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Establishing soil loss and erosion hazard maps in a developing country: a West African example

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ABSTRACT A flexible system of computer grid-square mapping of soil erosion promoting parameters is presented. Maps of potential soil erosion risk and actual soil erosion have been produced using this system. The method is intended for developing countries and has been used for two different projects in Sierra Leone. Constraints on the choice of parameters for environmental mapping and on erosion rate verification in developing countries are discussed.

INTRODUCTION

Although soil erosion has been recognized as a major constraint on tropical agriculture, maps of the relative scale of erosion hazard or erosion intensity are rarely available for tropical countries. As a result, agricultural development schemes are often planned in an information vacuum regarding the inherent susceptibility to erosion of different localities. This paper gives an example of the construction of actual and potential soil erosion maps for Sierra Leone using data generally available in the developing countries of the Third World. A particular feature of the mapping technique is the ease with which the maps can be constructed at different scales for different sized areas and different uses.

DATA AVAILABILITY AND PARAMETER CHOICE

The urgent need to produce useful reliable maps at minimum cost necessitates the maximum utilization of available data and the minimum use of expensive field survey and laboratory analysis. Wherever possible, the parameters chosen should involve data transformation rather than primary data collection. Data availability does not imply reliability and in many developing countries, reliable data tend to be infrequent and restricted in either length or area of coverage. The data base is usually inadequate for high resolution mapping of the parameters that promote erosion but is sufficient for the creation of medium resolution reconnaissance maps which are adequate to fill the present information void on the spatial distribution of soil erosion hazards.

The most appropriate parameters to use are always open to contention. The parameter inputs for the Universal Soil Loss Equation (USLE) are not generally available in developing countries and its applicability to tropical conditions is in any case uncertain. Inputs representing relevant aspects of rainfall, topography, soil, land use and vegetation are clearly required and the most relevant guidelines are probably those of the FAO (FAO, 1979a).

Rainfall

The raingauge networks of developing countries tend to be sparse and unevenly developed. There are few rain recorder sites and, where they do exist, records tend to be short and frequently incomplete. This greatly restricts the application of indices such as AI_m (Lal, 1976; Wischmeier, 1959) and KE_{25} (Hudson, 1971). Data from WMO 127 mm gauges are more widely available and records span much greater lengths of time. Sierra Leone has 46 stations with long records from WMO 127 mm gauges, but only seven comparable rain recorder sites. The preliminary results of Roose (1977) suggest that it may be possible to estimate the annual climatic index $R(EI_{30})$ for sites where only daily rainfall is recorded. However, until this is verified for a wider area of the tropics, the only index of erosivity calculable from the data base of many developing countries is p^2/P (Fournier, 1960).

Topography

Topographic maps provide the most convenient source of information at the scales required. They have provided the data source for work in Malaysia (Morgan, 1979) and Zimbabwe (Stocking & Elwell, 1973) although the extraction of data relating to streams may have special problems (Eyles, 1966). Data can also be extracted from aerial photographs or satellite imagery which may be the only source available in some countries where no suitable maps exist. Unfortunately the use of these other sources is sometimes restricted by a lack of the specialist equipment required for the extraction of topographic data. Sierra Leone is very fortunate in having a complete coverage of 1:50 000 contoured maps and two sets of aerial photography (1949/1951, black and white panchromatic 1:120 000, 1976 false colour infrared 1:70 000). Landsat imagery is available at the Centre Régional de Télédétection in Upper Volta.

Significant relationships have been shown to exist between a variety of topographic variables and erosion intensity. Slope angle, because it is one of the USLE parameters, is the most widely investigated. Slope angles can be measured from maps by a variety of methods. For Sierra Leone, the contour crossing method was used to obtain values of mean slope (Dury, 1960). Relative relief is an excellent indicator of land dissection and was found to be an important parameter in Zimbabwe (Stocking & Elwell, 1973). Drainage density was used in Malaysia (Morgan, 1979), and although it primarily indicates the efficiency of the river system to transport eroded material it has also been considered to indicate erosion intensity (Iana, 1972; Mikhailov, 1972).

Soil

Estimation of soil erodibility is potentially the most time-consuming step in the creation of an erosion hazard map. Most countries now have some form of soil survey for agricultural purposes but the data available are rarely suitable for the calculation of erodibility indices such as K even with the help of the nomograph (Wischmeier *et al.*, 1971). Where detailed soil maps are available, the mapped soil units can provide a comprehensive framework for rapidly sampling soils for erodibility estimation. Sierra Leone has three soil maps (Martin & Doyne, 1932; Odell & Dijkermann, 1967; FAO, 1979b), but only the most recent has sufficient mapping units on which to realistically assess variations in soil erodibility.

The erodibility index chosen should ideally be simple to measure and yet accurately predict a soil's behaviour. Some temperate-based indices have poor predictive value under tropical conditions because they do not account for some of the bonding agents present in tropical soils (Lal, 1981), such as organic acids (Escolar & Lugo-Lopez, 1968; Soong, 1980) and iron and aluminium (Deshpande *et al.*, 1964). The work of De Vleeschauwer *et al.* (1978) indicates that the accuracy of erodibility indices bears little relationship to the complexity or apparent sophistication of the various indices. Quick measures such as the dispersion ratio (Middleton, 1930), or per cent stable aggregates greater than 5 mm (Bryan, 1968) have approximately the same predictive value as the far more time-consuming index of Henin *et al.* (1958) or the raindrop technique of Bruce-Okine & Lal (1975).

The soil erodibility maps reproduced in this paper are based on the measurement of the dispersion ratio (Middleton, 1930). However, the work of De Vleeschauwer *et al.* (1978) suggests that the most appropriate simple index, for tropical soils is probably the assessment of the percentage of water-stable aggregates greater than 200 μm. This index and maps computed on this basis are currently being investigated.

Land use and vegetation

Maps of potential soil erosion illustrate the relative intensity of erosion that would occur if the soil surface was completely bare, and they therefore require no vegetation or land use input. Land use is, however, an important contributory factor affecting the actual rates of erosion and soil loss that occur at different sites and erosion rates can be calculated for areas under different land usages (Millington, 1981).

Accurate data on land use and vegetation are difficult to obtain. The dynamics of many systems of tropical agriculture, particularly bush fallowing, make survey results very ephemeral in their representation of reality. Information derived from recent aerial photography, satellite imagery and/or ground survey is essential. Landsat imagery, backed up by field survey to establish ground truths, may be particularly useful for this purpose. Sierra Leone is particularly fortunate in having both a recent comprehensive cover of aerial photographs and also two bush fallow surveys (FAO, 1979c; Turay, 1980) to act as ground truths.

DATA PRESENTATION AND MAPPING PROCEDURES

Areal presentation of quantitative data can be by isoline maps or choropleth maps. The former are best suited to the presentation of quantitative point data, the latter for the display of average values per unit of area. Some of the data collected are in the form of point data, e.g. rainfall, some are in the form of average values per unit area e.g. slope. In order to compute the soil loss and erosion hazard maps it is necessary to combine the individual erosion promoting parameters operative over each area of the map. This can be most easily achieved by presenting the data on a unit grid system. The maps of individual parameters can then be directly overlain both for computational purposes and for comparison of the area distribution of the different parameters. The mesh of the grid has to be sufficiently small as to minimize the internal variability of the parameters within each grid square and yet the total number of squares has to be small enough for data to be collected for each sample square within the time and financial constraints that are operative. The point data can be transformed into areal data by constructing an isoline map and data can then be collected from this by a grid overlay procedure.

In Sierra Leone a square grid of size 10 km x 10 km was used giving a total breakdown of the country into 752 data units.

The choropleth maps were drawn by computer using one of the number of commercial programmes that are now available for this task*. To do this, all the nodes of the grid have to be defined by pairs of Cartesian coordinates. For square mesh grids these can be produced quickly on the computer by a simple programme because each node of the grid has a specific location relative to every other node. The grid can be drawn on a visual display unit and by the simple expedient of changing the parameters on the relevant data file, the size of the map, the class intervals and the shading intensities can all be changed. Thus, it is possible to view and evaluate many different ways of mapping the data extremely quickly. Different sets of data relating to the same grid can be plotted without having to redefine or redraw the grid. Maps of different erosion parameters can be overlain and maps of two or more combined parameters easily obtained. A data bank of information can be held in the computer onto which further data can easily be added as it becomes available or the data updated and corrected. Sections of the grid rather than the whole grid can be accessed and the unit size of the mesh of the grid altered so that the data can be displayed at different scales and levels of complexity. The minimum

* *For the enclosed maps a series of Fortran subroutines called GINOZONE were used. These form part of the GINO subroutine library produced by Computer Aided Design Company (CADC), Cambridge, UK. Further details of its use for this type of data may be obtained from T.Browne.*

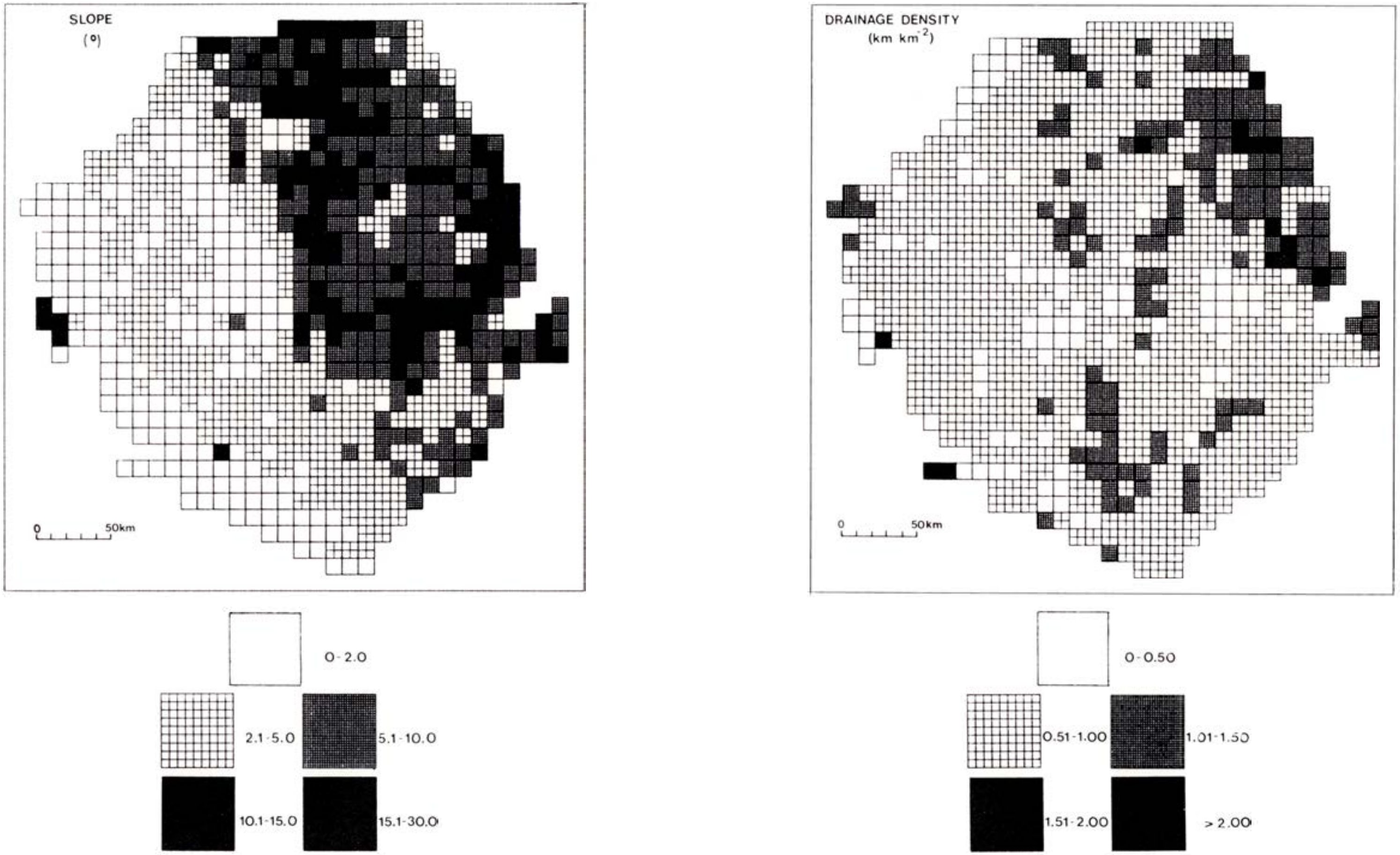


FIG.1 Sierra Leone: Computer drawn choropleth maps of slope and drainage density.

level of resolution of the grid is that at which the data are collected and stored.

When the most satisfactory representation of the data required has been obtained on the visual display unit, a hard copy of the map can then be drawn on either microfilm, microfiche, or on paper with a high quality plotter. Here too there are various alternative drawing mediums, instruments and colours that can be experimented with to produce the most satisfactory final map.

RESULTS

Examples of the computer drawn maps are presented in this paper and in the accompanying poster session (Figs 1-3). Initially, maps of the erosion promoting parameters were constructed for the whole of Sierra Leone and examples of these maps can be seen in Fig.1. However, while these were being constructed, the Magbosi Integrated Agricultural Development Project (IADP) requested maps covering their project area alone. Because of the computer storage of the data and the flexibility of the automated mapping system described, these could be produced extremely rapidly. To obtain maps of small areas, such as the IADP, from the main data files for the whole country, all that is required are the coordinates of the area or areas for which the data are required. Maps of the Magbosi IADP are shown in Figs 2 and 3.

The best combination of parameters for the construction of the map of soil erosion risk was:

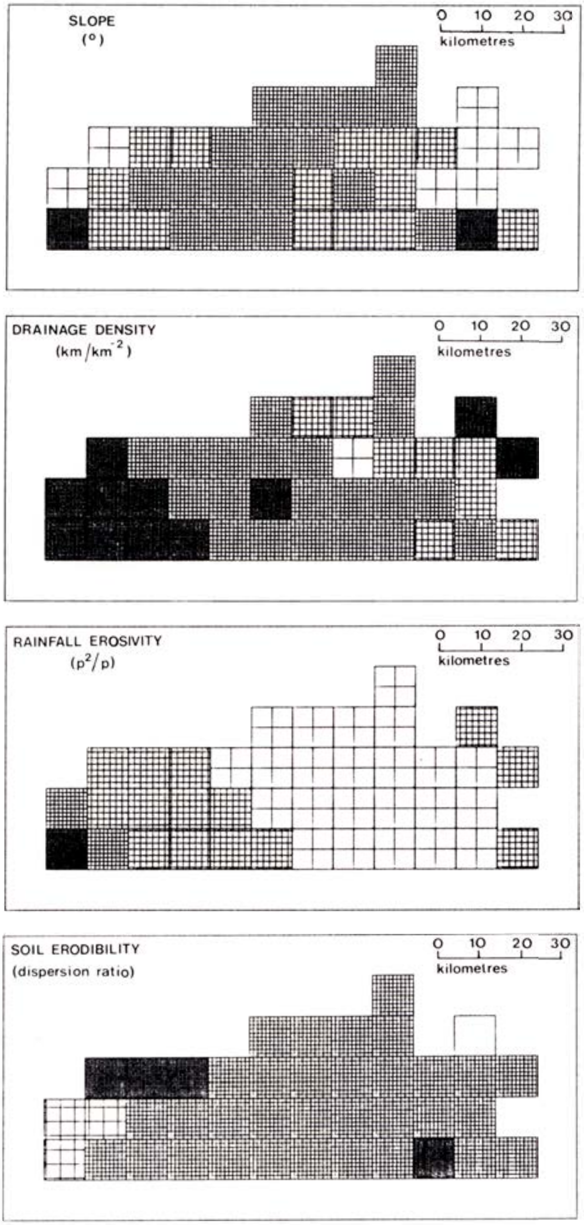
slope x soil erodibility x rainfall erosivity x drainage density

Use of the first three parameters alone produced a very similar result but the inclusion of drainage density gave better resolution. Relative relief appears to be a redundant variable, probably because of its overlap with slope. The map of actual erosion or soil loss was produced by the addition of information on the length of bush fallows. Bush fallow lengths decrease as land use intensity increases and thus the formula for the actual erosion or soil loss map was

$$\frac{\text{Slope x soil erodibility x rainfall erosivity x drainage density}}{\text{length of bush fallow}}$$

Comparing the soil erosion risk and soil loss maps for the Magbosi IADP (Fig.3), it is apparent that some areas of equal erosion risk score more highly than others on the map of soil loss due to the greater intensity of farming in these areas.

Validation of the maps remains incomplete. Erosion rates have been measured by erosion pins, erosion plots with troughs, and dam sedimentation records (Millington, 1981). However, results are available for only a restricted portion of the country and a restricted range of parameter combinations. Elsewhere, validation has had to be restricted to field surveys of the visual presence or absence of erosion and of the intensity and nature of the erosive processes active in areas suffering erosion. For example, in the



SLOPE (°)	—	0-1.0	—	1.1-2.0	2.1-4.0	4.1-6.0
RAINFALL EROSIVITY (p^2/p)	50	50-125	—	126-150	151-175	176-300
DRAINAGE DENSITY (km/km^{-2})	—	0.5-0.75	—	0.76-1.00	1.01-1.25	1.26-1.50
SOIL ERODIBILITY	0.15	—	0.15-0.20	—	0.21-0.30	0.31-0.40

FIG.2 Magbosi IADP: Maps of parameters used to determine soil erosion potential.

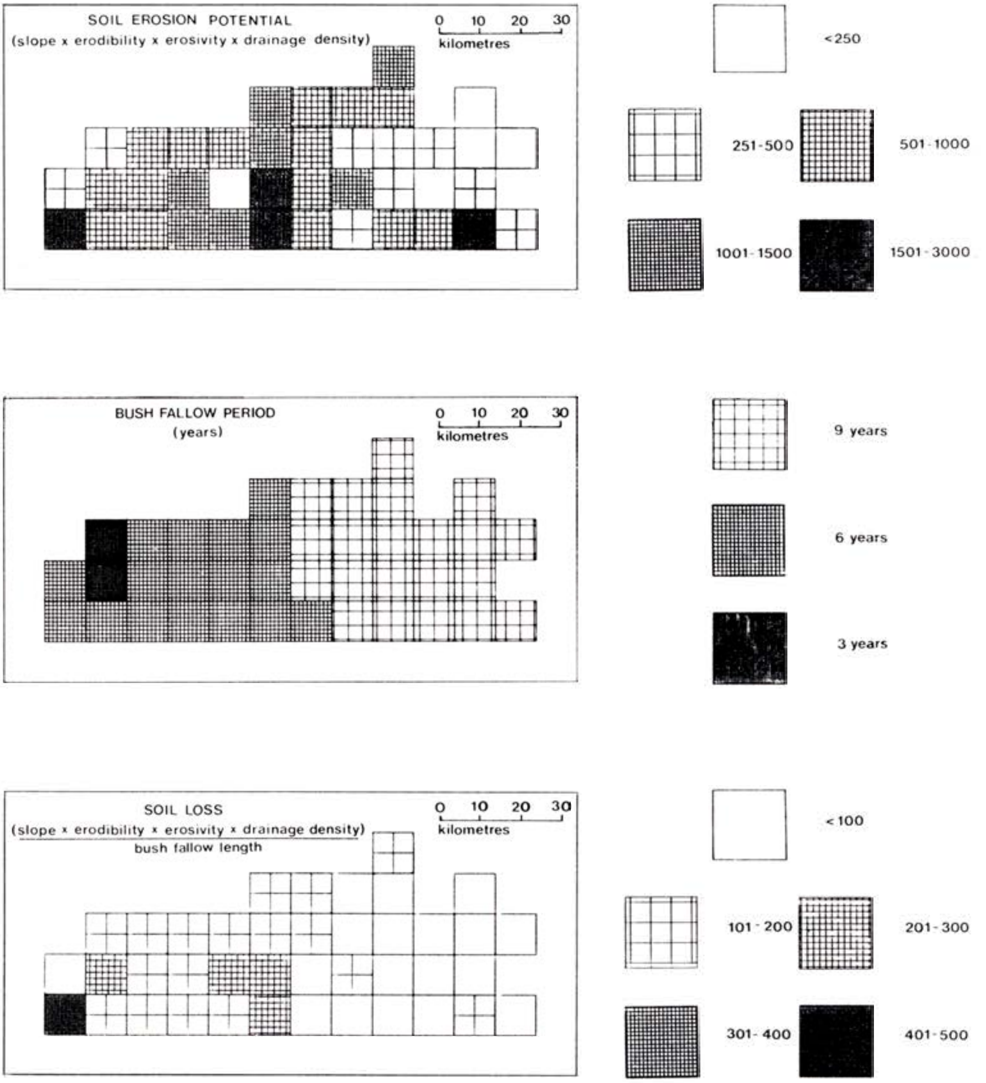


FIG.3 Magbosi IADP: soil erosion potential, bush fallow and soil loss.

area of the Magbosi IADP, no gully erosion occurs, but sheet wash and interrill erosion are clearly observable phenomena in the high risk areas. Thus, while the general accuracy of the picture portrayed by the soil loss and erosion risk maps is believed correct, no meaningful estimates of erosion can be assigned to the relative intensity classes indicated. This failing can only be overcome by further detailed field measurement or by the development of predictive equations that require only the same simple data inputs.

Despite these limitations the maps can form a useful basis for a variety of land use planning decisions. The categories of erosion risk can easily be provided with explanatory keys to indicate the types of erosion that are observed to be present within each category and, in particular, any that have been induced by past or present land use practices. Storage of information on a grid coordinate system facilitates rapid access to any section of the data and the easy addition of further information as it becomes available.

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