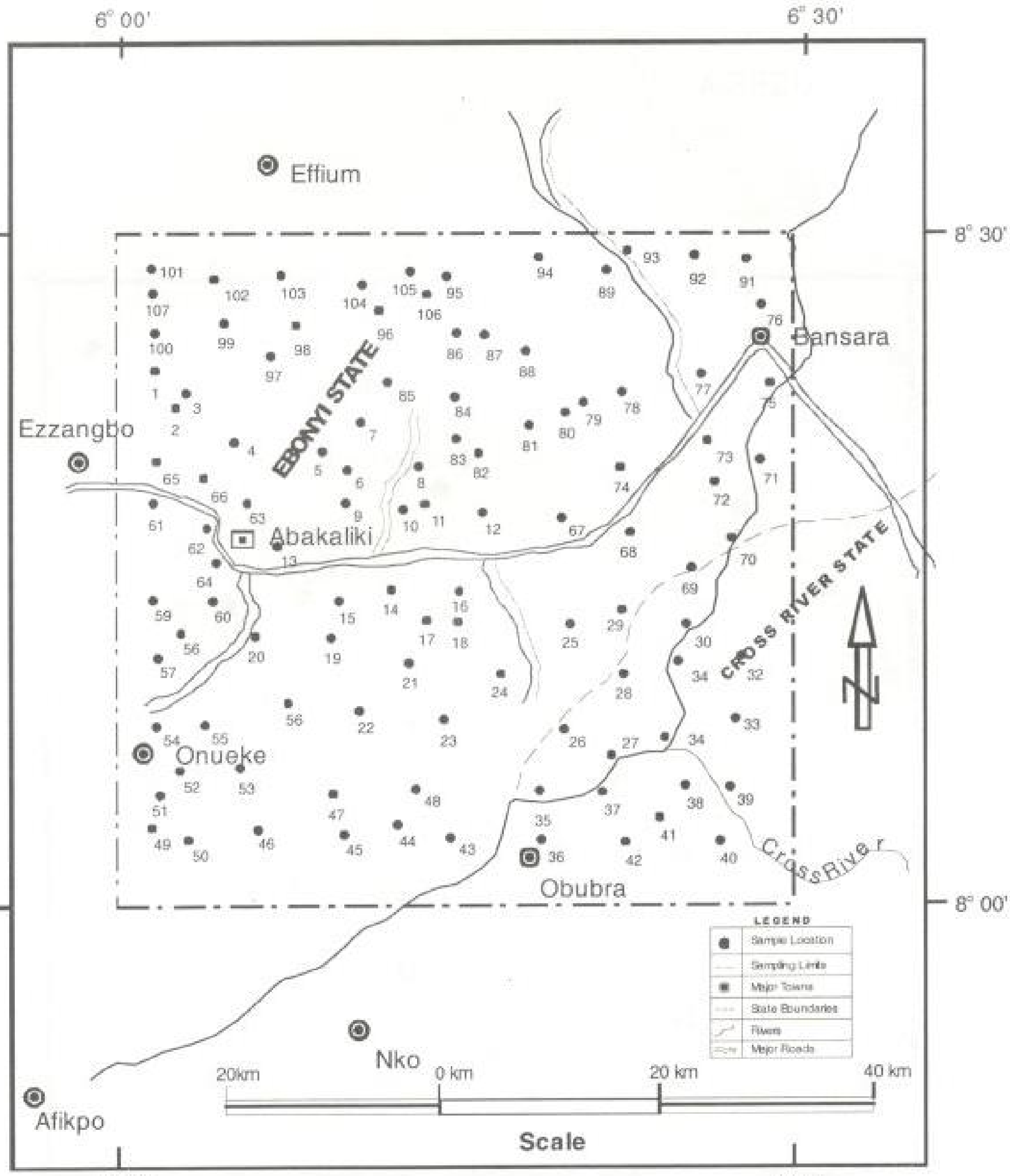
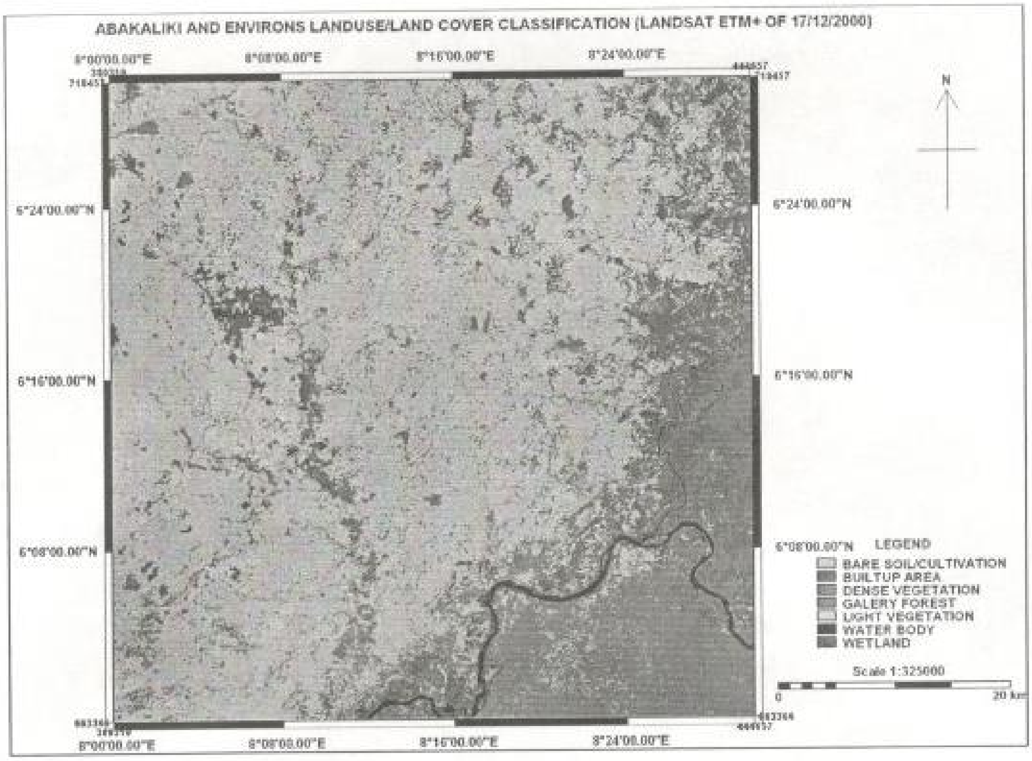


Figure 4.1: Sample Location


ABAKALIKI AND ENVIRONS LANDUSE/LAND COVER CLASSIFICATION (LANDSAT ETM+ OF 17/12/2000)
8°00'00.00"E
8°08'00.00"E
8°16'00.00"E
8°24'00.00"E
6°24'00.00"N
6°16'00.00"N
6°08'00.00"N
N
LEGEND
BARE SOIL/CULTIVATION
BUILTUP AREA
DENSE VEGETATION
GALERY FOREST
LIGHT VEGETATION
WATER BODY
WETLAND
Scale 1:325000
0
20 km

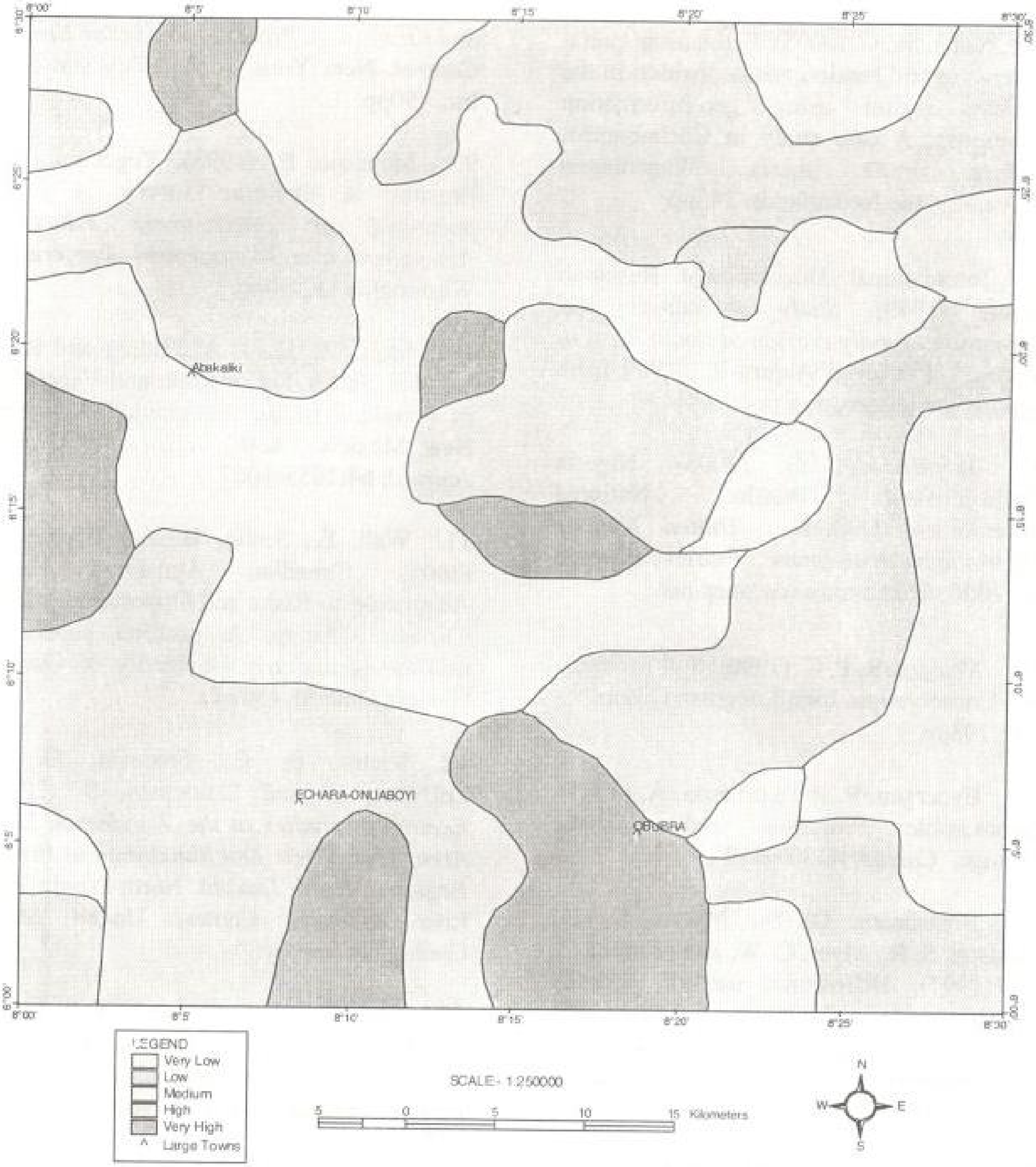


Fig. 9: Potential Soil Erodibility

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