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APPLICATION OF SLEMSA AND USLE EROSION MODELS FOR POTENTIAL EROSION HAZARD MAPPING IN SOUTH-EASTERN NIGERIA

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A b s t r a c t. Assessment of potential soil erosion aids in detailed farm planning and management. Two potential erosion hazard maps of Anambra and Enugu States of Nigeria were developed by the application of SLEMSA and USLE erosion models.The purpose was to ascertain which of these models is more applicable to the study area. Information was obtained from the soil map of the area, topographic map sheets of 1 : 50 000, aerial photographs, and rainfall data. In each case five erosion hazard classes were developed.

For the SLEMSA the erosion hazard unit (EHU) categories are moderate (<100), moderately high (101-250), high (251-500); very high (501-1000) and extremely high (>1000). The USLE model is categorised into very slight (<50 Mg/ha/yr); slight (50-150 Mg/ha/yr); moderate (151 -500 Mg/ha/yr); severe (501-1500 Mg/ha/yr, and very severe (>1500 Mg/ha/yr).

A combination of potential soil loss of USLE and the interception factor of SLEMSA was found to give more realistic soil loss values, although USLE model is found to reflect the actual field situations better.

K e y w o r d s: topography, erodibility, tropics, West Africa, cartography

INTRODUCTION

Soil erosion in sub-saharan Africa is very acute because of the high intensity rainfall and the erodibility of the soils. There is therefore the need to document the extent of soil erosion and other forms of soil degradation problems so as to propose an acceptable land use plan for agricultural development. These types of documentation are not readily available in developing countries or even when they are available, are not properly conducted or are done by non-specialists. Biot *et al.* [3] observed that until recently, both the study and mapping of erosion hazards have been restricted to geomorphologists, hydrologists and agronomists.

The failure of soil and water conservation programmes world wide has prompted renewed research in soil erosion hazard mapping. Setia [16] remarked that long-term planning for soil conservation is incomplete if it does not consider risk and uncertainty arising from environmental degradation.

The assessment of soil erosion hazard over large areas according to Stocking *et al.* [18], is an important aid to land evaluation and land use planning. Areas with a high natural hazard must either be avoided or be allocated additional resources for soil conservation. They remarked that most commonly, erosion hazard is presented in map form. Riquier [15] gave a series of reasons for erosion hazard mapping especially at small scale. These among others are to alert those at the policy making levels that certain areas within their countries are at risk and to seek technical advice; and also to serve as basic documents for educational research on development activities.

The major objective of this study was to produce a soil erosion hazard map of Anambra and Enugu States of South-eastern Nigeria for purposes of agricultural and environmental management and protection of the soil. An attempt is made to compare the applicability of Soil Loss Estimation Model for Southern Africa (SLEMSA) and Universal Soil Loss Equation (USLE) models in erosion hazard mapping and to develop a modified hazard map based on the interaction of the two models. The aim is to produce working maps for detailed planning purposes.

MATERIALS AND METHODS

The environment

The area under investigation is located between latitudes 5°38'and 7°07' North and longitudes 6°36' and 8°30' East covering an area of 17 500 km^2.

A tropical wet and dry climate (Koppen's Awi climate) prevails in the study area. Jungerius [8] reported that the mean annual rainfall is approximatelly 1651 mm. Maximum annual temperature is about 35°C.

The area is underlain by sedimentary rocks derived from successive marine deposits of the cretaceous and tertiary periods. The pattern of vegetation according to Jungerius [8] follows closely the rainfall distribution.

Keay [9] described the area as derived savanna zone. Original forest has been destroyed by extensive and repeated farming and bush burning.

Soil erosion hazard mapping

Two methods of mapping potential erosion hazards were employed. The first method used the SLEMSA while the second method employed the USLE model. Finally, a modified potential erosion hazard map was produced using the vegetative factor of SLEMSA and the USLE values.

In both cases topographic map sheets at 1 : 50 000 were divided into four grids. Each grid measures 13 x 13 km^2 and formed a quarter of 1 : 50 000 topographic sheet. The grids were super-imposed on the soil map of the study area at the scale of 1 : 250 000.

Mapping with SLEMSA methodology

The factors considered in this model were relief, soil erodibility, vegetation and erosivity of rainfall. For each grid the following analyses were performed:

Mean annual rainfall (mm) was obtained using records obtained from local meteorological stations. From these rainfall data, a mean seasonal rainfall energy (E) rounded to the nearest 100 J/m^2 was calculated using the method of Stocking *et al.* [17]:

$$E = 18.846p \quad (1)$$

where p - mean annual rainfall (mm).

Soil erodibility F_b rating of Stocking *et al.* [17] was adopted. This factor is based on taxonomic data and soil properties such as texture and depth. Using E and F_b, the potential erosion hazard index I_b, was calculated according to the following relationship:

$$K = \exp [(0.461+0.7663F) \ \ln (E+2.884-8.1209F)] \quad (2)$$

where K - potential erosion hazard index = I_b, F - soil erodibility rating, E - mean seasonal rainfall energy.

Interception values from vegetative cover and land use (C) were obtained using the method described by Chakela and Stocking [5]. This is by scoring different vegetation types for energy interception and utilising the relationship in the graph of C-submodel. Finally, the topographic factor (X) was calculated first by obtaining the average slope for each grid using Wentworths [18] method of counting contour crossing on each grid per kilometre thus:

$$\text{Mean slope \%} = [(\text{No. of contour crossing/km} \times \text{contour interval})/636.6]100. \quad (3)$$

Combining the slope percent and slope length, the topographic factor is obtained from the relationship proposed by Stocking *et al.* [17], and similar to the LS factor of USLE:

$$X = L^{0.5} (0.76 + 0.538 + 0.076S^2/25.65) \quad (4)$$

where X - topographic factor, L- slope length, S - slope percentage.

The estimated soil loss for each grid was calculated according to the relationship:

$$Z = K C X \quad (5)$$

and quoted as EHU (Erosion Hazard Unit) and not in Mg/ha /yr, where K - erosion hazard unit, C - vegetative, cover. X - topographic factor. This is to ensure that there is no confusion between the use of SLEMSA for prediction at the field level and for erosion hazard assessment over large areas (Stocking *et al.,* [17]).

Note that the value of Z for each grid square is the weighted average based on land area coverage.

Mapping with USLE model

The USLE of Wischmeier and Smith [20] was used for developing an erosion hazard map because of its wide use and simplicity. The purpose of this map is to obtain the maximum potential soil loss for the study area. Therefore the values of the cropping and management practices were taken to be one ($C = P = 1$).

Erosivity of rainfall (R-factor) was calculated using the modified Fournier's index as used by Arnoldus [2]:

$$R = 5.44 \sum p_i^2 / p - 416 \quad (6)$$

where R - erosivity of rainfall (J/ha), p_i - average monthly rainfall (mm), p - average annual rainfall (mm).

Erodibility factor (K-factor) was calculated using the erodibility nomograph developed by Wischmeier *et al.* [19].

Soil data were obtained from soil surveys of the area with a scale of 1 : 250 000 (FDALR, [6]. To develop the K-factor for each grid, a weighted average of the soil for each grid was obtained by multiplying area coverage of soil unit with the corresponding K-value.

The method of Wentworth [18] described earlier was used to obtain estimates of slope steepness for each grid. The topographic factor (LS) was finally obtained from a graph (Wischmeier and Smith, [20]), Soil loss (A) was calculated according to the relationship:

$$A = R K L S \quad (7)$$

where A - soil loss (Mg/ha/yr), R - erosivity factor, LS - topographic factor.

RESULT AND DISCUSSION

Application of SLEMSA mapping model

Figure 1 is a cartographic description of the erosion hazard categories based on the SLEMSA model. The map shows five categories of EHU; moderate <100; moderately high, 101-250; high, 251-500; very high, 501-1000 and extremely high >1000.

The area with less than 100 EHU reflects the real situation on the ground. These are areas with gentle terrain and subdued relief. They are the flood plains of the Cross-River, Niger, and Anambra Rivers. Holy [7] and Morgan [13] argued that soils with high clay content similar to the ones of this hazard category are less erodible. The moderate high erosion hazard class does not reflect actual erosion problem on the ground on grids 288S W-1, 2 and 3. Apart from these shortcomings this category predicts the real situation very well in other areas. Topography and climate are assumed to be responsible for the high erosion hazard category of 251-500 EHU, while rainfall may be the main contributing factor to the very high EHU of between 501 and 1000. The extremely high erosion class is probably due to the land use pattern resulting in low percentage interception of rainfall by vegetation. Lal [11] showed the positive contribution of land use in soil conservation while Chakela *et al.* [4] observed that agroecologically, the hazard becomes greater moving from the crop land dominated areas to grazing land.In this case the shift is from grassland/shrub land use to a bare/exposed land as a result of infrastructural development and constant use of land for purposes other than agriculture [1]).

The absolute values of the five categories of the SLEMSA model are high. According to Chakela and Stocking [5], these values are still high on the internationally relative scale. The

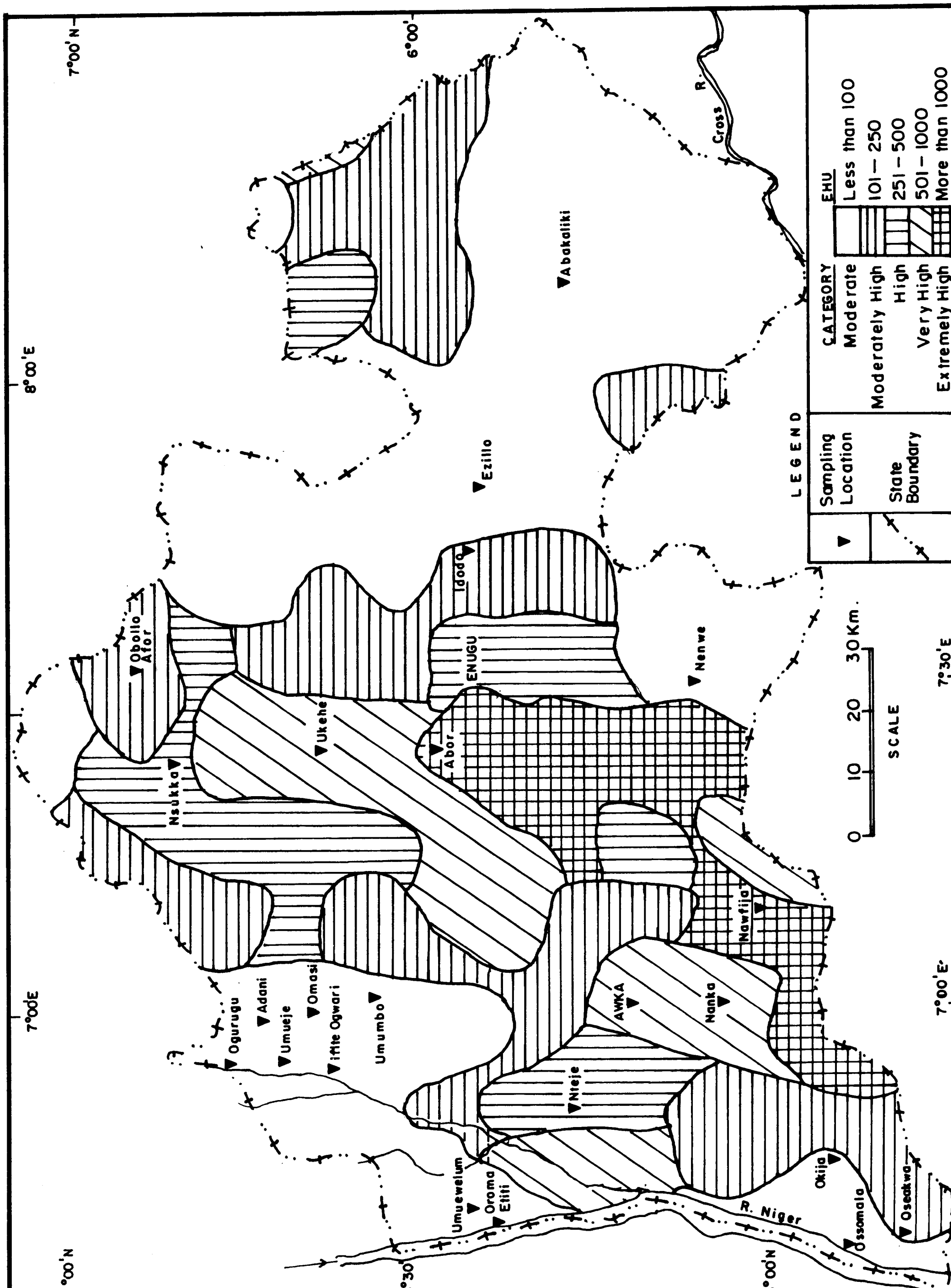

Fig. 1. Soil erosion hazard map of Anambra/Enugu States using SLEMSA model.

model may be faulted for its use of ratings because the behaviour of a soil group in Southern Africa for example under a High Veld condition may not be applicable to similar soil in humid tropical West Africa with high rainfall associated with leaching and high mineralization of organic matter. The rating of vegetative cover may be subjective and local conditions may also affect their values. The use of complex mathematical equations to derive the soil loss classes and values makes the model difficult to apply especially by farmers.

Application of USLE mapping model

The maximum potential average annual soil loss map (Fig. 2) is a cartographic attempt to show the classes of potential inter-rill erosion hazard according to the USLE. There are five categories of soil loss, namely – very slight <50 Mg/ha/yr; slight 50-150 Mg/ha/yr; moderate 151-500 Mg/ha/yr; severe 501-1500 Mg/ha/yr and very severe >1500 Mg/ha/yr. The values of potential soil loss are relatively high when compared with experimental data from the area. The values obtained for a bare plot at Nsukka, for instance, were between 35 and 55 Mg/ha/yr on a 5% slope [14]. In a Alfisol in Western Nigeria Lal [10] obtained a soil loss of 156 Mg/ha/yr on a slope of 15%. In the present study the predicted values lie between 360 to 1200 Mg/ha/yr on an average slope of 18%. Mbagwu and Salako [12] suggested that it is better to err on the side of overestimation than underestimation of the annual soil loss values in such a situation where the risk of failure of conservation structure can be catastrophic. Also when it is considered that soil loss value was calculated without cropping practice (*C*) and management practice (*P*) factors, the reason for the high values will be understood. Hypothetical or actual *C* and *P* values for the areas will yield a significant low soil loss (*A*) values.

The most significant aspect of this map is its relationship with actual erosion problems on the ground. Although, the USLE model does not predict gullying, there is a coincidence in the extent and degree of potential and actual erosion hazard in the form of gullying. Also rill and inter -rill are generally rampant but actual measurements have not been conducted hence no data are available to support or contradict the model prediction.

Comparison of erosion hazard maps produced by the SLEMSA and USLE models

There appears to be an overlap in the cartographic units of both maps (Figs 1 and 2). The soil mapping units included in the different categories of erosion hazard classes of the two maps overlap to some extent.

If soil ratings and interception of rainfall had not been incorporated in the SLEMSA model, the maps could have had some cartographic overlaps thereby indicating that the input or the information source is from the same parameters of climate, topography and the soil.

The different approaches employed by the models, notwithstanding, SLEMSA and USLE could be used in soil erosion prediction and farm planning with predictable reliable results. A modification is therefore made to produce a soil erosion hazard map based on the overlapping of the two models (Fig. 3). The modification is achieved by using the vegetation factor of SLEMSA to multiply the potential soil loss factor (*A*) in the USLE. The reason for this is that the *A*-factor of USLE is an interaction of climate, soil and topography as obtained from the map while the vegetation factor (*C*) of SLEMSA is based on natural factors of vegetation as read from maps and aerial photographs.

The soil loss values of modified map are quite reduced but the distribution of classes appear similar to the previous two maps (Figs. 1 and 2) with respect to very low erodible areas. The estimated soil loss values are very slight 0-50 Mg/ha/yr; slight 51-150 Mg/ha/yr; moderate, 151-300 Mg/ha/yr; severe 301-500 Mg/ha/yr and very severe being > 500 Mg/ha/yr. It is therefore suggested that methods used in achieving map (Fig. 3) be adopted for erosion hazard mapping in the study area because of its use of available factors obtainable from maps and air photographs which are also readily accessible and for its simplicity.

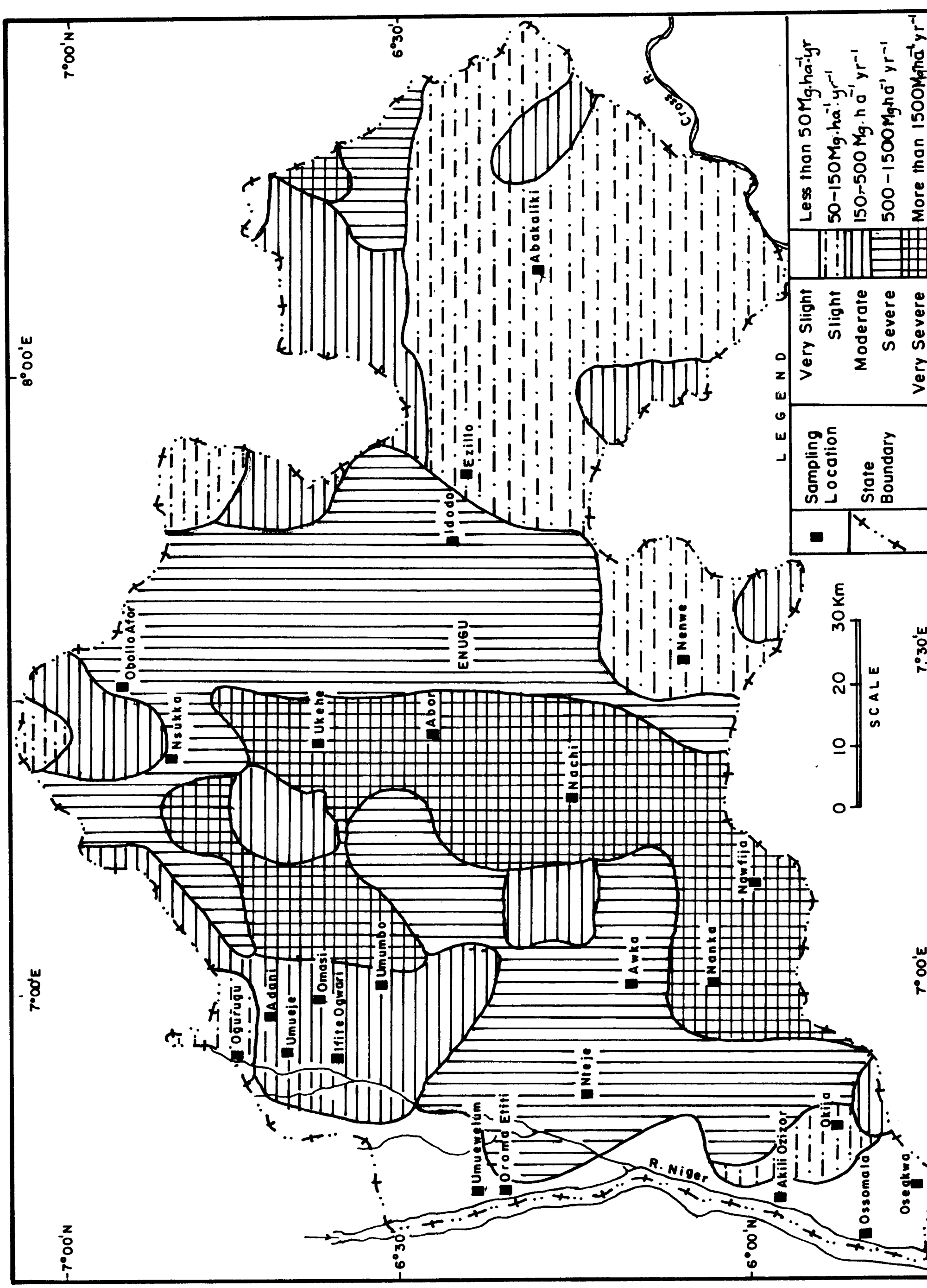

Fig. 2. Maximum potential average annual soil loss due to inter - rill (sheet) and rill erosion in Anambra/Enugu States.

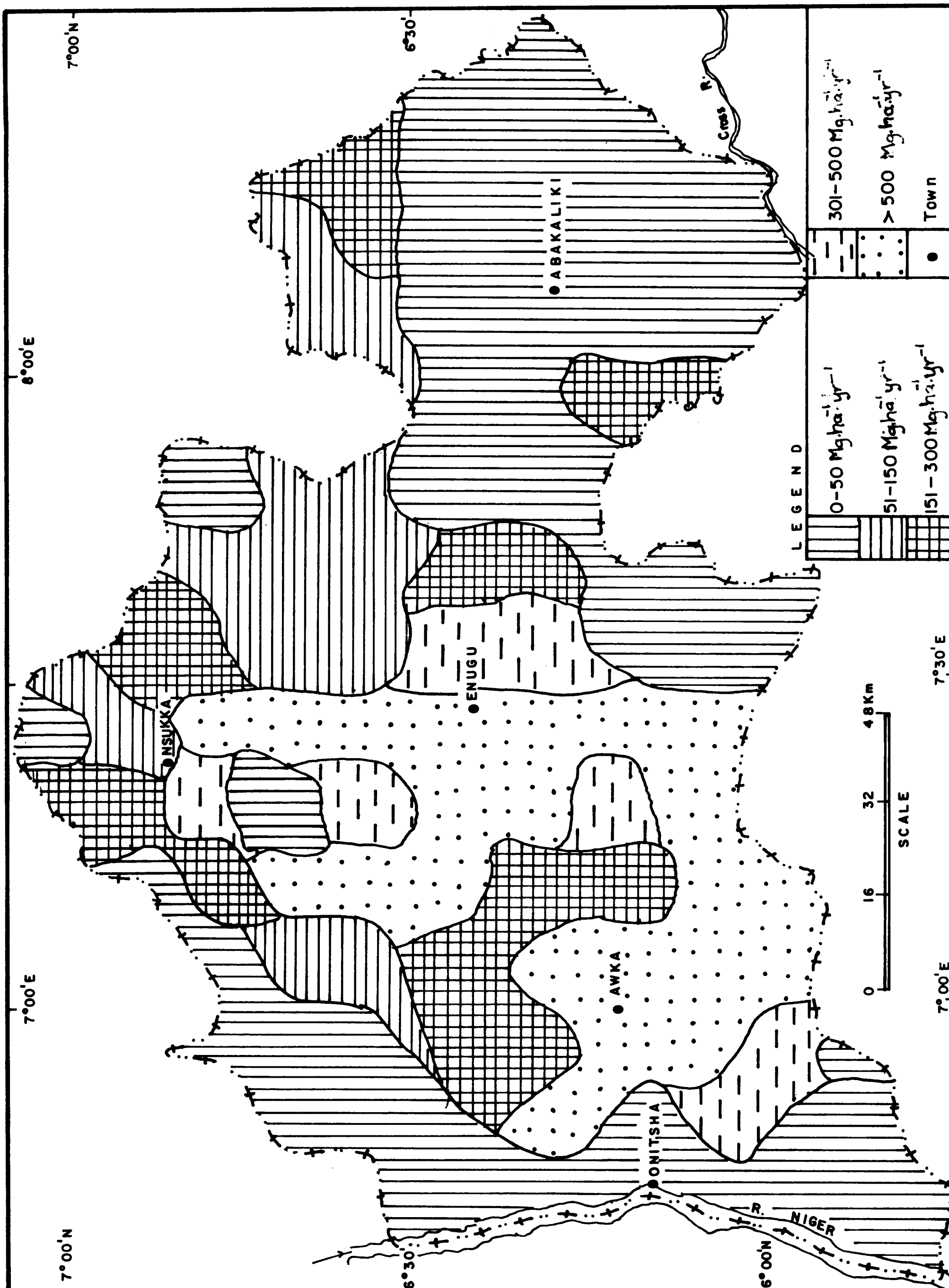

Fig. 3. Modified potential average annual soil loss due to inter-rill and rill erosion.

CONCLUSIONS

The major goal of this study was to produce a soil erosion hazard map of the study area for agricultural and management planning. Two potential soil erosion hazard maps were therefore developed by applying two different erosion models, SLEMSA and USLE. The absolute values of five erosion hazard classes obtained from the two models are high on the global scale.

The overall predictive ability of SLEMSA model is good and with some modifications may be employed for mapping erosion hazard in the study area. Such modifications include the assessment of individual soil erodibility and not rating or scoring based on taxonomy. The use of complex mathematical equations to derive soil loss values makes the model difficult to apply.

The USLE model-predicted erosion hazard would compare favourably with the pattern of actual soil erosion hazard in the area. Although higher erosion rates were obtained relative to actual measured values, it is suggested that it is better to err on overprediction than underestimation which could lead to catastrophic situation in an event of failure of a conservation structure. USLE model-predicted map is found to reflect better the actual field situation than the SLEMSA model.

A modified erosion hazard map is produced by using vegetative factor of SLEMSA in the USLE model. The advantage of modified erosion hazard map over others is that it has lower values which approximate some field data and the consideration of vegetation as an integral part of the natural environment.

REFERENCES

1. Anon: Land Census and Utilization Survery of Anambra State. University of Nigeria, Fac. of Agric., Progress Report No. 1, Nsukka, 1986.
2. **Arnoldus H.M.J.:** Methodology used to determine the maximum potential average annual soil loss due to sheet and rill erosion in Morocco. In FSO Bulletin 34, 39-48, 1977.
3. **Biot Y., Blaikie P., Stocking M.:** Erosion hazard mapping in the third world: a land users perspective. Soil Techn., 2, 301-311, 1989.
4. **Chakela Q., Molapo J., Putsoane T.G.:** Erosion Hazard Mapping of the SADCC Region. Part 3, Lesotho. Report No. 25, SADCC. 1989,
5. **Chakela Q., Stocking M.:** An improved methodology for erosion hazard mapping. Part II. Application to Lesotho. Geogr. Ann., 70A(3), 181-189, 1988.
6. FDALR: The Reconnaissance Soil Survery of Anambra State, Nigeria (1 : 250.000). Soils Report. Kaduna, Nigeria, 1985.
7. **Holy M.:** Erosion and Environment – Environmental Sciences and Applications. Pergamon Press Ltd., Vol. 9, 1980.
8. **Jungerius P.D.:** The Soils of Eastern Nigeria. Pub. Serv. Geologique de Luxemburge XIV, 185-196, 1964.
9. **Keay R.W.J.:** Vegetation Map of Africa. Oxford University Press, 1959.
10. **Lal R.:** Soil erosion on alfisola in Western Nigeria. I. Effects of slope, crop rotation and residue management. Geoderma, 16, 363-375, 1976.
11. **Lal R.:** Soil Erosion in the humid tropics with particular reference to agricultural land development and soil management. Proc. Hamburg Symp. IAHS Pub. No. 140, 221-239, 1983.
12. **Mbagwu J.S.C., Salako F.K.:** Estimation of potential soil erosion losses on an agricultural watershed in Southeastern Nigeria. Beit. Trop. Landwirtech. Vet., 23(4), 385-395, 1985.
13. **Morgan R.P.C.:** Topics in Applied Geography. Soil Erosion. Longman Group Ltd., London, 1979.
14. **Obi M.E.:** Runoff and soil loss from an Oxisol in Southeastern Nigeria under various management practices. Agric. Water Manag., 5, 193-203, 1982.
15. **Riquier J.:** Small scale mapping of present and potential erosion. In: Assessment of Erosion (Eds M. De Boodt and D. Gabriel). John Wiley & Sons Ltd. New York, 1980.
16. **Setia P.P.:** Consideration of risk in soil conservation analysis. J. Soil Water Conserv., 42(6), 435-437, 1987.
17. **Stocking M., Chakela Q., Elwell H.:** An improved methodology for erosion hazard mapping. Part I. The Technique. Geogr. Ann., 70A(3), 169-180, 1988.
18. **Wentworth C.K.:** A simplified method of determining the average slope of land surfaces. Am. J. Sci. Ser., 5, 184-194, 1930.
19. **Wischmeier W.H., Johnson C.B., Cross B.V.:** A soil erodibility nomograph for farm land and construction sites. J. Soil Water Conserv., 26, 189-193, 1971.
20. **Wischmeier W.H., Smith D.D.:** Predicting Rainfall Erosion Losses - A Guide to Conservation Planning. USDA - Sci. Education Admin. Agric. Handbook 537. US Govt. Printing Office, Washington D.C., 1978.