COMPUTER MAPPING TECHNIQUES FOR ASSISTING LAND EVALUATION AND ASSESSMENT OF EROSION HAZARDS IN KISII, KENYA

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1. INTRODUCTION

The aim of this exercise was to investigate changes in a land evaluation result due to landscape development. In particular, landscape development brought about by water erosion. The land characteristic investigated is soil depth, its evolution and its effect on the land quality availability of water. The resulting suitability classification changes are presented for the land utilization type "small-holder rain-fed maize cultivation".

Degradation due to water erosion is low for deep soils with a well-drained and easily weatherable parent material. On the other hand, degradation is rapid in shallow soils underlain by solid rock or plinthite and soils in which the natural soil fertility ingredients are located in the topsoil.

The various stages of land evaluation procedures are executed using computer-assisted methods. The mapping is also done by computer. In chapter 2, the concept of computer-assisted cartography and land evaluation is discussed in detail. Chapter 3 is devoted to a brief description of the soils of the study area and chapter 4 discusses the adapted land evaluation criteria. Chapters 5 and 6 describe an erosion model used to simulate the annual quantities by soil removed by erosion. Chapters 7 and 8 discuss the various aspects of the methodology and the results obtained.

2. COMPUTER - ASSISTED CARTOGRAPHY AND LAND EVALUATION

2.1 Introduction

A hand-drawn map has long been the standard means of recording and representing spatial data. To update such a map or to display results on any process performed on some or all of the spatial data, a new map must be drawn or the old one modified by hand. These operations are laborious and time consuming and require a high degree of skill and accuracy.

BURROUGH (1983) cited the following seven good reasons for using computer assisted cartography in natural resources appraisal:

i) To obviate the need for a map as a data store. Not all source data come from field observations, e.g. data from remote sensing techniques;

ii) Conventional map making is very expensive. The processes of drafting and updating are a big financial burden;

iii) To produce user-specified maps quickly and cheaply;

iv) To assist in combining data from several different sources. This is the process of post-survey integration;

v) To enable statistical manipulation of spatial data;

vi) The results of planning decisions on the landscape can be simulated leading to the selection of the best alternative(s);

vii) Pure simulations of stochastic and dynamic processes at work in resources can be quickly and efficiently handled.

The above list is by no means exhaustive. The possibility of teletransmission of cartographic information is a recent development and is expected to enhance digital handling of maps. Further considerations on aspects of computer assisted mapping are given by BOYLE (1979) and BIE (1980).

Overall mapping costs are not expected to lessen due to automation and may, in fact, become more expensive for the small user. BOYLE (1979) estimates minimum capital expenditures to be in the order of $ 100,000 to $ 2 m. BURROUGH (1982) looks into the requirements for soil survey and land evaluation in terms of computer hardware and software and attempts to give indications of the costs involved, and they are indeed considerable. In the past two decades however, automated cartography has undergone a revolution. Once change has taken root, the effect will snowball so that even the individual soil surveyor will then be able to handle data in digital form at reasonable cost.

2.1.1 Computer cartography

Computer cartography is part of the larger field of Geographic Information Systems (GIS). A GIS is a set of computer programs which perform all phases of storage, maintenance, analysis and retrieval of spatial data. Each phase consists of an assembly of sub-programs or modules. These sets of operations can be separated into three stages:

Data Gathering and editing → Data and Geometric Manipulation → Mapping

None of the trio work in isolation and there is a high degree of interdependence.

The core of any GIS is a Data Base Management System (DBMS). A DBMS is a computer program for organising the data in the computer's memory. Several kinds of operations are involved, such as data input, data output (printing results in paper or screen), editing and updating, sorting, merging and retrieval. The efficiency of the system depends very much on the data structure. BIE et al. (1977) recognized three basic data base structures: hierarchical systems, network systems and relational models. In hierarchical data handling, horizons may be grouped together to identify soil profiles, the profiles may be grouped to soil series and soil series to soil families.

Soil Family
↕
Soil Series
↕
Profile
↕
Horizons

Suppose now we would like to consider the relation between a given soil profile and some aspects of the landscape such as parent material. In a hiearchical system should we arrange the data structure so that the parent material is recorded for every profile or should we group the profiles according to parent material?

Soil Series ↕ Profile ↕ Parent material ↕ Horizons	or	Parent Material ↕ Soil series ↕ Profile ↕ Horizons

Obviously if every profile must have a parent material code, the total amount of data to be stored and searched is much greater than of the series are grouped by parent material. Suppose we add another landscape aspect such as slope class. In a situation like this a network structure is more appropriate in which slope class and parent material could reference each other without the data having a strict hierarchical relation.

Parent material ⟷ Slope class
↕
Soil Series ⟷ Slope class
↕
Profile ⟷ Slope class
↕
Horizons

Relational data base models extend the principles of cross-referencing as used in networks to data structures based on row and column tables (e.g. N soil sites as rows with M soil characteristics as columns, measured at each site).

The first full GIS to be acknowledged as such was the Canada Geographic Information System (CGIS). This system remains the most sophisticated GIS presently used on a continuous large-scale basis and thus offers an example of the combination of capabilities implemented within a single GIS. PEUQUET (1977) reproduces the overall concept of CGIS as presented by TOMLINSON (1973). This is illustrated in Figure 2.1. Since then, many GIS have been developed. BURROUGH (1980) described the development of a landscape information system in the Netherlands. OWEN et al. (1974) presented a GIS called TRIP (Tourism and Recreation Package) desgined to fulfill the remit given to the Tourism and Recreation Research Unit (TRRU) of Edinburgh by the Countryside Commission for Scotland (CCS) and the Scottish Tourist Board (STB).

2.1.1.1 Data Processing

There are two approaches to automated cartographic data handling: vector processing and raster processing.

Vector processing

Vectors are straight lines between points. The digital data is stored in a format that most faithfully reproduces the hand-drawn map. The map is then converted, point for point and line for line into strings of digital coordinates or vectors. These operations however, as well as the storage format of the data on which they are performed, generally replicate manual methods. The various mapping units are bounded by polygons in a similar way to a hand-drawn map.

Raster processing

In raster mapping, each mapping unit comprises a number of compartments. These compartments are known by the names pixels, rasters, cells or simply picture elements. Each pixel represents a rectangular area on the ground. The pixels are identified by giving them numbers in such a way that all the pixels within the same mapping unit are given the same number [Figure 2.2(a)]. To display the map, each number is associated with a different symbol [Figure 2.2(b)].

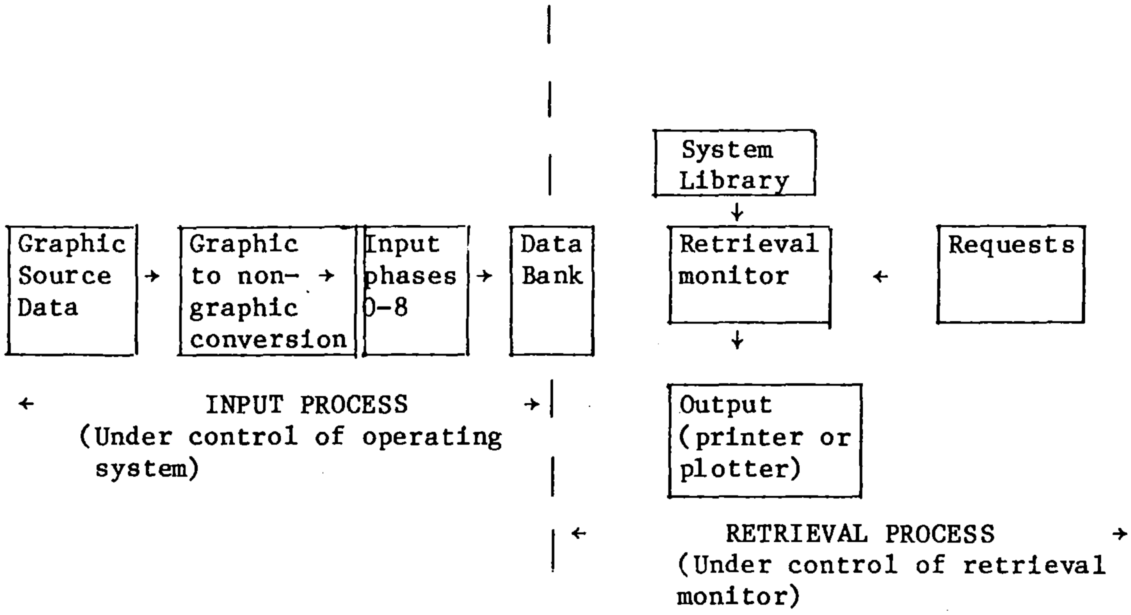
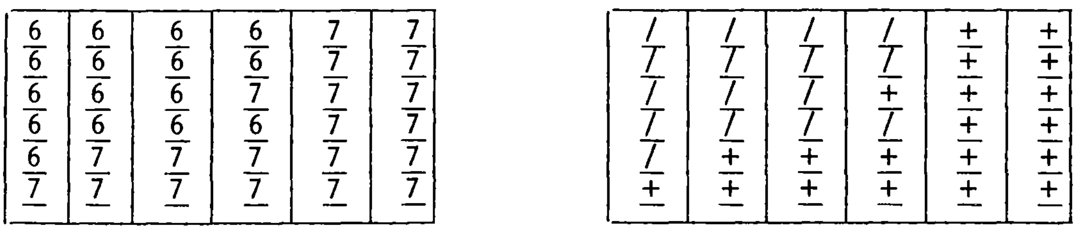


Figure 2.1- Overall System concept of CGIS (from Tomlinson 1973)



Map storage (a)

Map display (b)

Figure 2.2- Map storage and map display in raster processsing

2.1.1.2 Comparison between Vector and Raster formatted processing

POIKER points out that both vector and raster processing are necessary and that both have to be used for efficient systems. Certain problems are easy to solve in one system but would be immensely difficult in another. Maintenance of a line file (e.g. a road) consists mainly of addition and deletion of short line segments, operations very cumbersome in raster but very simple with a vector file. On the other hand, multiple-shade colour displays are impossible with vector systems but are easy to accomplish on raster displays. The following comparisons and contrasts are also important:

i) Algorithm repertoire for handling data in raster mode is not as developed as for vector format;

ii) Most of the devices in development showing greatest capacities in accuracy, reliability, flexibility and data handling capability operate in raster mode, e.g. remote sensing devices, Cathode Ray Tubes (CRT's), plotters and scanners;

iii) The ease with which data can be extracted from soil maps suggest that not only data be manipulated in terms of the original structure of the map, but that different structures can be overlaid to create new maps, as may be the case in, for example, a land evaluation exercise. In practice, vector overlay is not so simple because of the large number of small, meaningless polygons that can be created through the less-than-perfect alignment of boundaries. In contrast, in grid-cell or raster mapping, the overlay problem does not arise. Every pixel on one thematic map has a 1:1 location with a pixel on another thematic map (Figure 2.3). Overlaying is then a problem of deciding how to compute a new pixel value from the others. This is easy to program and easy to use and is consequently the method that has been used in many simple but effective GIS (e.g. MAP, to be described shortly). Because raster overlay is so easy, most modern systems using a vector data base first convert the resulting polygons to a raster format for the overlay, and then convert it back afterwards. This will result in some loss of resolution but the gain in time and intelligibility of the results makes it well worthwhile.
A disadvantage of raster mapping arises from the fact that the earth is not flat. This results in distortions especially when mapping large areas. Satellite imagery incorporates a correction factor in an attempt to annual the distortion.

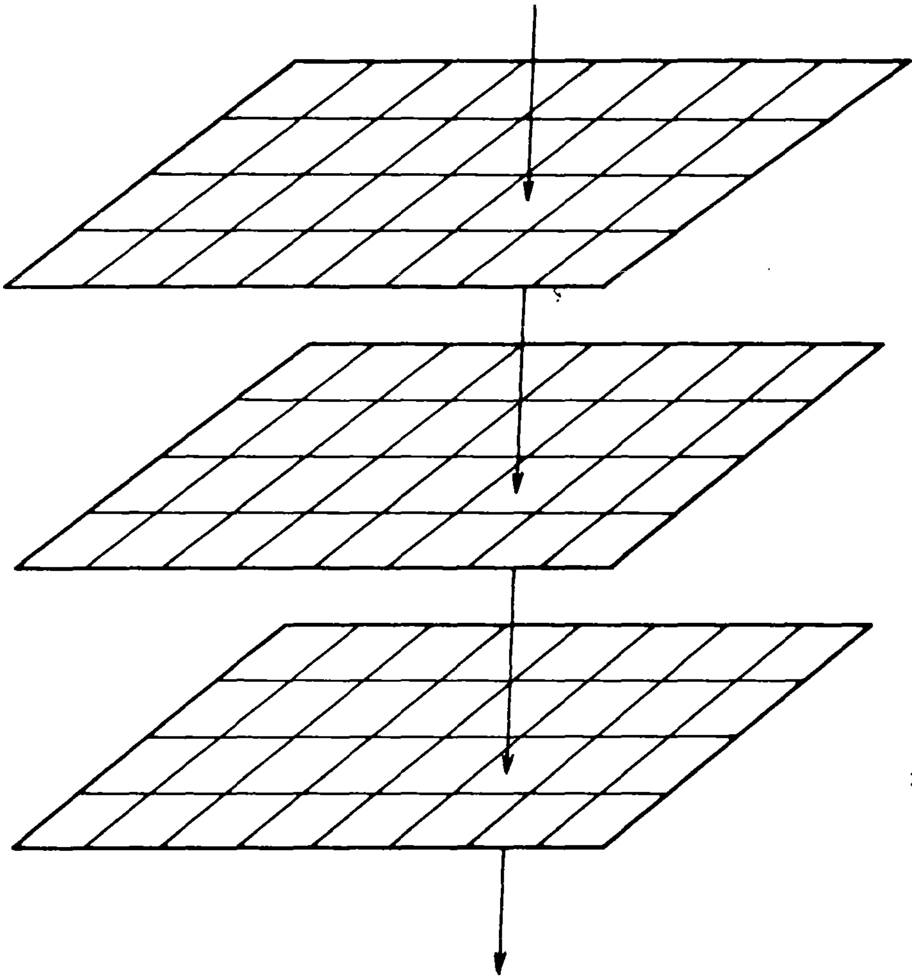


Figure 2.3: Map overlay using raster techniques.

2.2 The Map Analysis Package

2.2.1 Introduction

The Map Analysis Package (MAP) is a set of computer programs which provide for the encoding, storage, analysis and display of cartographic information. Its data processing capabilities are organized as a series of primitive operaitons which may be flexibly combined to perform complex map analyses. Sequences of operations are specified through a user-orientated command language of English phrases. Use of the Map Analysis Package for environmental analysis is generally analogous to the use of traditional hand-graphic techniques involving conventional geographic maps. Each of the analytic operations generally involves:
i) Retrieval of one or more maps from a data file;
ii) Manipulation of those data according to specified options;
iii) Generation of a new map as the result of that manipulation;
iv) Storage of that new map in the data file for subsequent processing.
None of the operations within the package are application-specific. The use of each is limited only by the general thematic (i.e., quantitative, qualitative or dichotomous) and spatial (i.e. points, lines, areas, or surfaces) nature of the data to which it is applied.
At present the Map Analysis Package employs a raster data structure for all analytic operations. Input data, however, may exist in the form of digitized points, lines or polygons and output may be produced in a line plotter form. In any case, a data base will generally include a number of maps registered over a common geographic area.
The MAP package is compatible with other computer-orientated, geographic information systems to the extent that those systems can accommodate mapped data in raster format. The programs are written in FORTRAN, may be run either interactively or in batch mode, and have been or are presently being implemented on IBM, DEC, HP and CDC computers.
The MAP package has been written by DANA TOMLIN of Yale University, U.S.A. The version used in this study was kindly supplied free-of-charge by Dana Tomlin and was mounted on the Agricultural University's DEC 1091 computer by members of the Agricultural University's Graphic User Group. Two examples where it has been used successfully are detailed by TOMLIN (1981) and STEINITZ (1982).

2.2.2 Overlays

McHARG (1969) described the original concept of an overlay. Base maps e.g. maps of land qualities such as susceptibility to erosion were prepared in such a way that the darker the tone on a mapping unit, the less suitable it (the mapping unit) was for a specified use such as highway construction. Each map was then photographed as a transparent print. The transparencies were then superimposed over a light table and a summary map was obtained with the darkest tone representing the least suitable areas and the lightest tone the most suitable areas.
Hence, an overlay is simply a special form of geographic map. In an overlay, each cartographic location is explicitly characterized in terms of only one thematic attribute, e.g. soil depth. In digital form, an overlay data structure can be expressed as a hierarchy of component parts that are ultimately comprised of an ordered set of numbers but which generally correspond to familiar elements of traditional

cartographic representation. These include what are termed here "maps", "overlays", "regions", "points", "coordinates", "attributes" and "values".

Defining these terms:

- A map is a set of overlays associated with a particular geographic area;
- an overlay is a set of mutually exclusive regions partitioning that area;
- a region is a set of points sharing a particular attribute;
- a point is a cartographic location defined by two planar co-ordinates;
- an attribute is a geographic or land characteristic represented by a numerical value.

This structure is illustrated in Figure 2.4.

000	1	1	1	1	1	1	1	1	1	1
001	1	1	1	1	1	1	1	1	1	1
002	1	1	1	1	1	1	1	1	1	1
003	2	2	2	2	1	1	1	1	1	3
004	2	2	2	2	2	2	2	2	2	3
005	3	3	2	2	2	2	2	3	3	3
006	3	3	3	2	2	2	2	3	3	3
007	3	3	3	3	2	2	3	3	3	3
008	3	3	3	3	3	3	3	3	3	3
009	3	3	3	3	3	3	3	3	3	3
	001				005					010

Figure 2.4- A general cartographic data structure organized on the basis of map overlays. Here each overlay is defined as a two-dimensional field of points. Each point is defined in terms of its location and a single land characteristic or land quality. All locations are represented by cartographic coordinates and all land characteristics and land qualities by numerical values.

Significant is the fact that numerical values rather than colours, symbols, or graphic patterns are used to represent geographic features. It is this which gives rise to the range, flexibility, and power of most automated techniques. It is also this which most distinguishes computer-aided overlay mapping procedures from more traditional methods.

2.2.3 Overlay processing

Overlay processing capabilities are provided in MAP in the form of individual operations that are functionally independent but which are capable of being combined. This is done by applying the operations to a common data base such that each accepts input and generates output on an overlay by overlay basis. By controlling the order in which these operations are executed and by using the data base to store intermediate results for subsequent processing, a variety of increasingly sophisticated procedures of land evaluation can be constructed.

One class of operations effects processing on a point-by-point basis. Each operation provides for the generation of a new overlay in which the value assigned to each point is computed as a specified function of one or more values already associated with that point on one or more existing overlays. Figure 2.5 illustrates this concept.

A

4	4	1	1	1
4	4	1	1	1
4	4	1	1	1
4	4	1	1	1
4	4	2	2	2
4	4	2	2	2

+

B

0	0	0	5	5
0	0	0	5	5
0	0	0	5	5
0	0	5	5	5
0	3	3	3	3
3	3	3	3	3

→

C

4	4	1	6	6
4	4	1	6	6
4	4	1	6	6
4	4	6	6	6
4	7	5	5	5
7	7	5	5	5

Figure 2.5 An overlay processing operation in which new values are computed on a point-by-point basis.
An overlay on the right is created such that each point is characterized according to the sum of the values attributed to that point by the two overlays on the left.

In some cases, none of these operations necessarily attaches any quantitative significance to the numerical values being processed, the numbers merely serving as nominal indentifiers.
Many operations for the transformation or combination of overlays on a point-by-point basis take increasing advantage of the fact that geographic information is represented in digital form by relating the numerical values associated with regions to ordinal, interval or ratio scales of measurement. It is at this point that operations become available to compute sums, products, minima, means, percentiles, weighted averages, variances, standard deviations, trigometric functions and so on.

TOMLIN and TOMLIN (1981) described the other two classes of operations: overlay processing on a neighbourhood-by-neighbourhood basis and processing on a region-by-region basis. In contrast to the point-by-point processing, these operations deal with sets of points at a time.

2.2.4 Processing control

The Map Analysis Package employs English-like phrases in order to specify particular operations and control the order in which they are performed. Each command is associated with a single operation and all operations are performed according to the order in which these commands are specified. Consider this command sequence:
ADD NEWMAP TO OLDMAP FOR THISMAP.
The command specifies an operation which algebraically combines values on a point-by-point basis. NEWMAP and OLDMAP are the titles of existing overlays while THISMAP refers to a new overlay created by the operation ADD. A few of the processing commands available in MAP are given in Appendix 1.

2.3 The advantages of automated cartography

Hand-drawn maps of land characteristics such as soil depth and slope provide the data base for computer mapping. Reproduction of these maps by computer is therefore merely a replication. Automated cartography becomes attractive when transactions are executed between these maps to produce new maps. A quotation from BOYLE (1981) would serve well at this point: "Cartographers still have the belief that the only use of computer-assisted cartography is as an aid to the 'pen-pushing' copying of maps. Cartographers must realize that computer-assisted cartography is too expensive to be simply used for drafting, and only becomes viable when the cartographic data is used for geographic information systems, thematic mapping and spatial computations such as for forest management". There is no doubt however, that it will be sometime before computer mapping becomes widespread especially in the developing world.

3. THE SOILS OF KISII

3.1 Introduction

Kisii district is situated in Nyanza Province in Western Kenya. A reconnaissance soil map has been prepared at a scale of 1:100,000 covering most of Kisii district and parts of South Nyanza and Narok districts. Figure 3.1 shows the extent of the area covered (approximately 300,000 ha). Six detailed soil surveys were carried out during the preparation of Soils of the Kisii area, Kenya by WIELEMAKER and BOXEM (1982). These were Marongo detailed stuvey (BOERMA et al., 1974), Irigonga detailed survey (VAN MOURIK, 1974), Magombo detailed survey (SCHOLTEN et al., 1975), Nyasiongo detailed survey (GUIKING, 1976), Ranen detailed survey (VAN KEULEN and VAN REULER, 1976), and Rangwe detailed survey (BREIMER, 1976). The soil survey of the East Konyango area by MILLER (1961), was also used.

This case study covers 1406 ha (3750 m x 3750 m) of the Marongo detailed survey (9800 ha). The study area straddles East Nyokal division in South Nyanza district and South Mugirango division in Kisii district (Figure 3.2).

3.2 Surfaces and parent material

WIELEMAKER (1979) identified four planation surfaces for the whole of the Kisii area, from which the present topography was derived. These are the Kisii surface (Jurassic), the Magombo surface (end cretaceous to early Tertiary), the Chepalungu surface (end Tertiary) and the Magena surface (Mid-Pleistocene) (Figure 3.3).

Six parent materials occur in the study area, namely Quartzite, Granite, Basalt, Rhyolite, Alluvium and Indurated Ironstone. For a long period, the soils have been under strong influence from Volcanic ash, presumably with the Mt. Longonot volcano as the source (Figure 3.4).

3.3 Soil fertility

The volcanic ash has had a positive influence on the natural fertility levels of Kisii soils. In fact, without the ash, Kisii would not be such a highly productive agricultural area. The soils are generally highly permeable and have low bulk densities (0.9 - 1.2 Mg/m^3). The soil profiles have many intricate pores maintained by soil fauna, namely termites and ants. WIELEMAKER (1983) stressed the vital role played by termites (Macrotermes spp) in the Kisii soil eco-system. They transport moisture and plant nutrients upwards from the subsoils and their activity may extend down to a depth of 10 m. This bioturbation does not only improve the soil chemically but also physically by promoting aggregation.

The termites are heavily dependent on organic matter for their food, stressing the importance of management practices such as mulching in certain instances. Some crops such as pyrethrum produce a very low biomass and therefore cannot sustain a high level of termite activity.

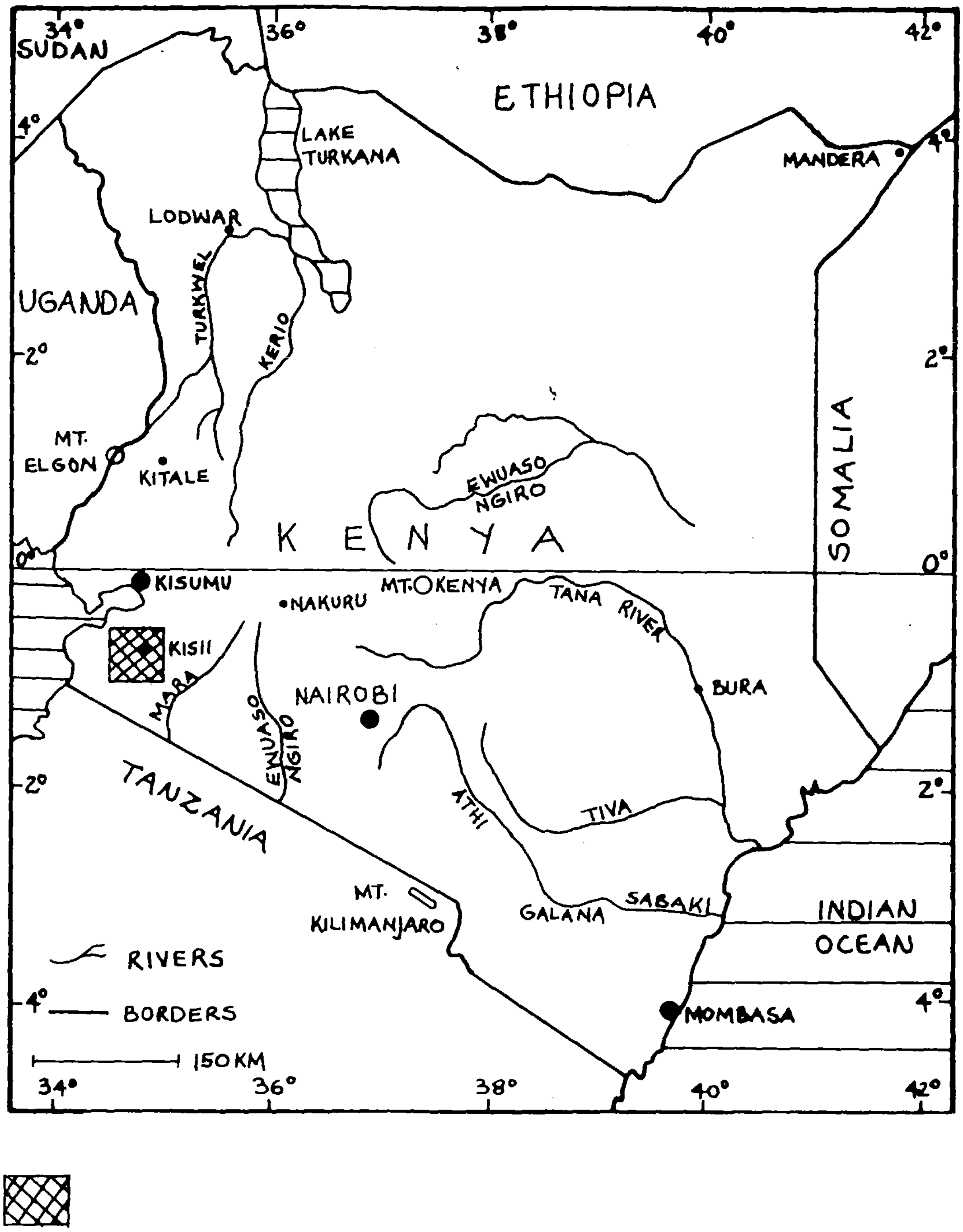


Figure 3.1- Location of the Kisii reconnaissance soil survey

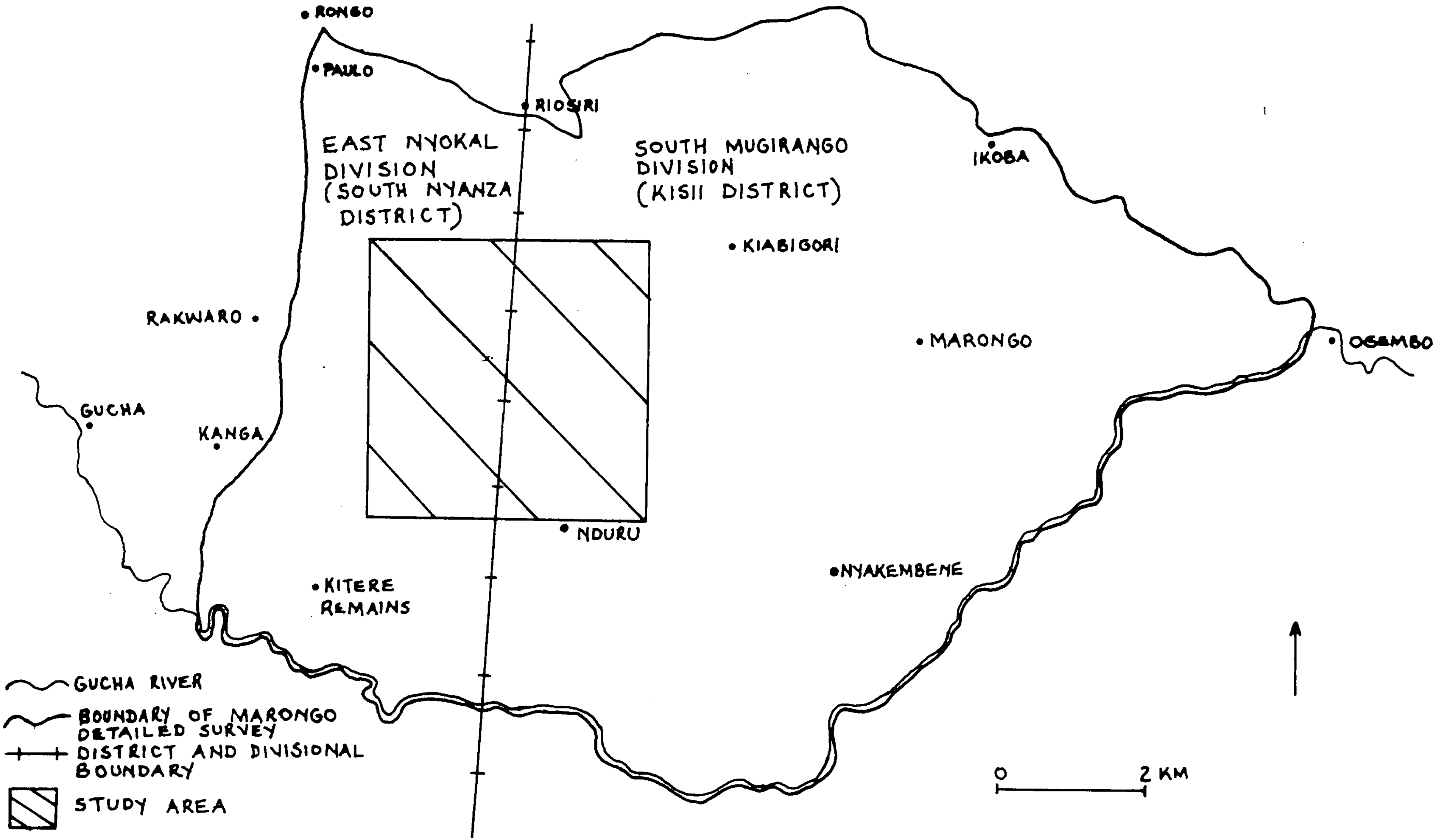
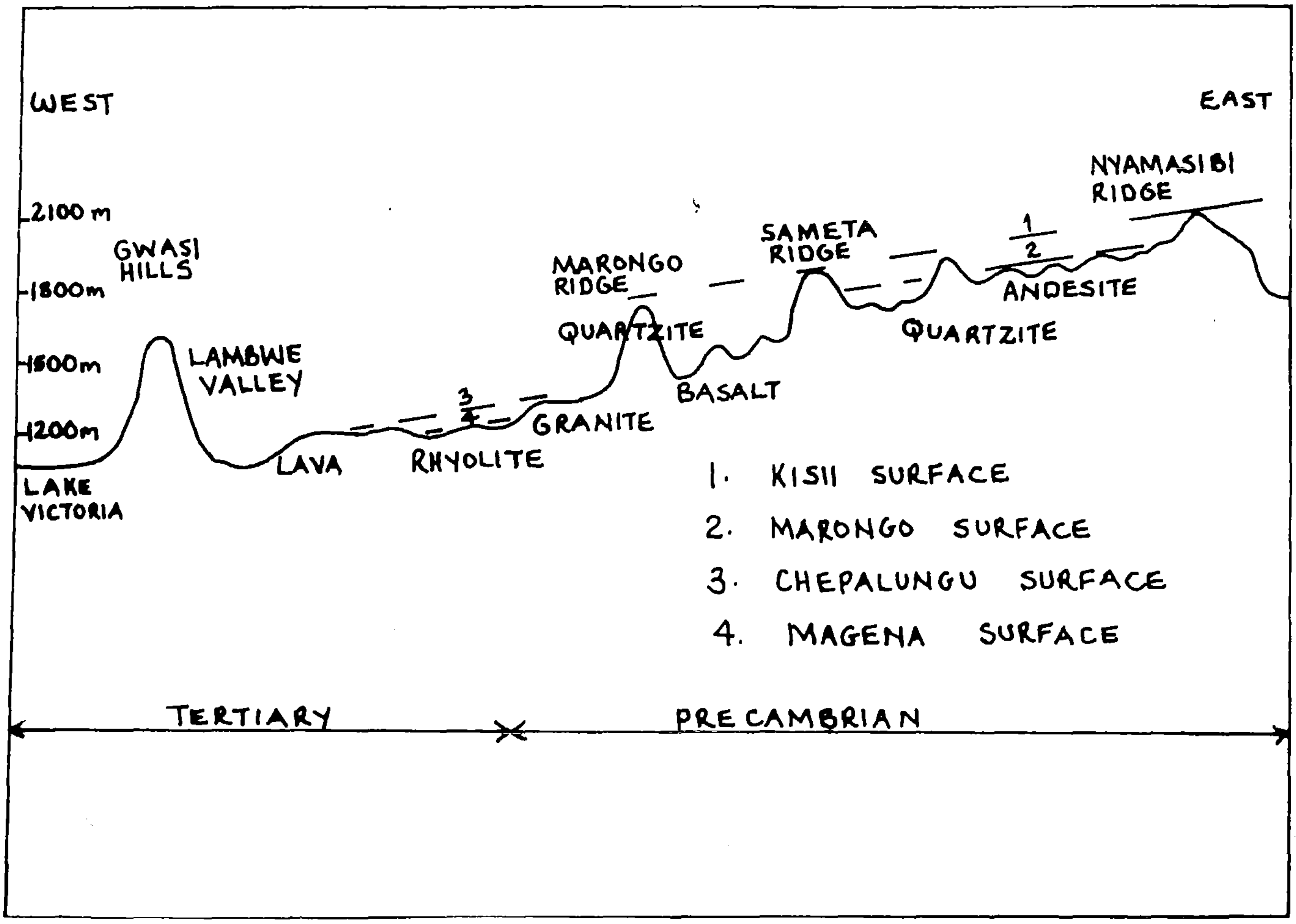


Figure 3.2: Location of study area.

Figure 3.3- Cross section through Kisii and South Nyanza showing location of planation surfaces



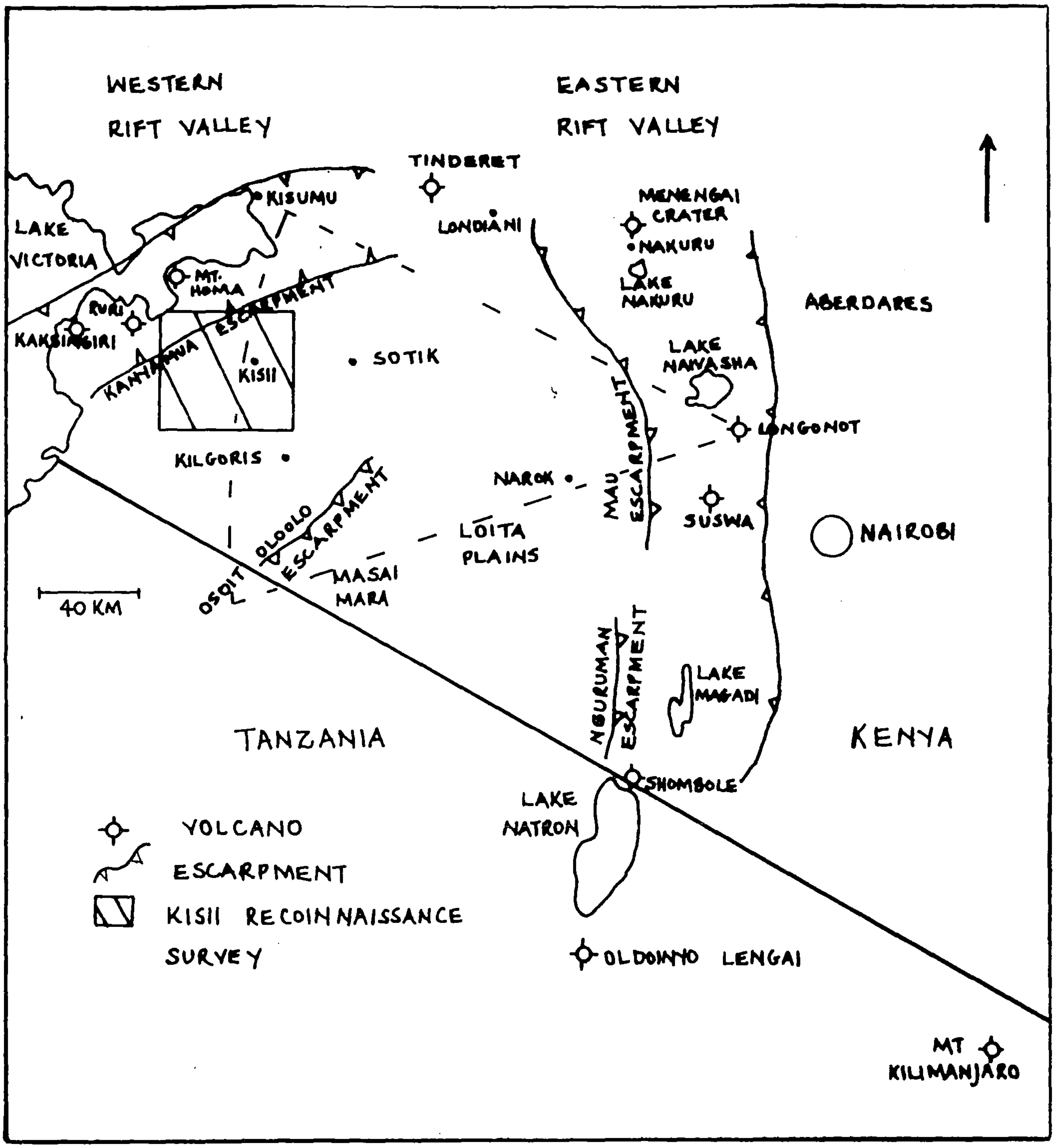


Figure 3.4- Location of neighbourhood volcanos

3.4 Physical properties

Significant run-off occurs only in shallow well-drained soils and inperfectly drained soils. In the well-drained soils, infiltration is so rapid that surface flow does not occur except in some soils susceptible to sealing.

Some valley bottom soils suffer from waterlogging. At footslopes, springs fed by groundwater from the hill soils do occur.

The available moisture (difference in water retention between pF 2.0 and 3.7) for each mapping unit (soil series) and rooting depth class, corrected for rootability and rooting intensity are given in Table 3.1.

3.5 Soil classification

Table 3.2 gives the FAO/Unesco (1974) soil units and the SOIL SURVEY STAFF (1975) Orders of the various mapping units.

3.6 Soil maps

Appendix III displays the following maps: slope class, soil stoniness, parent material, soil series, soil depth, soil rockiness and the topography of the study area.

3.7 Map data input

This was done by overlaying squared paper on the hand-drawn map of BOERMA et al. (1974). For each land characteristic, the boundaries of the various categories were traced to the nearest 5 mm x 5 mm cell. Each mapped category was then given a reference number. Entry of the reference codes into the MAP program may be effected in two ways: stripping and gridding.

In stripping, the reference codes are entered row-wise. For each row and for each mapping unit, the values of the reference code and the column number for the first and last columns are entered interactively into the computer. This method has the disadvantage that entry of an illegal character nullifies all previous entries which could have taken hours to input. The STRIP command is given in Appendix 2A.

In gridding, the reference codes are read from a file. To prepare such a file, a data file was created with an input format similar to the strip format. A computer program STRIP.FOR (Appendix 2B) was used to transform the data file into a grid file in which row numbers are followed by the reference codes for each cell. The GRID command is given in Appendix 2C.

SOIL SERIES	DEPTH RANGE (CM) Aeric volume of readily available moisture (mm)				
	0-50	0-80	0-120	0-180	0-300
Changaa	100	160	230	310	466
Nyangori	80	110	150	210	-
Nyasoka	60	95	193	203	323
Nyokal	105	155	215	295	-
Nduru	105	155	215	295	-
Kiabogori	80	110	150	210	-
Gucha	105	155	215	295	-
Itumbi	80	110	150	210	-
Paulo	80	110	150	210	-
Ndiwa	80	110	150	210	-
Nyerega	100	155	207	-	-
Rongo	40	60	-	-	-
Riosiri	40	60	-	-	-
Ogembo	40	60	-	-	-
Marongo (1)	97	156	-	-	-
Kananga	100	155	207	-	-
Olando	104	158	-	-	-
Maraba	104	158	-	-	-
Kiabogori + Marongo (1)	80	110	150	210	-
Valley complex	104	158	-	-	-

Table 3.1- Readily available moisture for the mapping units. (Adapted from WIELEMAKER and BOXEM, 1982)

SOIL SERIES	FAO/UNESCO SOIL UNIT	USDA SOIL TAXONOMY ORDER
Changaa	MOLLIC NITOSOLS	ULTISOLS
Nyangori	HUMIC FERRALSOLS	ULTISOLS
Nyasoka	HUMIC NITOSOLS	ULTISOLS
Nyokal	LUVIC PHAEOZEMS and MOLLIC NITOSOLS	ULTISOLS
Nduru	"	ULTISOLS
Kiabogori	HUMIC FERRALSOLS	ULTISOLS
Gucha	LUVIC and HAPLIC PHAEOZEMS and MOLLIC NITOSOLS	"
Itumbi	HUMIC FERRALSOLS	"
Paulo	HUMIC ACRISOLS	"
Ndiwa	"	"
Nyerega	LUVIC PHAEOZEMS and CHROMIC LUVISOLS	"
Rongo	HUMIC and FERRALIC CAMBISOLS	INCEPTISOLS and ENTISOLS
Riosiri	"	"
Ogembo	HUMIC CAMBISOLS	"
Marongo (1)	LITHOSOLS and RANKERS	"
Kananga	LUVIC PHAEOZEMS and CHROMIC LUVISOLS	"
Olando	SOLODIC PLANOSOLS	INCEPTISOLS
Maraba	EUTRIC PLANOSOLS	"
Kiabogori + Marongo (1)	LITHOSOLS, RANKERS and HUMIC FERRALSOLS	ULTISOLS, INCEPTISOLS and ENTISOLS
Valley complex	HAPLIC PHAEOZEMS and LITHOSOLS	INCEPTISOLS

Table 3.2- FAO/UNESCO and USDA Taxonomy classification

4. LAND EVALUATION

4.1 Introduction

Land evaluation is concerned with the assessment of land performance when used for specified purposes (FAO, 1976). It is only part of the process of land use planning and its major roles are threefold:

i) To formulate proposals involving alternative forms of land use and recognition of their main requirements;

ii) Recognition and delineation of the different types of land present in an area;

iii) Comparison and evaluation of each type of land for the different uses.

Land may be evaluated directly or indirectly. In direct land evaluation, a trial site is used to observe the degree of success of an enterprise such as irrigated agriculture. The results are often extrapolated to apply to the whole of a soil mapping unit, although strictly they are only applicable to the trial site and for that particular use. Direct land evaluation is normally of limited value due to the large amount of resources and time required to collect the necessary data. Most land evaluation systems are therefore indirect. They assume that certain selected soil and site properties influence the success of a particular enterprise in a reasonably predictable manner, and that the quality of land can be deduced from observations of those properties, McRAE and BURNHAM (1981). Most indirect land evaluation systems are either categoric or parametric.

4.1.1 Categoric land evaluation systems

These refer to broad agricultural systems and not to specific crops or management practices. They group land into discrete categories according to degrees of limitations posed by a number of soil and site properties such as risk of erosion, drainage conditions, root-zone limitations, climatic limitations, soil fertility status and availability of soil moisture. Two examples of categoric land evaluation systems are the USDA Land Capability Classification, KLINGEBIEL and MONTGOMERY (1961), and the Land Systems Approach, OLLIER et al. (1969) and VAN MOURIK (1979).

4.1.2 Parametric systems

These systems combine the various site and soil properties (called parameters) that are believed to influence the success of an enteprise in a mathematical formula. Three main kinds can be distinguished:

i) Additive, e.g. $P = A + B + C + D$;

ii) Multiplicative, e.g. $P = A \times B \times C \times D$;

iii) Complex functions, e.g. $P = A \sqrt{(B \times C \times D)}$.

where P is the parametric rating, score or index and A, B, C and D are soil and site parameters. These can either be direct values, such as soil depth in cm or scale ratings, usually 0-100 so that for instance, soils of depth 30 cm rate 10, those of 40 cm rate 15, and so on. An ideal combination of soil and site properties would gain the maximum score with progressively lower scores for poorer land. Three examples of parametric systems are the Parametric System of Sys (multiplicative), SYS (1978 and 1980), the Parametric System of Duclos (additive), DUCLOS (1971, 1973, 1977 and 1980), and the Storie Index Rating (Multiplicative), McRAE and BURNHAM (1981).

The above-mentioned categoric and parametric systems suffer from two main shortcomings. Firstly, the data bases on which they are founded are specific - they give realistic results only when applied to certain regions of the world. Secondly, the terminologies differ - each system has its own term for the same concept. In an effort to ease communication therefore, FAO have developed a "Framework for Land Evaluation", (FAO, 1976), on the basis of which local evaluation systems can be constructed. NYANDAT and MUCHENA (1978) for example, describe the Land Evaluation System of the Kenya Soil Survey which has been developed using the guidelines laid out by FAO's Framework. A comparison between the Framework and the parametric systems of Sys and Duclos, the USDA land capability classification and the Land Systems Approach are presented in M.Sc. (1982).

4.2 The Framework for Land Evaluation

4.2.1 Land

Land is a wider concept than soil. It includes the soil and underlying geology, the hydrology, the climate, plant and animal populations and the results of past and present human activity. Figure 4.1 depicts a land evaluation model. In the succeeding sections an attempt will be made to analyse the various components of the model.

4.2.2 Land Use System (LUS)

Land is normally not evaluated alone but in connection with a particular use. The land system comprises of subsystems like climate, soil, relief, hydrology and vegetation (see section 4.2.1). The use system, agriculturally speaking, may be subdivided into plant, man and machine subsystems. The land and use systems combined make up a land use system.

4.2.3 Land mapping unit (LU)

A land mapping unit is a mapped area of land with specified characteristics. It is often a soil mapping unit or a vegetation mapping unit.

4.2.4 Land Utilization Type (LUT)

BEEK (1975) described an LUT as "a specific subdivision of a major kind of land use serving as the subject of land evaluation and defined as precisely as is practical in produce terms, level of management, farm size, etc".

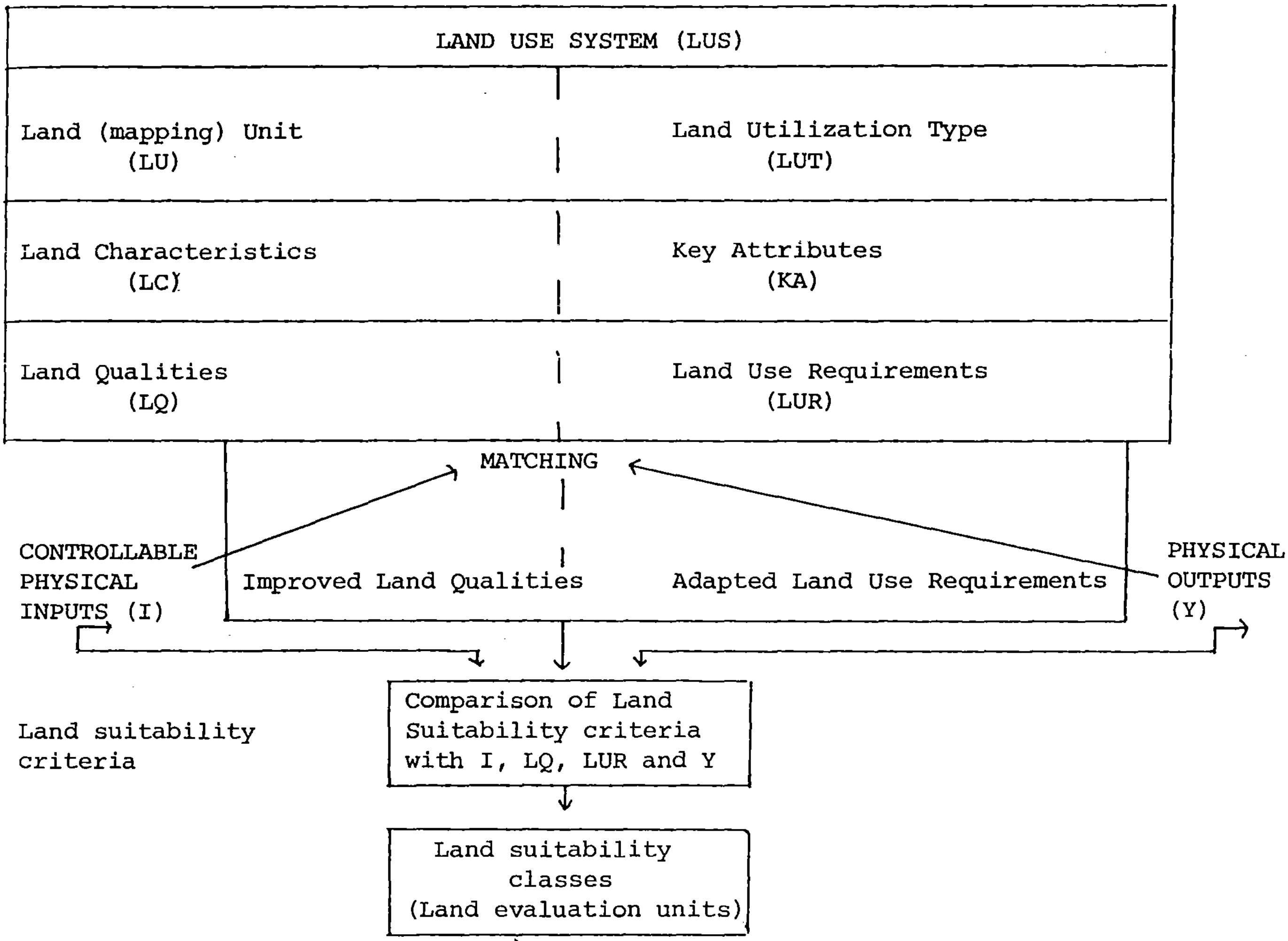


Figure 4.1- A Land evaluation model
(Adapted from Dijkerman, 1982)

A major kind of land use is a major subdivision of rural land use, defined in a general way such as rainfed agriculture, forestry and recreation. An LUT comes into existence as soon as man decides to make land one of the factors by which to reach his objectives.
LUT's are described in terms of key attributes. These may include, in addition to the kind of produce, labour intensity, capital intensity, level of technical know-how, land tenure system and farm power and type of implements used. An example of an LUT would be: rainfed annual cropping based on groundnuts with subsistence maize, by smallholders with low capital resources, using cattle-drawn farm implements, with high labour intensity, on freehold farms of 5-10 ha.

4.2.5 Land characteristics

A land characteristic is an attribute of land that can be measured or estimated. Examples include slope, parent material, texture and soil depth.

4.2.6 Land Qualities

A land quality is a complex attribute of land which acts in a distinct manner in its influence on the suitability of land for a specific kind of use. Examples are availability of nutrients, resistance to erosion, moisture availability and flooding hazard. Land qualities usually consist of combinations of land characteristics. The availability of moisture may depend, for example, on the land characteristics climate, effective soil depth and the soil moisture characteristics between field capacity and wilting point.

4.2.7 Land Use Requirements

Land use requirements are a set of land qualities and their rating required for the proper functioning of a specified land utilization type. The key attributes of a land utilization type determine the requirements posed on the land. These requirements may be ecological, e.g. availability of water; managerial, e.g. mechanization requirements during harvesting; conservational, e.g. risk of crust information; or improvement requirements, e.g. response to fertilizer application. Land use requirements must be expressed in terms of land quality ratings, otherwise no comparison is possible between the land qualities of a mapping unit and the land use requirements of a land utilization type. In a nutshell then, the different units of land are described in terms of several land characteristics which are then translated to a limited number of land qualities. The relevant land utilization types are described in terms of key attributes, which are translated to land use requirements. Land suitability classification involves comparison of the existing land qualities with the desired land use requirements.

4.2.8 Land use adaptations and land quality improvements

Quite often, certain land use requirements are not satisfied by the existing land qualities. One consideration here would be to adapt the land utilization type to suit the prevailing conditions. The choice of a different crop variety may render less serious a case of occasional flooding. A second consideration would be to incorporate improvements of the land. Land improvements fall under two categories: minor and major. Minor land improvements are those that lie within the capacity of the individual farmer, and are usually recurrent in nature. Major land improvements require large non-recurrent inputs which are usually beyond the reach of the individual farmer, for example the provision of irrigation facilities. When major land improvements are involved, the term potential suitability is used. The process of investigating land utilization type adaptations and land quality improvements is called matching. After the matching process a comparison must be made between the inputs, e.g. costs of land improvements, and the resulting outputs, e.g. yield levels.

4.2.9 Land suitability classification

Land suitability is the degree of fitness of a given type of land for a defined use. The degree to which the land is capable of meeting the land suitability criteria (and thus the land use objectives) determines the land suitability class. A possible land suitability criterion would be a good reliability of the yield of food corps, the land use objective being adequate food supply for the rural population. The structure of the suitability classification is summarized in Table 4.1.

4.3 Land evaluation for mixed and arable farming BOERMA et al. (1974)

BOERMA et al. (1974) proposed two land utilization types for the Kisii area: mixed farming with subsistence crops, cash crops and grazing and arable farming with subsistence crops and cash crops. The relevant land qualities are availability of water, availability of nutrients, availability of oxygen and resistance to erosion. The following grades of land quality ratings were used:

1. Very high availability / Very low risk;
2. High availability / Low risk;
3. Moderate availability / Moderate risk;
4. Low availability / High risk;
5. Very low availability / Very high risk.

Four kinds of land improvements were proposed:

A. Soil conservation works;
B. Maintenance and improvement of soil fertility;
C. Increased quantity and quality of the extension service;
D. Road construction works.

The suitability classificaiton for both mixed and arable farming is as follows:

I. High suitability;
II. Moderate suitability;
III. Restricted suitability;
IV. Low suitability

Land suitability orders	Land suitability classes	Land suitability subclasses	Land suitability units
reflecting the kinds of suitability	reflecting degrees of suitability within orders	reflecting kinds of limitation or main kinds of improvement measures required within classes	reflecting minor differences in required management within subclasses
S = Suitable	S1 = highly suitable S2 = moderately suitable S3 = marginally suitable	e.g. S2n, S3me, possible codes of limitations: moisture availability m oxygen availability o nutrient availability n climatic hazards c resistance to erosion e workability w accessibility a	S2n-1 S2n-2 S3me-1 S3me-2
N = Not Suitable	N1 = currently not suitable N2 = permanently not suitable	e.g. N1m, N1me	

Table 4.1 Structure of the Land Suitability Classification

The mapping units of the suitability map consist of classes as shown in Table 4.2. A and B are land improvements as discussed above. The resulting land quality maps and the overall suitability map for mixed and arable farming are presented in Appendix 4(A-E). Each map is preceded by the MAP commands used in its creation.

SUITABILITY CLASS	MIXED FARMING SUITABILITY	ARABLE FARMING SUITABILITY
A	I	I
B	IB	IAB
C	IAB	IAB
D	IAB	IIAB
E	IIAB	IIAB
F	IIB	IIIB
G	III-V	IV

Table 4.2- Suitability classificaiton for mixed and arable farming

4.3.1 Comparison of suitability map with BOERMA et al. (1974)

The suitability map that was prepared by BOERMA et al. (1974) is shown in Appendix 4F. Comparing this map with Appendix 4E, the following can be said against 4F:
i) Class C is under-represented with some of it included in class D;
ii) Class E is over-represented and include classes D, F and G.
The overall result is that class G, the lowest class, is substantially under-represented resulting in an over-rating of the suitability of this land.

4.4 Land evaluation for maize cultivation

Maize is the staple food of the Kisii people and indeed that of most Kenyans. Within the study area, maize is grown on 75% of the area (WIELEMAKER and BOXEM, 1982, Appendix 2). Improved (hybrid) maize varieties are used but fertilizer application is insufficient for the realization of top yields. Cultivation is by ox-plough and weeding by jembe (hoe). Some erosion control measures are practised, such as terracing with trash lines. The recurrent costs go into purchase of fertilizer, hybrid seeds and insecticides. The relevant land qualitites are availability of water, availability of oxygen, availability of nutrients and resistance to erosion.

4.4.1 Availability of water

This depends on two land characteristics: soil series and soil depth. The soil series determines the moisture capacity of the soil which is the amount of water held by the soil between pF 2.0 and 3.7. To assess the actual available moisture capacity, the moisture capacity is corrected for rooting depth, rootability of the soil and crop rooting intensity. The actual available moisture capacity and the effective rainfall determine the amount of water available for the crop. The water availability rating is shown in Table 4.3. The MAP commands precede the water availability map in Appendix 5A.

4.4.2 Availability of oxygen

Its assessment is based on the frequency, duration and degree of waterlogging, crop tolerance to waterlogged conditions and soil drainage characteristics. The rating is shown in Table 4.4 and the map in Appendix 5B.

4.4.3 Availability of nutrients

This depends on the potential nutrient supply of the soils and the nutrient requirements of the crop. The natural soil fertility is very low due to the lack of sufficient organic matter in the topsoil. However, the soil fertility can be boosted to faily high levels by the addition of fertilizer, manure and by mulching. The rating, which incorporates these improvements, is shown in Table 4.5. The resulting map is presented in Appendix 5C.

4.4.4 Resistance to erosion

This land quality depends on the soils susceptibility to sealing and the slope. Table 4.6 gives the ratings. The map is presented in Appendix 5D.

4.4.5 Conversion table for suitability

The overall suitability class is determined by the most deficient land quality. Resistance to erosion is generally high owing to the high permeabilities of the soils largely due to termite activity. Oxygen availability is critical only in the few waterlogged soils. The soil fertility can be stepped up to quite high levels by modest addition of fertilizer. The most limiting land quality is water availability especially in the shallow soils. Table 4.7 shows the suitability conversion table used in the preparation of the suitability map presented in Appendix 5E.

Table 4.3- Rating for availability of water

SOIL SERIES	SOIL DEPTH CODE	RATING
Changaa, Nyokal	1, 2, 3	1
Nduru, Gucha	4	2
Nyerega, Kananga	5	3
Nyangori, Nyasoka	1, 2, 3	2
Kiabogori, Paulo, Ndiwa Rongo, Riosiri, Ogembo, Marongo (1), Olando, Maraba, Kiabogori + Marongo (1), Valley Complex	4, 5	3

Table 4.4- Oxygen availability

SOIL SERIES	RATING
Changaa	1
Nyangori	1
Nyasoka	1
Nyokal	1
Nduru	1
Kiabogori	1
Gucha	1
Itumbi	1
Paulo	1
Ndiwa	1
Nyerega	1
Rongo	2
Riosiri	2
Ogembo	1
Marongo (1)	1
Kananga	1
Olando	3
Maraba	3
Kiabogori + Marongo (1)	1
Valley Complex	3

Table 4.5- Rating for availability of nutrients

SOIL SERIES	RATING
Changaa	1
Nyangori	2
Nyasoka	2
Nyokal	1
Nduru	1
Kiabogori	2
Gucha	1
Itumbi	2
Paulo	2
Ndiwa	2
Nyerega	1
Rongo	1
Risoiri	1
Ogembo	1
Marongo (1)	2
Kananga	1
Olando	2
Maraba	1
Kiabogori + Marongo (1)	2
Valley Complex	2

Table 4.6- Rating for resistance to erosion

SOIL SERIES	SLOPE CLASS	RATING
Nyangori, Nyasoka	1, 2	1
Kiabogori, Itumbi	3	2
Ndiwa, Marongo (1)	4	3
Kiabogori + Marongo (1)		
Changaa, Nyokal, Nduru Gucha, Paulo, Nyerega, Rongo, Riosiri, Ogembo, Kananga, Olando, Maraba, Valley complex	1, 2, 3, 4	1

Table 4.7- Conversion table for suitability

Suitability class	Rating for Water	Oxygen	Nutrients	Erosion
1	1	1	1	1
2	2	2	2	2
3	3	3	2	3

5. EROSION

Erosion is as old as the world. It is the removal of surface material by wind or water. Soil erosion is one aspect of landscape development. The other major processes of sediment removal are mass movement and solution, and each of these may be dominant in suitable environments.

Soil erosion by water is most active where solution is least active. Where rainfall cannot infiltrate the soil, it flows over the surface as run-off and is able to transport soil materials away. As large depths can flow over the surface, soil erosion sometimes acts catastrophically even on mild gradients. Severe soil erosion associated with gullies can initiate mass movements from steepened slopes around the gullies.

Soil erosion by wind relies on the force which air can exert on soil particles. This force depends to a large extent on the surface roughness. Where the surface is rough, with for example plants or large stones which cannot be lifted by the wind, the wind speed near the surface is low and little erosion occurs. Any smooth surface, like a bare field is liable to wind erosion and the risk is increased where the soil contains large amounts of silt, which settles out of the air only slowly after being picked up.

This work focuses on water erosion. Interrill (formely sheet) erosion represents a topsoil removal rate of 0.1-10 mm/year in the tropics (ROOSE, 1975). Although this rate of lowering of the land surface has little apparent effect in a human lifetime, its long-term effect is significant: up to 10 000 m over a million years. More important however, is the fact that erosion removes the top-soil which contains a high proportion of the soil organic matter and the finer material fractions which provide water and nutrient supplies for plant growth.

Various civilizations in the past have attempted soil conservation measures with varying degrees of success. Terracing in areas of mechanized farming and high populated areas are examples. Population explosions and high concentrations have led to decreased use of the "fallow" practice and accelerated erosion.

In current soil conservation practice, it is normal to plan for acceptable rates of erosion of up to 20 tons/ha/year (about 2 mm/year). It is argued that this rate will keep pace with the rate of formation of new soil by chemical weathering. However, in the long-term perspective of sustained agriculture, the equilibrium between mechanical soil erosion and chemical soil formation needs more careful examination. One complication arises from the fact that any increase in soil erosion tends to be associated with an increase in overland flow. Consequently, the subsurface flow is slightly reduced, so that the amount of material removed in solution, which is an indicator of bedrock weathering, is also slightly reduced. Thus, any increase in erosion should reduce the permissible level set by the rate of new soil formation. Another important aspect is that the milder the slopes and the more the vegetal cover, the more is erosion selective vis a vis organic colloids, and minerals and nutritive elements.

5.1 Soil erosion and land evaluation

Soil erosion is usually incorporated in land evaluation procedures in the land quality "susceptibility to erosion". The permissible soil loss in the context of land evaluation at farm level, is the soil loss which does not negatively affect the land qualitites of a specific land utilization type. It is high in deep soils with a well-drained easily-weatherable parent material and soils with a subsoil that is more suitable for the land utilization type in question than the topsoil. On the other hand degradation of land qualities is high in soils underlain by solid rock or plinthite and soil in which the natural soil fertility ingredients are located in the top-soil.

Although in most cases soil loss is accompanied by degradation, it may sometimes have a positive result. BENNEMA and DE MEESTER (1981) cited a situation in Southern Netherlands and Belgium where large areas are covered with loess soils and where sugar beet is the main crop. The soils have an eluvial horizon high in silt but low in clay and an illuvial B horizon with a higher clay content. Most of the eluvial layer has been eroded and a new Ap horizon has formed in the B horizon. This situation is more favourable for the land utilization type than the one earlier.

5.2 Soil erosion in Kisii West

The Kisii West area was originally covered by a dense vegetation of a broad-leaved savanna tree (combretum spp.). At the end of the 19^{th} century, the Kisii people moved into the area and started practising shifting cultivatin with some pastoralism. As the population grew, shifting cultivation changed to permanent cultivation and accelerated erosion became a problem.

In the early 1940's, conservation works were started and consisted mainly of the construction of trashlines. These were built from maize stalks, weeds or stones laid along the slope contours. Their levels were raised on an annual basis developing into semi-natural terraces. Improved rotation systems with fallow periods and the use of farmyard manure were also introduced. From the 60's however, these conservation works have fallen behind the population pressure (300-400 persons/ha) and the situation is steadily deteriorating. In many places, the trashlines have been dug up.

Some Kisii West soils are moderately susceptible to sealing. Precipitation intercepted by maize leaves may make the rainfall intensity below leaf-ends three to four times that of free precipitation.

5.3 Soil loss estimation

The most widely used method of soil loss prediction by soil conservationists is the Universal Soil Loss Equation:

$$A = RKLSCP$$

where:

A = the soil loss in tons/ha;
R = the rainfall erosivity index;
K = the soil erodibility factor (tons/ha);
L = the slope length factor;
S = the slope gradient factor;
C = the cropping management factor;
P = the erosion control practice factor.

5.3.1 The rainfall erosivity factor, R

Soil loss is closely related to rainfall through the detaching power of rainfall striking the soil surface and through run-off. The R-value may be estimated with the FAO formula:

$$R = 0.11\,abc + 66$$

where:

a = the average annual precipitation in cm;

b = the maximum day-precipitation occuring once in 2 years in cm;

c = the maximum total precipitation of a shower of one year occurring once in 2 years in cm.

For the study area:

a = 226.7 cm (WIELEMAKER and BOXEM, 1982).

The maximum rainfall intensity in 12.5 minutes with a return period of 100 years is 28.1×10^{-3} mm/s. The total rainfall in 12.5 minutes with a return period of 100 years is therefore $28.1 \times 10^{-3} \times 12.5 \times 60 = 21.1$ mm.

From SPAAN (1979):

$$\frac{12.5\ \text{min.} - 100\ \text{years}}{1\ \text{hour} - 2\ \text{years}} = 0.935$$

Giving a 2-year 1-hour maximum precipitation of $\frac{21.1\ \text{mm}}{0.935}$ is 22.54 mm. This is the value of c.

Further,

$$\frac{2\text{-year 1-day}}{2\text{-year 1-hour}} = 2.4$$

Giving a 2-year 1-day maximum precipitation of $22.54 \times 2.4 = 54.1$ mm. Then:

$$R = 0.11 \times 226.7 \times 5.41 \times 2.25 + 66 = 370$$

36% of the annual precipitation falls in the period March-May, 21% in June-August, 27% in September-November and 15% in December-February. The percental distribution of R over the months of the year is shown in Figure 5.1.

5.3.2 The soil erodibility factor, K

K represents a quantitative description of the inherent erodibility of the soil. It reflects the fact that different soils erode at different rates when the other erosion factors are the same. Erodibility varies with soil texture, aggregate stability, shear strength, infiltration capacity and organic and chemical content. for the study area, HENNEMANN and KAUFMANN (1975) suggested a K value of 0.05.

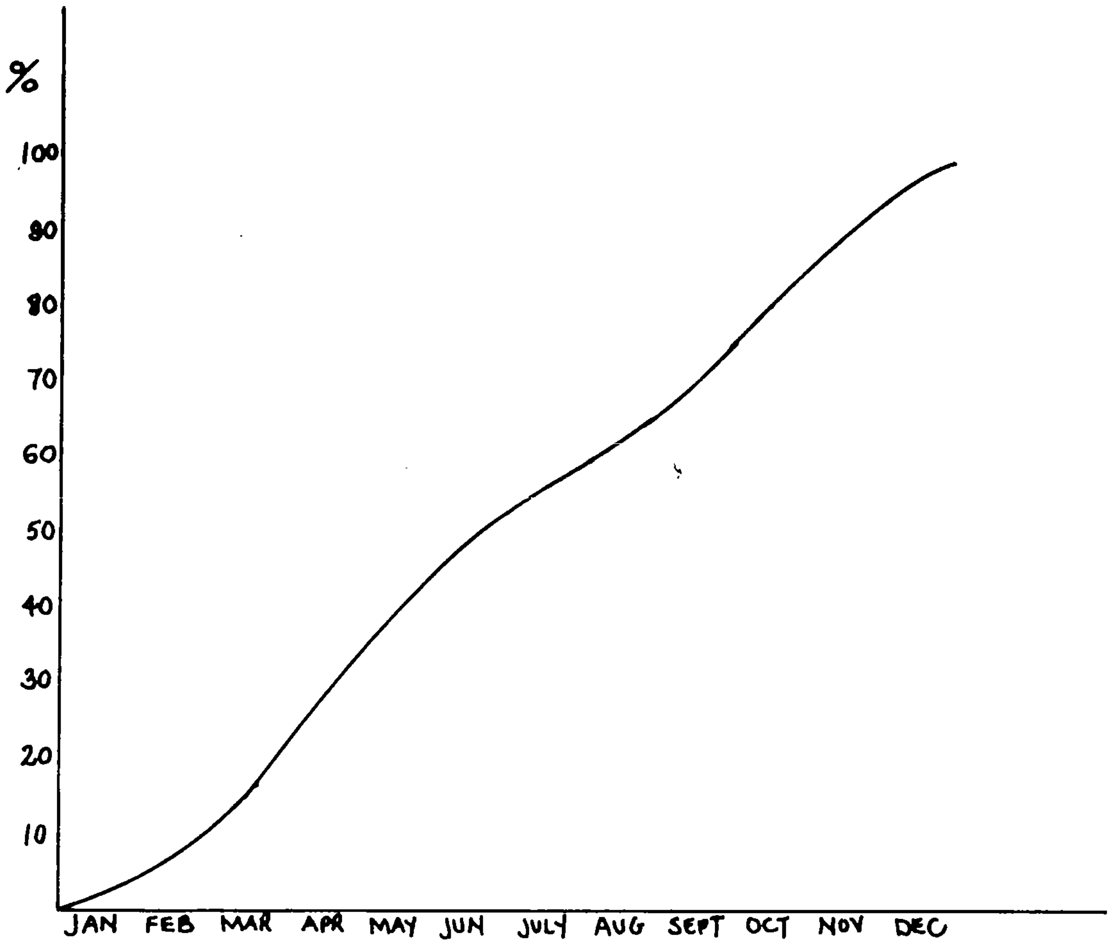


Figure 5.1- Cummulative percental distribution of R.

5.3.3 The slope length factor, L

Slope length is defined as the distance from the point of origin of overland flow to the point where the slope decreases sufficiently for deposition to occur or to the point where run-off enters a defined channel. L is given by:

$$L = \left(\frac{\lambda}{22.1}\right)^{0.5}$$ (WISCHMEIER and SMITH, 1978).

where:

L = slope length factor;
λ = slope length in meters.

5.3.4 The slope gradient factor, S

Soil loss is correlated with a parabolic description of the effect of gradient. S is given by:

$$S = 0.0065s^2 + 0.0454s + 0.065$$

where s is the slope expressed as a percentage (SMITH and WISCHMEIER, 1957).

5.3.5 The cropping management factor, C

The cropping management factor represents the ratio of soil loss from a specific cropping or cover condition to the soil loss from a tilled, continuous fallow condition for the same soil and slope and for the same rainfall. Each segment or period of crop growth must be evaluated in combinaiton with the rainfall erosivity distribution for that period.

Five growth periods may be distinguished in the case of maize:
Period 1 - seedbed preparation and up to 10% canopy cover
Period 2 - Establishment period; 10-50% canopy cover;
Period 3 - Developement and maturity; 50-75% canopy cover;
Period 4 - Harvesting;
Period 5 - Stubble to ploughing.

ROOSE (1975) found that the C-value for maize ranges from 0.4 - 0.9. Using Figure 5.1, Table 5.1 is constructed:

Table 5.1- Computation of the C-value

Growth period	Date	C value	% R value	Weighted C value Col 3 x col 4
1	15/3-15/4	0.9	0.13	0.12
2	15/4-15/5	0.7	0.12	0.08
3	15/5-15/7	0.4	0.16	0.06
4	15/7-15/8	0.7	0.07	0.05
5	15/8-15/9	0.1	0.07	0.007
1	15/9-15/10	0.9	0.13	0.12
2	15/10-15/11	0.7	0.12	0.08
3	15/11-15/1	0.4	0.16	0.06
4	15/1-15/2	0.7	0.07	0.05
5	15/2-15/3	0.1	0.07	0.007
			Total	0.63

5.3.6 The erosion control practice factor, P

The erosion control practice factor is the ratio of soil loss using the specific practice compared with the soil loss using up-and-down hill culture. The practices usually included in this factor are contouring, contour stripping and terracing. For the study area, a value of 0.5 seems appropriate.

5.4 Limitations of the Universal Soil Loss Equation

The universal soil loss equation was derived from stations in the U.S.A. over an equivalent of 10,000 years of records and is therefore reliable. However, its data base is restricted to the U.S.A. East of the Rockies, slopes of 0-7° and soils with a low content of montmorillonite. Application of the equation outside these boundaries must therefore be done with caution.

In addition, there are theoretical problems with the equation. There is considerable interdependence between the variables and some are even counted twice. Rainfall for example, influences the R and C factors and terracing the L and P factors. Other interactions between factors, such as the greater significance of steepness of slope in areas of intense rainfall are ignored. One important factor to which soil loss is closely related, namely runoff, is omitted.

6. A PARAMETRIC SOIL EROSION MODEL

Basically there are three types of erosion models: physical, analogue and digital (MORGAN, 1979).

i) Physical models are scaled-down hardware models usually built in the laboratory. A dynamic similitude between the model and field conditions is assumed.

ii) Analogue models use mechanical or electrical systems to simulate erosion mechanisms. For example, the flow of electricity may be used to simulate the flow of water.

iii) Digital models are based on the use of computers to process vast quantities of data. Digital models fall under three categories: deterministic, stochastic and parametric.

Deterministic models are based on mathematical equations to describe the processes involved in the model, taking account of the laws of conservation of mass and energy.

Stochastic models are based on generating artificial sequences of data from the statistical characteristics of existing sample data. They are useful for generating input sequences to deterministic and parametric models where data is only available for short periods of observation.

Parametric models are based on identifying statistically significant relationships between assumed important variables where a reasonable data base exists.

6.1 The model

The model is based on the Universal Soil Loss equation. A computer program, EMODEL (Appendix 6C), was used for the various calculations and output of results in a form usable by the Map Analysis Package.

Two more land characteristics were required: length of slope and eroding and depositional sites. Sites on slopes were classified as eroding and those in flood plains and valley bottoms depositional. The site and length of slope maps are presented in Appendix 6A and 6B. The data used in both cases was obtained from aerial photographs.

The sequence of operations of EMODEL is as follows:

i) Accept the values of R, K, C and P;

ii) Accept D, a conversion factor from tons/ha to depth of soil in cm. D was assigned the value of 0.01, assuming a soil density of 1000 kg/m^3;

iii) Accept the names of the following files: DEPTH, SLOPE, ROCKINESS, STONINESS, SLOPE LENGTH and ERODING SITE;

iv) Accept NYEAR, the number of years that the model is required to run;

v) Accept the values of the parameters in (iii) for each grid cell.

Then for each grid cell:

vi) Calculate the values of S, L and A;

vii) Correct for stoniness by substracting from A the value of A X % stoniness;

viii) Correct for rockiness by substracting from the A value obtained in (vii) the value of A X % rockiness;

ix) Convert the value of A obtained into tons/grid cell;

x) Accumulate the total number of tons in YTOT;

xi) Convert A to cm of soil by multiplying with D and update the depth file. If new depth is greater than or equal to the original depth, set depth equal to 0, and rockiness equal to class 3;

xii) Get next cell;

xiii) Get next year. This is to be repeated up to NYEAR. For each year, accumulate YTOT in TOTAL.

6.2 Results

The model was run for 30 years. The updated rockiness map is shown in Appendix 7A.

For the depositional sites, the total amount of eroded soil over 30 years was assumed to be all deposited uniformly on them. In cm, this is equal to TOTAL/Depositional area. The area of deposition covers 5460 cells (Appendix 6A) while the total area of 1406.25 ha covers 14400 cells. The soil depth added is then equal to:

$$\frac{\text{TOTAL} \times 100}{(5460/14400) \times 3750 \times 3750} \text{ cm}$$

The value of TOTAL after 30 years is 440780 tons. This represents an accumulation of about 8 cm of soil on all the sites of deposition. This is however not sufficient to upgrade the corresponding depth classes and its effect has therefore been ignored.

The new depth map is shown in Appendix 7B.

6.3 New Land Evaluation for maize cultivation, after 30 years

Using the new depth map, a new water availability map was created (Appendix 7C). With the new water availability map and the old nutrient, erosion and oxygen maps, a new suitability map was created (Appendix 7D). The MAP commands used are identical to those used in Appendices 5A and 5E respectively.

6.4 Comments on the new map

The new rockiness map shows that 1.9% of the total area is now completely bare of soil. A quick superposition of the parent material map reveals the exposed parent material as indurated iron.

The most significant change in the soil depth map is the increase of 13.6% in the coverage of soils less than 20 cm deep. There is no change in soils deeper than 150 cm, while soils in the category 100-150 cm show a decrease of 13.4%. The other depth classes show no significant changes.

The new water availability map shows a decreased water availability status from class 2 to class 3 of about 10% of the area.

The overall suitability is strongly dependent on the availability of water. The new suitability map shows a downgrading of one class (from class 2 to class 3) of approximately 10% of the area.

Further, Appendix 7E shows areas that presently have soils less than 50 cm deep while Appendix 7F shows the extent of these soils after 30 years. Subtracting the former from the latter yields Appendix 7G, soils that presently are deeper than 50 cm but will have, after 30 years depths of less than 50 cm.

7. DISCUSSION

A few aspects of computer mapping deserve special mention. These are map input, map quality, map size and map colouring.

7.1 Map input

The map input process is a very laborious one. Each of the land characteristic maps given in Appendix III took about 4 hours to prepare. More advanced techniques for inputting maps are available in the market but they are still very expensive.

7.2 Map quality

Boundaries between units are stepped. The larger the cells, the bigger the steps. There exist, however, systems in which the grid cells are so small that the steps are practically unnoticeable.

7.3 Map size

The maps produced herein measure about 25 cm x 25 cm. This means that if a map of larger size is required, it would have to be constructed from a mosaic of smaller maps. This would mean additional manual labour and would also demand a high degree of precision.

7.4 Map colouring

Although each mapping unit is represented by a different symbol, discrimination between units is sometimes difficult especially when a large number of units is involved. Colour separation techniques are available in raster mapping but they only add to the overall costs.

8. CONCLUSIONS

Computer-assisted cartography and land evaluation offers a quick way of processing spatial data and producing maps. The relevant data may be stored on computer storage devices with savings in space and a retention of precision.

It is important to be able to predict the evolution of a piece of land over time when that land is used for a certain purpose in a certain way. Water erosion removes the topsoil and results in a decrease of soil depth. This in turn limits the amount of soil moisture available to crops and leads to a decrease in yield. In the exercise described here, 10% of the area is rendered marginally productive after 30 years of continuous, unchecked erosion. This figure could be related to a proportional decrease in maize production over 30 years.

Such an exercise also reveals areas which are most sensitive to erosion under the land utilization type being considered and this would help in setting priorities over matters pertaining to soil conservation works.

REFERENCES

BEEK, K.J., 1975
Land Utilization Types in Land Evaluation. Land Evaluation in Europe, Soils Bulletin 29, 87-104. FAO, ROME;

BENNEMA, J. and T. DE MEESTER, 1981
The role of Soil erosion and land degradation in the process of land evaluation. SOIL CONSERVATION: PROBLEMS AND PROSPECTS. 77-85. Edited by R.P.C. Morgan;

BIE, S.W., R.W. BOWEN, K.G. JEFFREY, M. LENCI and G.M. MARTIN, 1977
Relevant Data Structures. COGEODATA Working Group on Data Structures and Data Management. Netherlands Soil Survey Institute, Wageningen;

BIE, STEIN W., 1980
Computer Assisted Soil Mapping. The computer in contemporary cartography. Edited by D.R.F. Taylor (1980) John Wiley and Sons Ltd.;

BOERMA, P.N., HENNEMAN, G.R., KAUFFMAN, J.H. and VERWEY, H.E., 1974
Detailed Soil Survey of the Marongo area Preliminary Report no. 3. Department of Soil Science and Geology, Agricultural University, Wageningen, The Netherlands;

BOERMA, P.N., G.R. HENNEMANN, J.H. KAUFFMAN and H.E. VERWEY, 1974
A Detailed Soil Survey of the Marongo Area. A reconnaissance study Preliminary Report No. 3, Training Project in Pedology, Kisii, Kenya; Agricultural University, Wageningen, The Netherlands;

BOYLE, A.R.
Concerns about present applications of computer assisted cartography. CARTOGRAPHICA Vol 18 No. 1 1981 pp 31-33;

BOYLE, A.R., 1979
Automated cartography. World Cartography, 15 (1979) p. 63-70;

BREIMER, R.F., 1976
Detailed Soil Survey of the Rangwe area. Preliminary Report 17. Department of Soil Science and Geology. Agricultural Unversity, Wageningen, The Netherlands;

BURROUGH, P.A., 1980
The Development of a landscape information systems in The Netherlands, based on a turn-key graphics system. Geo-processing, 1:257-274;

BURROUGH, P.A., 1982
The ISSS. Working group on Soil Information Systems and the role of computer assitance for soil survey and land evaluation. Wageningen, The Netherlands. Soil survey and Land Evaluation, vol 2, no. 2, May 1982;

BURROUGH, P.A., 1983
Department of Regional Soil Science, Agricultural University, Wageningen, The Netherlands;

DUCLOS, G., 1971
Appréciation de l'aptitude à la mise en valeur (Agricole) des sols de Provence. Bulletin de l'Association Francaise d'Etudes des Sols;

DUCLOS, G., 1973
Appréciation de l'Aptitude à la mise en valeur (agricolé) des sols de Provence. L'irrigant no. 60: 16-32;

DUCLOS, G., 1977a
Les analyses de sols et leur interprêtation en vue du conseil fertilization. Eau et aménagement de la region provencale No. 15: 2-24;

DUCLOS, G., 1977b
Carte Pedologue et Carte des Aptitudes à la mise en valeur et a l'irrigation, Trevaresse-Ouest, 1:20 000;

DUCLOS, G., 1980
Apprêciation de l'Aptitude à la mise en valeur forestière et agricole des zones accidentées de Provence Eau et Aménagement de la région provencale No. 24: 4-18;

DIJKERMAN, J.C., 1982
Introduction to Land Evaluation Lecture notes, M. Sc.-Course in Soil Science and Water Management, Agricultural University, Wageningen, The Netherlands;

FAO-UNESCO, 1974
Soil Map of the World. 1:5 000 000. Volume 1. Legend. UNESCO, Paris;

FAO, 1976
A Framework for Land Evaluation. Publ. 22, ILRI, Wageningen, The Netherlands;

GUIKING, I.M., 1976
Detailed Soil Survey of the Nyasiongo area. Preliminary Report 18. Department of Soil Science and Geology, Agricultural University, Wageningen, The Netherlands;

HENNEMANN, G.R. and J.H. KAUFMAN, 1975
Erosion in the Western part of Kisii district. Preliminary Report No. 8, Training Project in Pedology, Kisii Kenya; Agricultural University, Wageningen, The Netherlands;

KEULEN, J. VAN, REULER, H. VAN, 1976
Detailed Soil Survey of the Ranen area. Preliminary Report 16. Department of Soil Science and Geology. Agricultural Unversity, Wageningen, The Netherlands;

KLINGEBIEL, A.A. and P.H. MONTGOMERY, 1961
Land capability classification. USDA Soil Conservation Service, Agricultural Handbook 210;

McHARG, IAN L., 1969
Design with nature. Natural History Press. Philadephia, U.S.A.;

McRAE, S.G. and C.P. BURNHAM, 1981
Land Evaluation Clarendon Press, Oxford;

MILLER, F.T., 1961
Soil Survey of the East Konyango area. Department of Agriculture, Kenya Soil Survey, Nairobi;

MORGAN, R.P.C., 1979
Soil erosion. Topics in applied geography. Longman Inc., New York;

MOURIK, D. VAN, 1974
Detailed Soil Survey of the Irigonga area Preliminary Report 2. Department of Soil Science and Geology, Agricultural Univeristy, Wageningen, The Netherlands;

MOURIK, D. VAN, 1979
Land in Western Liberia. A reconnaissance land evaluation of the Mano River Union Project Area in Liberia. Mano River Union Secretariat, Freetown, Sierra Leone;

M.SC.-Course in Soil Science and Water Management, 1982
Four Land Classification Systems Compared to the Standards set by the FAO Framework for Land Evaluation. Student Reports in the course "Introduction to Land Evaluation". Edited by J.C. Dijkerman;

NYANDAT, N.N. and F.N. MUCHENA, 1980
Land Evaluation in Kenya with particular emphasis on the criteria used. World Soil Resources Report no. 51, 26-48. FAO, ROME;

OLLIER, C.D. et al., 1969
Land Systems of Uganda; terrain classification and data storage. MEXE Rep. 959, Dept. Agric. Univ. Oxford;

OWEN, M.L., STEVE DOWERS, BRIAN S. DUFFIELD
Tourism and Recreation Research Unit (TRRU) of Edinburgh, Sept. 1974 Research Report no. 11;

PEUQUET, DONNA J., 1977
Raster Data Handling in Geographic Information Systems. First International advanced study symposium on topological data structures for Geographic Information systems. Vol. 2. Edited by Geoffrey Dutton;

POIKER, THOMAS K.
Vector vs Raster. The Handling of Lines and ploygons Lecture 5. Dept. of Geog. Simon Fraser University, Burnaby, BC, V5A 156, Canada;

ROOSE, ERIC, 1975
Erosion et ruissellement en Afrique de l'ouest: vingt années de mesures en petites parcelles expérimentales, Cyclo. ORSTOM, Abidjan, Ivory Coast;

SCHOLTEN, J.H.M., MAAT S. TER, TORREN, K. VAN DER and VUYK, D.. 1975
Detailed Soil Survey of the Magombo area. Preliminary Report 9. Department of Soil Science and Geology, Agricultural University, Wageningen, The Netherlands;

SMITH, D.D. and W.H. WISCHMEIER, 1957
Factors affecting sheet and rill erosion. Trans. Am. geophys. Union, 38, 889-896;

SOIL SURVEY STAFF, 1975
A basic system of soil classification for making and interpreting soil surveys. United States Department of Agriculture, Agricultural handbook no 436. Government Printing Office, Washington D.C., U.S.A.;

SPAAN, W.P., 1979
Course instruction in soil conservation and erosion control. Agricultural University, Wageningen, The Netherlands;

STEINITZ, C., 1982
"The Manadnock Region of New Hampshire, U.S.A.: Planning for Major Landscape Change". Paper presented at the International Symposium on Landscape Information Systems: The Application of Computer Technology for Landscape planning. Bonn-Bad Godesberg, Federal Republic of Germany, March 9, 1982;

SYS, C., 1978
Evaluation of Land Limitations in the Humid Tropics. Pedologie XXVIII 3, 307-335;

SYS, C., 1980
Land characteristics and qualities and methods of rating them. Land Evaluation Guidelines for Rainfed Agriculture. World Soil Resources Report 52, 23-49;

TOMLIN, C. DANNA and TOMLIN, SANDRA M
An overlay mapping language. Proceedings of the Regional Landscape Planning Committee of the ASLA. Washington D.C., November 22-24, 1981;

TOMLIN, C. DANNA, 1980
"The Map Analysis Package", unpublished draft, Yale School of Forestry and Environmental Studies, New Haven, Connecticut;

TOMLIN, SANDRA M., 1981
Timber Harvest Scheduling and spatial allocation Master's Thesis. Harvard Graduate School of Arts and Sciences, Cambridge, Massachusetts;

TOMLINSON, R.F., 1973
Application of Electronic Computing Methods and Techniques to the Storage, Compilation and Assessment of Mapped Data, unpublished doctoral dissertation, University of London;

WIELEMAKER, W.G., 1979
Soil formation in the Kisii area and the role of volcanic ash. Preliminary Report no. 5. Department of Soil Science and Geology, Agricultural University, Wageningen, The Netherlands;

WIELEMAKER, W.G. and BOXEM, H.W., 1982
Soils of the Kisii Area, Kenya Agricultural Research Reports 922 (Also published as Reconnaissance Soil Survey Report no. R4). PUDOC, Agricultural University, Wageningen, The Netherlands;

WIELEMAKER, W.G., 1983
Doctoral Thesis, in prep. Department of Soil Science and Geology, Agricultural University, Wageningen, The Netherlands;

WISCHMEIER, W.H. and D.D. SMITH, 1978
Predicting rainfall erosion losses. Agricultural Handbook no. 537, United States Department of Agriculture, Washington D.C.;