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PART I: ASSESSING THE RELATIVE ERODIBILITY OF SOME KENYAN SOILS USING A RAINFALL SIMULATOR AND THE PREDICTION OF RELATIVE ERODIBILITY FACTORS.

PART II: AN ASSESSMENT OF THE SOIL EROSION SUSCEPTIBILITY OF A SELECTED AREA IN KILIFI DISTRICT.

by

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A THESIS SUBMITTED IN PART FULFILMENT FOR THE DEGREE OF MASTER OF SCIENCE IN THE UNIVERSITY OF NAIROBI.

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University.

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This thesis has been submitted for examination with my approval as University Supervisor.

....

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Dedicated

To my beloved parents, wife and daughter

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LIST OF ABBREVIATIONS AND SYMBOLS

C	Cover and management factor
P	Support practice factor
R	Rainfall erosivity factor
K	Soil erodibility factor
L	Length of slope factor
S	Angle of slope factor
USLE	Universal Soil Loss Equation
KSS	Kenya Soil Survey
$\sum$	Summation
%	Percent
KE	Kinetic energy
KE>25	Kinetic energy of rain falling at intensities greater than 25mm/hr
>	More than
≥	More than or equal to
<	Less than
≤	Less than or equal to
et.al.	and others
r/Eo	Ratio of average annual rainfall: annual potential evaporation
mm	Millimeters
μ	Microns
CEC	Cation exchange capacity
me	Milliequivalent
km	Kilometer
ha	Hectares

LIST OF ABBREVIATIONS AND SYMBOLS CONT'D.

loc.cit.	Cited elsewhere
EI_{25}	Product of the kinetic energy of the rainstorm and the maximum 25 minute rainfall intensity
KN	Kilo Newton
k	Relative erodibility
k_{td}	Relative k values determined from trays(t) in dry(d) state
k_{pred}	Relative k-values predicted by regression equation (2)
K_{nom}	Estimated K-values determined by Wischmeier's soil erodibility nomograph
k_{fw}	Estimated k-values determined under field (f) conditions in wet (w) state
k_{fd}	Estimated k-values determined under field (f) conditions in dry (d) state
NS	Non-significant

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PART I

Abstract

This study was an attempt to assess the relative erodibility of some Kenyan soils using a rainfall simulator, and to develop a regression equation based on easily measured soil properties that would predict relative soil erodibilities.

The surface horizons of 15 contrasting soils from cultivated land were selected for this study. The air-dried soils were packed into metal trays and positioned on a 6^{o} incline beneath a rotating disc rainfall simulator. The duration of the simulated (47mm/hr) rainstorms was 1hr, except for 3 soils where a 1½hr storm was necessary in order to obtain runoff.

The soil losses ranged from 2.03 to 7.91g/m^2/ unit of erosivity, while the relative erodibility k factors ranged from 0.054 to 0.210. For five of these soils, the soil losses correlated fairly well (r=0.79) with measured soil losses obtained under field conditions using the same rainfall simulator and similar rainfall intensities. The k values for all 15 soils correlated rather poorly (r=0.54*) with the erodibility factors K_{nom} obtained from Wischmeier's soil erodibility nomograph, but the k factors of the 13 non-swelling, well drained soils

correlated reasonably well (r=0.84***) with K_{nom}. Spearman's ranking coefficients for the k factors as given by K_{nom} values for all 15 and for the 13 soils were r_s=0.679** and r_s=0.885** respectively.

To try and improve on the prediction of the k values, simple and multiple linear regression analyses on the k factors of the 13 non-swelling, well drained soils were carried out using various easily measured soil properties. The best single predictive factors for the relative erodibilities were the % fine sand (r=0.79**), % clay (r=-0.62*), % organic matter (r=-0.54), % fine and very fine sand (r=0.80***) and dispersion ratio (r=0.75**). In a multiple linear regression analysis, four soil properties viz. dispersion ratio, % clay, % organic matter and bulk density explained 90% of the variations in k. In comparison, Wischmeier's soil erodibility nomograph accounted for only 71% of the variations in k for the 13 soils though both Wischmeier's relationship and the multiple regression were able to rank the soils equally well in order of their relative erodibility factors (r_s=0.88** and 0.87** respectively).

PART II

Abstract

In this study, the erosion susceptibility of a small area of 185ha at Kizurini, Kilifi District was evaluated and mapped at a detailed scale. Three approaches were used viz. a detailed quantitative parametric method based on the Universal Soil Loss Equation and two simpler rating methods which had the advantage of being quicker and easier to carry out, particularly with respect to the modal slopes in the landscape.

A detailed soil survey was carried out using 1:6,250 aerial photographs and simultaneously with the mapping of the soils, slope lengths and slope gradients were measured. In the quantitative method, the erosivity and erodibility were evaluated and the slope lengths and slope gradients measured for each slope segment, as delineated by a change in soil type, a break in slope, or a change in slope category. In the qualitative methods, the erosivity, erodibility and the slope length and slope gradients for the whole slope lengths (i.e. crest to drainage line) were rated on a 1 to 5 basis, and the sub-ratings for each of these parameters were either multiplied or added together to give a product or total score.

The areas with the highest erosion susceptibility according to the quantitative parametric method

were associated with chromic luvisols and chromic luvisols with pockets of lithosols occupying lower slope positions and slopes of more than 5°, whereas the areas of lowest erosion susceptibility were associated with luvic arenosols and the plinthic luvisols in the most gently sloping areas ($<3^{\circ}$).

The quantitative erosion susceptibility method gave a very detailed erosion susceptibility map that was assumed to be reasonably accurate, whereas the two qualitative rating methods did not give such a detailed or as similar an assessment of the erosion susceptibility distribution. However, the distribution of soil erosion susceptibility classes by one of the qualitative methods coincided fairly well with the quantitative method, while the other qualitative method coincided poorly.

PART I

ASSESSING THE RELATIVE ERODIBILITY OF SOME KENYAN SOILS USING A RAINFALL SIMULATOR AND THE PREDICTION OF RELATIVE ERODIBILITY FACTORS.

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CHAPTER 1: INTRODUCTION

1.1 Introduction

Soil erosion can be defined as the detachment and movement of soil particles by water, wind or gravity. The dominant factors controlling the severity of soil erosion by water are rainfall erosivity, topography, crop and management practices and soil erodibility. While management practices (land and crop management) can be modified to reduce soil losses, rainfall erosivity and soil erodibility can seldom be altered (Hudson, 1973).

Soil erosion is a serious problem in many parts of Kenya. With increasing pressure on agricultural land due to increased population, it has become necessary to utilise marginal lands that are highly vulnerable to erosion. This is already taking place in many parts of Kenya (e.g. Baringo and Machakos Districts) where clearing the land for agriculture removes the natural protective cover of the soils exposing them to the forces of water erosion. Erosion has also become a problem in some high potential areas particularly in some parts of Central Province where the intensive cultivation of steep long slopes with annual crops, often without effective conservation measures, has resulted in very high erosion rates. Available data indicate that excessive quantities of

Kenyan topsoil have been washed from cultivated slopes and overgrazed pasture lands. Ongweny (1976, 1977) found the sediment yield of Mathioya catchment to be 885 tonnes/km^2/yr while from the Maragua catchment the value was 1355 tonnes/km^2/yr, both in Central Province. Ongweny has attributed this to expanded cultivation, charcoal burning and overgrazing. In his analysis of existing suspended sediment data, Edwards (1977) has shown that heavy losses of suspe-nded sediment of the order of 600 tonnes/km^2/yr do occur in areas of Machakos and Kitui Districts. He further cautions that total bed load losses in excess of 1,000 tonnes/km^2/yr should be expected from small catchments developed on the light sandy soils of the Basement System. Thomas and Barber (1981) were able to measure an erosion loss of 7.8 and 14.1mm of soil within a one-year period on 15 and 10% slopes respectively at Kamweleni, Machakos District. Under such conditions, the soil is depleted both quantitatively and qualitatively. The overall effect is that, not only are the soils' fertility reduced, but also soil depth and hence the amount of water available for plant growth is reduced.

The seriousness of the erosion problem in Kenya emphasises the need to carry out soil conserva-tion measures. The period 1930-1940 saw the introduc-tion of urgent soil conservation measures in areas such as Western Province, Muranga and Ukambani (Machakos) (Maher, 1937). However, the soil conservation measures introduced in these areas during the colonial period were never widely accepted. Nevertheless, attempts are now being made to educate the local people on how to guard their soil against erosion. In Machakos District, the main conservation measures are cut off ditches and steep backslope terraces, construction of the latter is known locally as the fanya juu method (Thomas, 1977). Similar types of conservation measures are carried out in Uasin Gishu District (Rift Valley Province) Ogola, 1977) and in the Coast Province (Mwangi, 1977). At the national level, afforestation is now encouraged to control erosion.

The planning and design of conservation measures ought to be based on what are the tolerable soil erosion losses and runoff data for a given situation. Unfortunately, there is inadequate data on the erodibility and runoff susceptibility of different soils in Kenya which could be used in the design of suitable conservation measures. The accuracy of using Wischmeier's nomograph (USDA, 1978) to determine the erodibility of Kenyan soils has not been established. In tropical countries where the Universal Soil Loss Equation USLE (Wischmeier et.al., 1971) has been tested, it appears to have been reasonably accurate in West Africa (Roose, 1977(a)) but inaccurate in Zimbabwe (Elwell and Stocking, 1975). In Kenya, measured soil losses and run-off have been made by several workers, e.g. Pereira et.al. (1967), Othieno (1975), Othieno and Laycork (1977), Dunne (1977) and Barber et.al. (1979) but only very few reliable values of soil erodibility factors have been obtained. Hence there is need for much more research into the magnitude of erodibility and runoff losses from different Kenyan soils. Indeed, the significance of expected runoff losses is well portrayed by Thomas and Barber (1979) who took into consideration the run-off and infiltration data obtained on a Luvisol at Katumani when proposing a new design procedure for steep backslope terraces in Machakos District. A decision-making model for selecting appropriate support practices for different agroenvironments has been developed by Thomas and Barber (1982). However, much more data is still required before the model can be considered as a sound basis for selecting conservation measures.

1.2 Objectives

The objectives of this study were:

(a) To obtain a measure of the relative erodibility of fifteen different Kenyan soils with a rainfall simulator.

(b) To try and determine a good index of the relative erodibility of the soils by correlating easily measured soil physical/chemical properties in simple and multiple linear regression with their relative erodibility values determined from the rainfall simulator. For this, the use of soil chemical/physical properties which are measured on a routine basis were preferred.

It is hoped that the findings would help to increase the meagre data presently available on the erodibility of soils in Kenya, and would help in selecting and designing appropriate conservation measures for different soil types and agricultural environments.

CHAPTER 2: LITERATURE REVIEW

2.1 Soil erodibility

Erodibility is defined as the vulnerability of a soil to erosion due to its inherent characteristics (Hudson, 1973; Morgan, 1979). A commonly used method of expressing the erodibility is in terms of the K factor of the Universal Soil Loss Equation (USLE)+ but this will only give realistic values if the soil loss measurements were obtained from several years of runoff plot data (Wischmeier, 1976). It has been claimed (Morgan, 1979) that, although soil loss depends in part on rainfall, topography, crop and management factors etc, the inherent soil characteristics are the most important determinants. Middleton (1930) was the first soil scientist to try to establish an index of soil erodibility. He argued that even where rainfall, topography, crop and management practices remain constant, variations in soil properties can bring variations in soil loss i.e. soils erode at different rates depending upon their physical and chemical characteristics.

+ The USLE (USDA, 1978) is given as A = R.K.LS.P.C where A = average annual soil loss, R = rainfall erosivity factor, K = soil erodibility factor, L = length of slope factor, S = angle of slope factor, C = cover and management factor and P=support practice factor.

Any property that prevents or deters soil detachment or soil transportation reduces soil erodibility. Sand particles are difficult to transport because of their size even though they are easily detached from the soil mass. Thus, Mazurak and Mosher (1968) and Farmer (1973) have shown that the detachment of soil particles by raindrop impact is generally highest in the fine sand fraction. Clay particles at the other extreme, tend to be cohesive and are difficult to detach, but are easily transported once separated from the soil mass. Silt soils are frequently well aggregated, but the aggregates break down readily when wetted and the particles are easily detached and transported because they are less cohesive and are small in size. Bouyoucos (1935) found a direct relationship between his clay ratio (% (sand and silt)/ % clay) and the amount of erosion.

Some of the factors that influence the stability of aggregates (hence influencing erodibility of the soils) are particle size distribution, the kind of the ions on the cation-exchange complex, type of clay mineral, organic matter content and cementing materials in addition to clay and organic matter. Soils low in organic matter and high in silt and very fine sand frequently form aggregates which are relatively unstable. These aggregates are easily destroyed (Barber et.al., 1979) by the beating action of rain. Raindrop energy and fine grains flowing into and plugging surface pores combine to produce a dense compact layer at the soil surface. As a result, there is reduced infiltration which results in increased runoff and erosion (Barber, loc.cit.). Soils with high organic matter contents have more stable aggregates because of the strong bonds between their colloids. Another important factor is that organic colloids by coating ped surfaces and pores can provide a hydrophobic coating by increasing the angle of wetting and so delaying wetting of soil particles (Greenland et.al., 1975; Greenland, 1977). Under natural field conditions, soil aggregates are subjected to various degrees of slaking due to air-trapping, depending on such factors as initial moisture contents, wetting patterns and rates of water application by rainfall. Cernuda et.al. (1954) showed that the ease of destruction of soil aggregates with water drops increased with decreasing initial moisture content. Thus in drier soils, the destructive effect of wetting is greater because of the trapped air which by forcing its way out of the aggregates causes a disruption of the aggregates. Another important factor is that moisture content of the soil influences erodibility through changes in rainsplash effectiveness and the duration of the period before overland flow commences during a storm (Moore, 1978). The K factor determined for dry and wet soils shows the latter to be several fold higher than the former (Barber et.al., 1979; Dangler and El-Swaify, 1976). However, the K factor as normally determined over a long period of time under field conditions gives an intermediate value between the values for dry and wet soil conditions depending on how often the soils are initially dry or wet before an erosive event. Soils high in sodium often possess a weak structure and soil colloids will be deflocculated if the exchange sites are occupied by large amounts of sodium. The deflocculated colloids cause low permeability. Certain iron compounds in soils bind clay and other soil grains together in quite stable forms. These soils are generally quite resistant to erosion (Bryan, 1968). The cohesion and internal frictional strength determine a soil's shear strength which will influence a soil's susceptibility to detachment (Cruse and Larson, 1977). At moist moisture contents, there is a greater strength of cohesion in a soil with 1:1-type lattice clay than in soils high in 2:1-type lattice clays (Troeh et.al., 1980; de Meester and Eppink, 1980). The higher the moisture content, the lower the cohesion and internal frictional strength of soils.

Large, stable aggregates make a soil difficult to detach and transport. An important point about the size of aggregates, is that the larger they are, the greater the delay before they are reduced to fine particles which can be transported, and the higher the surface retention capacity of the soil surface, hence the greater the infiltration. The proportion of a soil in water stable aggregates less than 0.5mm is a good index of erodibility (Bryan, 1968; Rai et.al, 1954), the greater the proportion of the aggregates <0.5mm, the greater the erodibility of the soil.

2.2 Methods of measuring the erodibility of soils

Five commonly adopted procedures have been used to assess soil erodibility (Bryan, 1968; Moore, 1978). These are: (a) runoff plots (b) rainfall simulator measurements in the field (c) laboratory measurements with rainfall simulators (d) laboratory indexes of erodibility and (e) predictive equations based on a number of physical/chemical properties of the soils which are related by multiple regression equations to soil losses measured either in the field or laboratory.

2.2.1 Measuring erodibility from runoff plots using natural rainfall

Measurements of soil losses and runoff are most accurately obtained from permanent large plots exposed to natural rainfall. Some plots consist of a border, a channel to concentrate runoff at the lower end of the plot and a collector to accept the runoff and sediment produced from the plots. The collector should have a capacity adequate to contain the maximum runoff and soil loss expected. Djorovic (1977) has given a formula for calculating the required capacity of a collector. Dunne (1977(c)) discusses the advantages and disadvantages of various types of runoff plots. Small plots, (varying in length from about 2m to 5m) bounded up-slope suffer from the absence of runoff and sediment influx at the top end. However, such plots are easy to construct and install. Thus, a sufficient number can be installed to obtain a representative sampling of the major characteristics of the study area. When it is necessary to also measure surface runoff and/or susceptibility to rill erosion, then longer plots are required so that the cumulative effect of the runoff (thus also affecting soil losses) increasing down the slope is reproduced (Hudson, 1973). Large volumes of sediment and runoff are to be expected from such large plots. This requires special devices which are used to divert only a small portion of the runoff and sediment into the measuring tank (Othieno, 1975) rather than constructing a very large storage tank to cope with the whole volume of sediment and runoff. Unlike small plots, large plots are suitable for cropping or rotation experiments provided that it is acceptable for the tillage operations to be carried out by hand. However, the larger plots are expensive, time consuming and they require a high labour cost. Many permanent plots have been established. The standard erosion plot used to calculate the parameters of the USLE measured 70 to 90ft long and 0.01 to 0.20 acre in area. Othieno (1975) used plots 60x12ft in tea fields near Kericho; Lal (1976) used plots 25x4m in Nigeria; and Roose (1967) and Roose and Lelong (1976) (quoted from Moore, 1978) measured runoff and erosion from plots 16x6m. Where field-scale farming operations are an essential part of the treatments under test, larger plots are used from 0.02ha upwards. Plots of this size also require some mechanical division of the runoff, and there still remains the high labour cost of operation. Runoff plots (unless carefully positioned parallel to the maximum slope) sometimes have the disadvantage of encouraging runoff concentration along the plot boundaries. Hudson (1973) gives this as one of the problems of setting up field experiments on soil erosion. Another disadvantage of runoff plots is having to rely on natural rainfall which is always unpredictable. Hence the plots must be in place and measurements carried out for many years to obtain reasonably accurate values for average annual soil losses that include the effects of the infrequent very intense storms which may be rare but which may still contribute significantly to total soil loss.

2.2.2 Measuring erodibility by using a rainfall simulator in the field

This has the advantage of applying rainfall, although simulated, to undisturbed soil under field conditions and the researcher is able to adjust the amount, intensity and frequency of rainfall. In this way the researcher can replicate similar rainstorms on different soil types or different management practices in a short period of time, obtaining results quickly. If relying on natural rainfall it may take a long time before obtaining results from similar rainstorms on different soil types. In any case, natural rainstorms are also unlikely to be exactly the same. However, this method has some disadvantages. When using small plots, there is no influx of runoff from the upper slope and hence the soils may not suffer from rilling, whereas on large plots rilling may be important (Meyer et.al., 1976). Thus, on small plots, one is measuring the interrill erodibility rather than interrill and rill erodibility. Foster et.al. (1973) showed how a soil's susceptibility to rill and to interrill erosion might be separated into K_r and K_i instead of lumping both effects into one factor as is done for the USLE K-factor. This shows the importance of using large plots of at least 10m (Meyer et.al., 1976) if rainfall simulator measurements are to be used to establish K factors.

Another consideration which will affect the accuracy of K factors or soil losses measured will be the initial soil conditions, in particular, the moisture content, surface aggregate size (see 2.1) and surface microtopography (Evans, 1980). Thus soil losses should be measured under a range of different surface conditions. However, this creates problems as one ought to know the frequency with which particular surface conditions prevail during the rainy season.

The different types of rainfall simulators that are used have been discussed by Hudson (1973) and Stout (1965). The non-pressurized droppers use small nozzles which produce drops of constant size. The disadvantage of non-pressurized nozzle droppers is that the drops can only achieve terminal velocity if they fall from a considerable height. The largest size of drops require a height of about 12m and this is too high for the simulator to be used in the field. Rainfall simulators with pressurized spraying nozzles are designed specially for imitating natural rainfall. Meyer and McCune (1958) developed a simulator called a rainulator which was designed for field plots up to 3m wide and 25m long. Though the first simulator to reproduce the kinetic energy of natural rainstorms it was complicated, expensive and required considerable labour to assemble it. Simpler and smaller rainfall simulators have been developed to overcome the difficulties involved in Meyer's simulator. The problem with the simpler designs is that the kinetic energy is lower than that of the natural rain of the same intensity. However, the advantage is that the machines are light and portable and can therefore be used in remote areas with poor road access. Morin et.al. (1967) developed a rotating disc simulator which gives a reasonable approximation to the natural drop size distribution and KE expected in natural rainstorms which are not obtained in other designs. This consists of a rotating metal disc with a radial slot cut in the disc. The slot can be changed during simulation so that the intensity can be varied during the simulated storm. This type of simulator has been used by Barber et.al. (1979) in Kenya under field conditions. The author's work also involved the use of this type of simulator. Elsewhere in Kenya, Dunne (1977) used a portable sprinkler system for generating artificial rainstorms over a 5m by 2m plot on hillside plots in Kajiado District.

2.2.3 Laboratory measurements of erodibility with a rainfall simulator

This approach involves the use of disturbed soils that are packed into trays or containers. The trays or containers are then placed beneath the simulator and subjected to a storm of predetermined amount, intensity and duration. A number of different workers have used this approach. Farmer (1973) determined the relative detachability (whereas erodibility is a function of detachability and transportability) of soil particles by simulated rainfall under laboratory conditions. Schmidt et.al. (1964) determined the relative erodibility (referred to as relative erodibility so as to distinguish from erodibility K factor of the USLE which cannot be obtained from disturbed soils in small trays) of three loess-derived soils in Southwestern Iowa. De Vleeshouwer et.al. (1978) obtained the relative erodibility of some important Nigerian soils by packing the soil samples into specially designed trays. Moldenhauer and Long (1964) undertook a study to determine the effect of soil texture on the infiltration and erosion characteristics of 5 Iowa soil types by using a laboratory rainfall simulator and disturbed soil samples. More recently, Quansah (1981) used trays of 10cm by 20cm by 4cm and slopes of 0.0, 3.5, 7 and 14% to determine the effect of soil type, slope, rain intensity and their interactions on splash detachment and transport. The important advantages of this approach are that, the researcher can easily adjust the soils to a uniform moisture content, aggregate size, slope and can apply the same storm to each soil and measure soil losses under specific conditions for large numbers of soils in a short time. However, the main disadvantage is that, the work is carried out on disturbed soil samples and the influence of subsoil horizons on water movement through the profile and hence on run-off and soil loss are absent. Moreover the packing of soils into trays is unlikely to reflect the original packing, the field aggregate size distribution or the microtopography under field conditions. Another problem is that, using short lengths of slope, one is measuring susceptibility to interrill erosion which may not be well correlated with the soil's susceptibility to rill erosion (Meyer et.al., 1976).

Nevertheless, the method is less time consuming and less expensive than methods 2.2.1 and 2.2.2 described above and the researcher can also make reasonable comparative estimates of detachability or of relative erodibility due to interrill erosion of many different soils quite quickly and cheaply.

2.2.4 Determination of the relative erodibility from laboratory indices of erodibility

Many of the early studies (Middleton, 1930; Bouyoucos, 1935; and Anderson, 1951) assessed soil erodibility by isolating certain soil properties as indices of erodibility. Such studies concentrated on the particle size distribution of the soil, and the ease with which the soil could be dispersed.

For instance, a "dispersion ratio" was proposed based on the ratio of silt and clay contents in the undispersed and dispersed states. Middleton (1930) found the ratio to be >15% for 'erodible' and <15% for 'non-erodible' soils. However, the ratio is based on the theoretical assumption that only material which is in a dispersed condition can be eroded (Ahn, 1979; Tefera, 1981) and again it does not reflect accurately the erodibility of soils with high sand content. Another index based on the dispersion ratio is the "flocculation index". This ratio compares the amount of clay in a sample previously treated with a dispersing agent with a sample where the dispersing agent is omitted. The Kenya Soil Survey (Braun and van de Weg, 1977) is currently using the flocculation index to assess soil erosion hazard (see also Part II). Like dispersion ratio, the flocculation index assumes that, only clay which is in a dispersed condition can be eroded. This assumption is unlikely to be correct for some soils with sand-sized aggregates (of clay) are found to be transported by rill erosion (Troeh et.al., 1980; Weaxly, 1962; Tefera, 1981).

The "clay ratio" express the ratio of sand to silt plus clay (Bouyoucos, 1935). Bouyoucos argued that, the ratio indicated a measure of the amount of material 'binding' the soil particles. However, when the clay content is very low, the ratio

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The "clay ratio" express the ratio of sand to silt plus clay (Bouyoucos, 1935). Bouyoucos argued that, the ratio indicated a measure of the amount of material 'binding' the soil particles. However, when the clay content is very low, the ratio is liable to become meaningless due to the high water transmission status. Bryan (1968) pointed out that, the "clay ratio" places undue weight upon the importance of clay as a 'binder' (this is not always the case as other materials e.g. organic matter and iron and aluminium oxides and hydroxides are also important agents in stabilising soil aggregates).

Other important measures of aggregation are the water drop and wet-sieving tests. These tests are used to measure aggregate stability and aggregate size distribution.

In the water drop test, water drops are allowed to strike a soil aggregate which is placed on a mesh sieve. The method measures the number of standard drops of water required to break down air-dry clods so that they pass through a 2mm sieve. Various workers have used the water drop test. Bruce-Okine and Lal (1975) used a simple laboratory rain-drop technique to predict which tropical soils were highly erodible. Rose (1960) worked on five East African soils by using a rain drop test to determine the relationship between soil detachment and the physical characteristics of rainfall. Mc-Calla (1944) devised a simple water drop method for observing the effect of individual falling water drops on the stability of soil aggregates.

The wet-sieving test requires a nest of sieves. The crumbs of air-dry soil are distributed on the top-sieve of the nest and then allowed to soak until thoroughly wet. The sieves are raised and lowered mechanically in water generally at 30 strokes per minute. During the sieving operation each sieve is raised clear of the water at each stroke. The soil retained on the sieves is then dried and weighed. Using a simple wet-sieving technique, Martin (1944) determined the percentage of water stable soil aggregates as influenced by some East African grasses. Conaway and Strickling (1962) showed that the percentage weight of water stable aggregates >0.5mm and >2mm in diameter were the most reliable measures of aggregate stability. Using wet-sieving test, Bryant et.al. (1948) found that water-stability may be characterized by two parameters: an initial stability to wetting and a secondary stability that characterizes soil aggregates on continuation of the wetting process. Emerson (1967) has shown that soils may be easily divided into classes of different stability depending upon whether their aggregates disperse, slake or remain intact on dropping them into water. Although Emerson's test was developed to assess the suitability of Australian soils for earth dam construction, it has been found useful in classifying English and Welsh soils in terms of their relative stability (Greenland et.al., 1975).

However, there are some disadvantages associated with the water drop and wet-sieving tests. The presence of gravel in a soil may interfere seriously with the operation of both tests. Whereas erodibility is a function of detachability and transportability, both tests tend to concentrate on measuring aggregate detachability only. Research carried out elsewhere (e.g. Tefera, 1981; Wustamidin et.al., 1982) found no relationship between water-drop tests and soil losses obtained from a rainfall simulator. Nevertheless, the approach outlined is the most simple, rapid and inexpensive as compared to methods 2.2.1, 2.2.2 and 2.2.3.

The Kenya Soil Survey (KSS) index of erodibility (Braun and van de Weg, 1977) is based on organic matter, flocculation index, silt/clay ratio and bulk density in the topsoil. These soil parameters are rated as follows:

(a)

% carbon	subrating
>2%	1
1-2%	2
<1%	3

(b)

flocculation index	subrating
>70%	1
50-70%	2
<50%	3

(c)

silt/clay ratio	subrating
<0.20	1
0.20-0.40	2
>0.40	3

(d)

bulk density (g/c.c)	subrating
<1.2	1
1.2-1.5	2
>1.5	3

According to the KSS method, the subratings (a), (b), (c) and (d) are added up to identify whether the soil is 'none', 'slightly', 'moderately', 'strongly', or 'very strongly' erodible. Thus, each parameter is given equal weight and each is treated independently, whereas there is interaction between them (see also Part II).

2.2.5 Determination of the erodibility of soils using regression equations

Research workers have attempted to develop regressions relating soil erodibility to soil physical and chemical properties which would enable predictions to be made on soil erodibility (Wischmeier et.al., 1971). Important soil parameters which appear to affect the erodibility of soils are related by multiple regression equations to soil losses measured either in the field or under laboratory conditions i.e. by 2.2.1, 2.2.2 or 2.2.3 methods discussed above. It should be noted that these methods are only valuable if the equation developed correlates well with measured values of erosion, and the equation will only be as good as the measurements of erosion are realistic. The predictive equations are generally of the form $Y = b_0 + b_1X_1 + ...+ b_nX_n$ where Y is soil loss, b_0 is the water intake by the soil before runoff begins and, therefore, is a function of initial infiltration rate; b_1, ..., b_n are coefficients determined by multiple regression analysis and X_1, ..., X_n are the independent variables (Barnett and Rogers, 1966).

Several studies have developed regression equations to predict erodibility values from soil parameters. Past analyses have mostly focused on the physical properties of soils. Barnett and Rogers (1966), working in Southwestern U.S.A. found 9 variables to explain 90% of the variation in soil loss per EI_{25}. Among the soil parameters they used were bulk density, % silt, % carbon and detailed divisions of the sand fraction (Soil Survey Manual, 1951). Wischmeier and Mannering (1969) derived an empirical equation for calculating the soil erodibility factor K. They identified 17 soil parameters which, when combined in a multiple regression model accounted for 96.5% of the total variance in soil concentration in runoff. They found that, % sand, % organic matter, % silt, structure and permeability among others, contributed significantly to soil loss. Using these 5 soil parameters, they converted their regression equations into a nomograph (Wischmeier et.al., 1971; USDA Handbook No. 537, 1978) which allows a rapid estimate of a soil's erodibility factor K. The nomograph has been easily and widely used in U.S.A. but the extent of its applicability under tropical conditions has not yet been established (Hudson, 1973). (For instance results obtained in the field by Roose (1977) and Barber et.al. (1979) on ferruginous tropical and ferralitic soils, and the Kabete nitosol, respectively, compared well with Wischmeier's nomograph. Elwell and Stocking's (1975) and Ngatunga's (1981) erodibility values obtained from field measurements for some Zimbabwe and Mlingano soils (Tanzania) respectively did not compare well with Wischmeier's nomograph). Young and Mutchler (1977) performed experiments on 13 Minnesota soils. They found that individual soil properties rarely possessed correlation coefficients greater than .70 but multiple regressions involving 6 or 7 parameters could explain up to 95% of the variation in K. Romkens et.al (1977) found that nearly 90% of the variation in erodibility for some North Central United States soils could be explained by (silt plus very fine sand) x (silt plus sand), structure, permeability and the % organic carbon.

This regression method has the advantage of removing the necessity for actual measurements of erodibility of all soils in the field provided the multiple regression equation gives a good fit with erosion values measured in the field. However, the best regression analyses are still not perfect in their predictive abilities (Moore, 1978).

CHAPTER 3: MATERIALS AND METHODS

3.1 The soils

The surface horizons of 15 contrasting soils from cultivated land were selected for this study. They include six clays, two sandy clays, two sandy clay loams, one clay loam, three sandy loams and one loamy sand. Seven of the soils are of volcanic origin, five are derived from metamorphic rocks (Mozambiquan System) and three represent some of the sedimentary rocks of the Coastal region. Table 1 gives the selected properties of the surface horizon of the soils.

3.1.1 Soil sampling and preparation

Soil samples were collected from the 0-20cm surface horizons. Each sample comprised several subsamples which were then bulked. The samples were air dried. Samples for physical and chemical analysis were sieved through a 2mm sieve but the soil samples for use with the rainfall simulator were not sieved. The occasional soil aggregates greater than 2cm in diameter were excluded from the samples put in trays for the rainfall simulator studies.

3.1.2 Laboratory determination of soil properties

Standard laboratory techniques were used to determine the physical and chemical properties. The U.S.D.A. textural analysis was carried out by sieving

Table 1: Selected Properties of the Plowed Layer Soils

Location	Soil type*	Dominant Clay Minerals	Organic Matter (%)	pH(H_2O) 1.1	Bulk Density (g/cc)	% Very Coarse Sand 2-1mm	% Coarse Sand 1-0.50mm	% Medium Sand 0.50-0.25mm	% Fine Sand 0.25-0.10mm	% Very Fine Sand 0.10-0.05mm	% Silt 0.05-0.002mm	% Clay <0.002 mm	Textural Class U.S.D.A.	Parent Material
THIKA I	Rhodic Ferralsol	Kaolinite and illite	2.28	5.4	0.96	0.1	0.6	1.4	1.8	2.0	14.1	80.0	Clay	Tuffs
KILIFI-YR	Chromic Luvisol	Kaolinite and illite	1.71	6.9	1.31	0.0	0.0	4.9	59.6	14.7	7.7	13.1	Sandy loam	Sandstones
THIKA II	Humic Acrisol	Kaolinite and illite	5.36	6.0	0.96	0.6	2.4	4.5	6.2	4.1	23.2	59.1	Clay	Trachytic tuffs
MASINGA	Ferral-orthic Acrisol	Kaolinite and illite	2.09	6.2	1.40	1.4	6.5	18.6	33.3	9.4	13.5	17.3	Sandy loam	Banded gneisses
KILIFI-SHALES	Vertic Luvisol	Illite	3.99	7.2	1.19	1.9	2.8	2.7	2.5	1.8	28.0	60.3	Clay	Shales
NGENGE	Rhodic Ferralsol	Kaolinite and illite	4.19	6.0	0.99	0.4	0.6	2.7	7.8	4.3	11.1	73.1	Clay	Kenyte
KAPENGURIA	Humic Acrisol-Ferralsol Intergrade	Kaolinite and traces of Illite	8.18	5.1	1.16	10.7	8.8	15.5	20.8	6.2	13.6	24.4	Sandy Clay Loam	Quartzo Psammite
KILIFI-YB	Luvic Arenosol	Kaolinite	1.57	6.6	1.27	0.0	0.0	1.1	65.7	17.6	9.1	6.5	Loamy Sand	Sandstone
LONGONOT	Humic Andosol	Amorphous	4.13	6.5	0.94	1.5	5.0	11.9	21.3	13.8	26.6	19.9	Sandy Loam	Volcanic ashes
MWEA	Pellic Vertisol	Montmorillonite	3.09	7.5	0.97	1.1	0.7	0.6	1.0	1.5	17.8	77.3	Clay	Basalts
KABETE	Humic Nitosol	Kaolinite and traces of Illite	4.11	5.8	1.05	0.5	1.3	2.0	4.2	3.6	24.4	64.0	Clay	Trachyte
KITALE	Orthic Ferralsol	Kaolinite and traces of Illite	3.94	5.1	1.23	3.0	14.3	19.4	15.6	3.7	13.5	30.5	Sandy Clay loam	Gneisses
GITUAMBA	Humic Andosol	Amorphous	12.03	4.5	0.64	0.5	0.5	1.6	6.9	10.6	46.7	33.2	Clay loam	Basalts
SIAKAGO	Orthic Ferralsol	Kaolinite and Illite	2.71	5.9	[illegible]	0.2	0.8	8.9	29.7	[illegible]	10.0	38.7	Sandy Clay	Banded Gneisses
[illegible]	Ferral-chromic Luvisol	Kaolinite and Illite	2.20	[illegible]	[illegible]	[illegible]	2.0	7.2	30.7	12.1	7.7	39.0	Sandy Clay	[illegible]

* Classified according to the legend of the Soil Map of the World (FAO-UNESCO, 1974) except for the Kapenguria, Masinga and Katumani soils which are classified according to the 'Kenya Concept' (Siderius and van der Pouw, 1980).

and pipetting (Soil Survey Staff, 1951) while natural clay was obtained by the hydrometer method (Day, 1956). Bulk density was determined from the oven dry (105°C) weight of a soil core of known volume (Richards, 1954).

The % carbon content was obtained by the Walkley and Black method (Black, 1965) and the value obtained was multiplied by 1.724 to give % organic matter. Soil pH was determined in a 1:1 soil-water suspension (Ahn, 1973). Clay mineralogy was carried out according to National Agricultural Laboratory (NAL) methods (Hinga et.al., 1980).

3.2 Laboratory determination of soil loss and runoff

The rainfall simulator used (see Plate 1) is of the rotating-disc type, and was the same as that used by Barber et.al. (1979). This has been designed to produce raindrops of a similar size to those of natural rainfall. During the rainfall simulation, the intensity of the simulated rainfall (46.6mm/hr), the height of the nozzle above the soil surface (2.11m) and the pressure of the water pumped through this nozzle ($13.8KN/m^2$) were kept constant. The duration of the simulated rainstorms was one hour except for some soils, viz. Kabete, Thika I and Thika II, where one and a half hour storm was necessary in order to obtain runoff. A tarpaulin tent over the simulator was used to exclude wind effects.

The unsieved, air-dried soils were packed into metal trays, 60cm long, 30cm wide and 10cm deep, to a depth of 6.4cm overlying a 3.6cm layer of fine sand. A uniform packing procedure was used for all soils and the field bulk density values were reproduced in the trays. The 3.6cm layer of fine sand allowed water percolation and air movement while an outlet at the bottom of the tray (Plate 1) provided adequate drainage. Two soil trays were positioned (per run) under the rotating disc so that similar amounts of rain were intercepted by each tray and the trays were set to a fixed slope of 6^{o}. The trays were designed to allow runoff and soil losses to be collected in small troughs attached to the lower end of the trays (Plate 1). Metal shields prevented raindrops from falling directly into the troughs. Each soil was replicated four times, i.e. requiring two runs of the simulated rainstorm.

Runoff and transported sediment was collected from the troughs and then measured by evaporating off the water at $180^{o}C$ and weighing to give the soil loss in g/m^2 for each soil.

Plate 1: The rotating-disc type rainfall simulator* without wind shield. Note the two metal trays set to a slope of 6^{O}, their small troughs attached to the lower end and two metal shields at the left bottom corner of the photograph which are used to prevent raindrops from falling directly into the troughs.

* constructed by students of the National College of Agricultural Engineering Silsoe, England.

CHAPTER 4: RESULTS AND DISCUSSIONS

4.1 Relative erodibility of the soils

The relative erodibility+ of the soils as determined by the rainfall simulator can be compared by means of their mean soil losses in g/m^2/unit of erosivity. The order of the relative erodibility of the 15 soils is shown in Table 2. Since the sequence of applying simulated rainstorms to the soil was not randomized, the soil losses were not analysed statistically. Nevertheless the positions of the trays beneath the rainfall simulator were fixed and the simulated rainfall volume and intensity was periodically checked throughout the duration of these experiments. The standard deviations and coefficients of variation for the 4 replicates from each soil are also given in Table 2. The coefficients of variation ranged from 3.1% to 44.6% with a mean C.V = 21.6%. The soil losses in g/m^2/unit of erosivity ranged from 2.03 for a sandy clay loam humic Acrisol-Ferralsol intergrade (Kapenguria) of high organic matter content to 7.91 for a pellic Vertisol (Mwea).

+ the relative erodibility is a measure of erodibility under conditions of the experiment and is unlikely to be the same as true erodibility under field conditions.

Table 2: Mean soil losses in g/m^2/unit of erosivity eroded from the trays.

Soil	Mean soil loss (g/m^2/unit of erosivity)	± s.d (standard deviation)	C.V (%) (coefficient of variation)
Kapenguria	2.03	0.78	38.4
Thika II	2.07	0.41	19.8
Gituamba	2.43	0.16	6.6
Thika I	2.56	0.60	23.4
Siakago	2.67	1.19	44.6
Kabete	2.89	0.75	26.0
Ngenge	3.21	0.97	30.2
Masinga	3.67	0.83	22.6
Kitale	4.19	0.40	9.5
Katumani	5.06	0.64	12.6
Kilifi-shales	5.14	1.42	27.6
Longonot	5.56	1.16	20.9
Kilifi-YR	6.18	0.19	3.1
Kilifi-YB	6.38	1.05	16.5
Mwea	7.91	1.79	22.6

To aid in describing the relative erodibility of these soils, the relative erodibility classes shown in Table 3 were adopted. Another method of comparing the relative erodibility is by means of the relative erodibility factor k_{td} (where k_{td} signifies relative erodibility factor as measured from trays (t) in dry

Table 3: Relative erodibility classes.

Soil loss (g/m^2/unit of erosivity)	Adopted classes
<2.20	very slightly erodible
2.20-2.93	slightly erodible
2.93-3.66	moderately erodible
3.66-4.39	highly erodible
>4.39	very highly erodible

(d) state) which is derived in the same way as the K factor of USLE (Smith and Wischmeier, 1962). The relative erodibility factor k_{td} can therefore be calculated as:

$$k_{td} = \frac{A}{RLSCP} \quad (1)$$

where k_{td} is the relative erodibility factor as measured from trays(t) in dry(d) state, A, R, LS, C and P are as defined on page 6. The soil losses obtained for the 3 soils from 1½hr storm durations were converted into the equivalent soil losses expected from 1hr storms assuming a linear relationship between soil losses and erosivity as is implied in the USLE. The R value for 1hr storm of 47 mm/hr intensity is equal to 27.3 and was then used for all the soils. The LS factor is 0.21 (6^{o} slope, 0.6m), C is 1 (bare plot) and P is 0.8 (neither terraces, contour ploughing nor downslope ploughing). The

Table 4: Relative k_{td} values as derived from equation (1).

Soil	k_{td} values
Kapenguria	0.054
Thika II	0.055
Gituamba	0.065
Thika I	0.068
Siakago	0.071
Kabete	0.077
Ngenge	0.085
Masinga	0.097
Kitale	0.111
Katumani	0.135
Kilifi-shales	0.137
Longonot	0.148
Kilifi - YR	0.164
Kilifi - YB	0.170
Mwea	0.210

computed relative k_{td} values are shown in Table 4. The k_{td} factor values therefore range from 0.054 to 0.210. For five of these soils, (viz. Longonot, Katumani, Kabete, Thika I and Gituamba), the $^{+}k_{td}$ values could compare with measured soil erodibility factors $^{++}k_{fd}$ obtained in the field (f) in dry (d) state using the same rainfall simulator and similar

$^{+}$ k - values from trays by sheet and splash erosion.

$^{++}$ k - values from field plots by rill and interrill erosion.

rainfall intensities (Barber and Thomas, 1981). Both sets of data placed four of the five soils in the same relative order (Table 5). The k_{td} values correlated fairly well (r = 0.79, NS; Fig. 1) with the k_{fd} values and the correlation would have been much higher (r = 0.99**) if Gituamba soil had been excluded. The discrepancy due to the fifth soil - Gituamba could be attributed to the high quantities of organic manures applied between the time the field trials were conducted and the time of sampling for the laboratory study. The organic matter content

Table 5: Comparison of field (at dry and wet states) and laboratory derived relative k values.

Soil	$^1k_{td}$	$^2k_{fd}$	$^3k_{fw}$
Longonot	0.148	0.14	0.47
Katumani	0.135	0.11	0.56
Kabete	0.077	0.01	0.05
Thika I	0.068	0.01	0.03
Gituamba	0.065	0.09	0.28

$^1k_{td}$ Relative k-values determined in this study from trays(t) in dry(d) state.

$^2k_{fd}$ Estimated k-values determined by Barber and Thomas (1981) under field(f) conditions in dry (d) state.

$^3k_{fw}$ Estimated k-values determined by Barber and Thomas (1981) under field(f) conditions in wet (w) state.

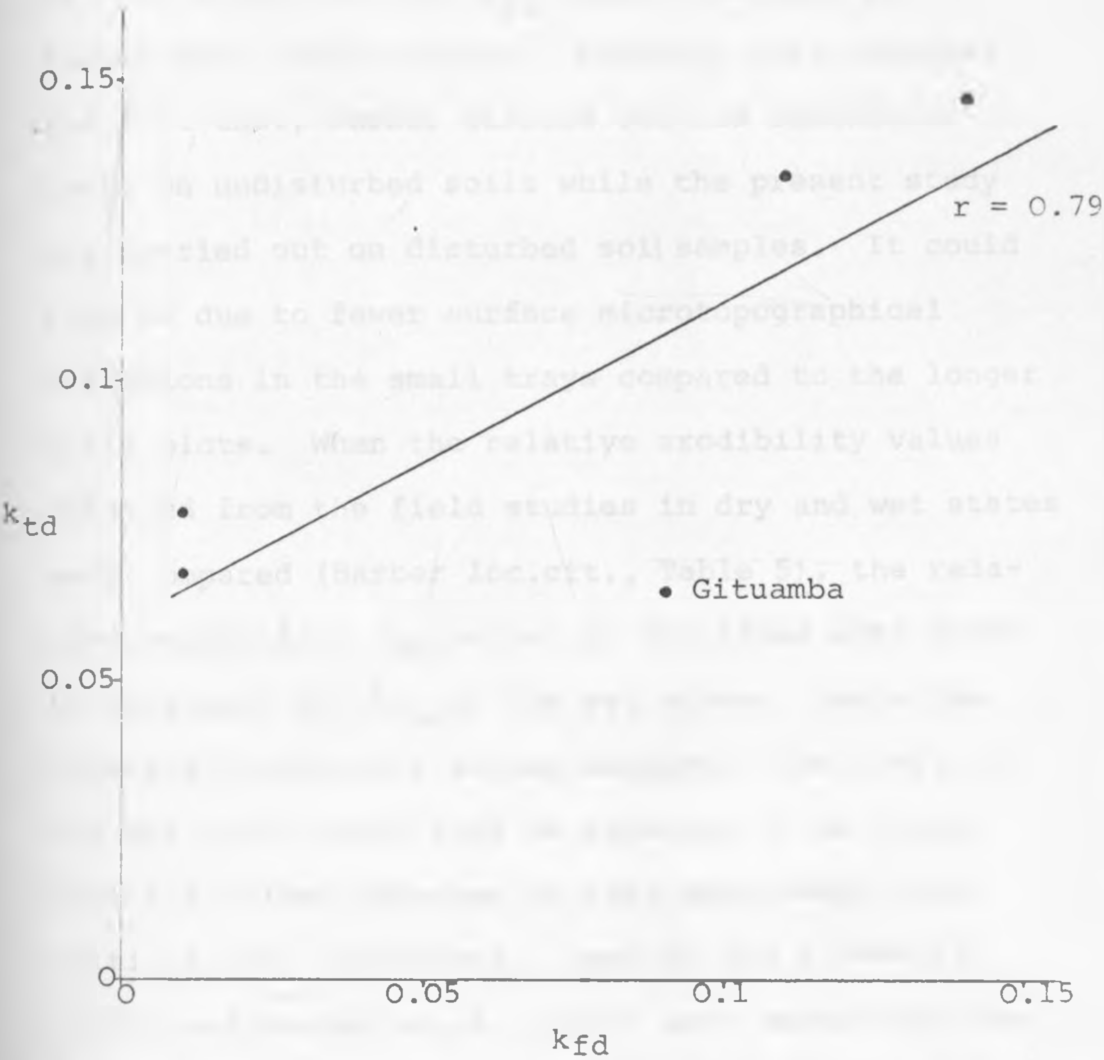


Fig. 1. Relationship between relative erodibility factors k_{fd} as measured in the field(f) in dry(d) state and relative erodibility factors k_{td} as measured from trays(t) in dry(d) state.

increased from 8.71% during the field trials to 12.03% at the time of sampling for the laboratory study. Thus higher k values for Gituamba soil would be expected from the laboratory experiment than from the field experiment which is borne out by these results.

The k_{td} values for the dry soils were higher in this study than the k_{fd} values observed by Barber from field studies. Probably this reflects the fact that, Barber carried out his simulation tests on undisturbed soils while the present study was carried out on disturbed soil samples. It could also be due to fewer surface microtopographical variations in the small trays compared to the longer field plots. When the relative erodibility values obtained from the field studies in dry and wet states were compared (Barber loc.cit., Table 5), the relative erodibility k_{fd} values in dry state were found to be almost 1/3 k_{fw} in the wet state. Hence the relative erodibility values measured from trays in the wet state would also be expected to be higher than the values obtained in this experiment under initially dry conditions. Dangler and El-Swaify (1976) and Barber et.al. (1979) have shown that the K factor value measured for initially dry and wet soils increases several-fold from a dry state to a wet state, under the same rainfall conditions.

A comparison of the k_{td} values with estimated K_{nom} factors for the same soils established by Wischmeier's nomograph (Wischmeier et.al., 1971) was carried out (see Table 6). The calculated erodibility factors (K_{nom}) obtained from Wischmeier's soil erodibility nomograph ranged from 0.008 for a humic Acrisol-Ferralsol intergrade (Kapenguria) to 0.231

for a humic Andosol (Longonot) and correlated rather poorly ($r = 0.54^*$) with k_{td} values. A

Table 6. Comparison of relative erodibility k_{td} factors with estimated K_{nom} factors established by Wischmeier's nomograph

Soil	Relative erodibility factor $^1k_{td}$	Estimated erodibility factor $^2K_{nom}$
Kapenguria	0.054	0.008
Thika II	0.055	0.042
Githamba	0.065	0.033
Thika I	0.068	0.047
Siakago	0.071	0.079
Kabete	0.077	0.076
Ngenge	0.085	0.048
Masinga	0.097	0.153
Kitale	0.111	0.087
Katumani	0.135	[illegible]
Kilifi-shales	0.137	0.104
Longonot	0.148	0.231
Kilifi - YR	0.164	0.161
Kilifi - YB	0.170	0.203
Mwea	0.210	0.044

$^1k_{td}$ Relative k-values determined from trays (t) in dry(d) state.

$^2K_{nom}$ Estimated K-values determined by Wischmeier's soil erodibility nomograph (Wischmeier et al., 1971).

notable discrepancy between the k_{td} and K_{nom} factors was given by the pellic Vertisol (Table 6) which is probably due to the swelling nature of its clay. A high content of swelling clays, which disperse under wet conditions, would be expected to give a much higher relative erodibility in wet conditions in contrast to a non-swelling clay soil that would be expected to possess greater cohesion and a lower relative erodibility (Ngatunga, 1981; Troel et. al., 1980; de Meester and Eppink, 1980). When the Mwea and Kilifi-shales soils were excluded because of the swelling nature of their clays (see also Section 4.2), the erodibility factors (K_{nom}) of the 13 well drained, non-swelling soils correlated reasonably well ($r = 0.84^{***}$) with the k_{td} values. The Spearman's ranking coefficients for the k_{td} factors and Wischmeier's K_{nom} factors for all 15 and the 13 soils were $r_s = 0.679^{**}$ and $r_s = 0.885^{**}$ respectively. Wischmeier's nomograph, not surprisingly, does not compare very well with the k_{td} values and this can be attributed to the fact that, on such small trays, one is measuring the interrill erodibility rather than rill plus interrill erodibility (Foster et.al., 1973; Meyer et. al., 1976) and of course the soils were disturbed. However, although Wischmeier's nomograph does not compare very well with the k_{td} values, this does not mean that Wischmeier's nomograph is not accurate in predicting the actual erodibility K factors of these soils. The actual K factors of these soils are not known and Barber's k factors estimated for 5 of these soils from the rainfall simulator field trials cannot be taken as realistic.

4.2 Statistical analysis

Statistical analysis was only applied to the well drained, non-swelling soils. Mwea and Kilifi-shales soils were therefore excluded. The experiments of Heush in Morocco (quoted by Roose, 1977) showed that Vertisols react differently because of the swelling nature of the clay. Therefore, the Mwea (pellic Vertisol) and the Kilifi-shales (vertic Luvisol) were excluded because of the nature of the clay and the free draining conditions under which soil losses were measured in the laboratory. Under field conditions, these soils have an impeded drainage which would be expected to enhance the soil's susceptibility to erosion.

The relative erodibility k_{td} factors were statistically correlated with selected soil parameters. Table 7 shows the correlation coefficients obtained from simple linear regressions of soil loss on some easily measurable soil properties. The best single predictive factor for soil loss was fine sand (0.10-0.25mm) which explained 62.4% ($r = 0.79^{**}$) of the

Table 7: Soil properties used in simple linear regression analysis and their correlation coefficients with soil losses.

Independent variable X	Variable Description	Correlation coefficient r
X_1	Organic matter, %	-0.54
X_2	Clay, <2μm	-0.62*
X_3	Silt, 2-50μm	-0.37
X_4	Sand, 0.05-0.10mm	0.74**
X_5	Sand, 0.10-0.25mm	0.79**
X_6	Sand, 0.25-0.50mm	0.01
X_7	Sand, 0.50-1.0mm	-0.10
X_8	Sand, 1.0 - 2.0mm	0.28
X_9	Bulk density, gm/c.c	0.37
	<u>Interaction factors</u>	
X_{10}	Silt/clay ratio	0.37
X_{11}	Flocculation index	-0.17
X_{12}	% Sand (0.05-0.10mm) + % Sand (0.10-0.25mm)	0.80***
X_{13}	Dispersion ratio	0.75**

Significant at: * -5%; ** -1%; *** -0.1%

variations in soil loss. The best interaction predictive factor for soil loss was very fine sand (0.05-0.10mm) plus fine sand (0.10-0.25mm) which explained 64% (r = 0.80***) of the variations in soil loss. The Kenya Soil Survey index of erodibility (Braun and van de Weg, 1977) only explained 44.9% (r = 0.67*) of the variations in soil loss (see page 21).

The results showed that the dispersion ratio was highly and positively correlated with k_{td} values. Various researchers have found that soils with higher values of dispersion ratio are more erodible than those with low values (Middleton, 1930; Anderson, 1951; De Vleeshauwer et.al., 1978; Ngatunga, 1981). The dispersion ratio was found to be generally above 1 for the soils classified as 'very highly erodible' in this study. Although the dispersion ratio reflects the content of easily dispersable and hence transportable clay, it is not only clay which is in a dispersed condition that can be eroded (Tefera, 1981; Ahn, 1979; Weaxly, 1962).

The % clay was negatively correlated with the relative soil erodibility factors k_{td}. Three of the four soils under the 'very highly erodible' class had 6 to 25% clay content. Evans (1980) examined the erodibility in terms of clay content and found the most erodible soils to have clay contents between 9 and 30% which is in good agreement with these results. The % clay reflects the presence of binding agent and therefore seems to play a significant role in the coherence of soil particles (Bouyoucus, 1935; Troel et. al., 1980).

Organic matter content ranked next to particle size distribution as an indicator of the relative erodibility of the 13 soils. Similar findings were made by Wischmeier and Mannering (1969) and Barnett and Rogers (1966). Like clay, organic matter is negatively correlated with erodibility i.e. organic matter also acts as a binding agent which should therefore be inversely related to soil erodibility. Even for a soil such as Kapenguria, which had less than 25% clay, the high organic matter content was enough to give a 'very low' relative erodibility. Generally, soils within the 'very highly erodible' class had less than 2.30% organic matter. Morgan (1979) considered soils with less than 2% organic matter to be erodible. Soil aggregates very high in organic matter are generally quite small, stable, and have low densities. Improved structure invariably is accompanied by increased permeability and by decreased runoff and erosion (Troel et. al., 1980 ; Buckman and Brady, 1969; Greenland, 1979). Greenland (loc.cit.) has also stated that the integrity of aggregates and microaggregates is dependent on the cementation between domains (clay particles up to about 5μm in diameter) or microaggregates by inorganic precipitates, or on organic materials acting as a lining spread over the surfaces of domains or microaggregates. Thus molecules of organic matter acts as bonding agents between domains and microaggregates, and sand and silt particles. The effect organic matter has on erodibility can best be explained by the Gituamba soil (see Table 1). Although it has been reported elsewhere (Richter and Negendank, 1977) that soils with 40-60% silt content are the most erodible, Gituamba soil with the highest % silt content of 46.7% was ranked as the third 'least erodible' soil (see Table 4). This can probably be explained by the fact that this soil had the highest organic matter content of 12.03% of which would encourage the development of stable aggregates. Stable aggregates were still observed after the cessation of the simulated rainstorm (Plate 2).

Other soil characteristics found to influence erodibility were the bulk density and the crusting of the soil surface. Those soils classified as 'moderately', 'highly' and 'very highly erodible' have in general a bulk density of >1.05gm/c.c. However, Kapenguria soil has a higher bulk density of 1.16gm/c.c and yet ranked as the 'least erodible' soil. This is probably due to its high organic matter content of 8.18% which, as has been pointed out earlier, has the effect of improving the stability and porosity of the aggregates. The 'higher erodibility' of the first six soils, viz. Mwea, Kilifi - YR, Kilifi - YB, Longonot, Kilifi-shales and Katumani can also be explained by their tendency to develop surface crust (Plate 3). Tefera (1981) showed a good correlation between crust thickness and runoff for the same soils i.e. crust thickness was highly correlated with percent runoff (r = 0.81*) and soil loss (r = 0.80**). This is a result of weak aggregates which readily break down. These soils have relatively low organic matter contents, high percentage of fine sand and very fine sand while others are characterized by impeded drainage due to the swelling of clay when wet (Mwea and Kilifi-shales). Under raindrop impact, the dispersed particles of these soils seal the soil surface and form a crust. McIntyre (1958) and Tackett and Pearson (1965) have shown that an impermeable crust only a fraction of a mm thick can greatly reduce infiltration rates. As a result of crust formation, pools of standing water will form and coalesce and surface runoff will be increased and accelerated.

Simple linear regression analysis did not succeed in accounting for more than 65% of the variations in the relative soil erodibility factors, and therefore to try and account for more of the variation, the use of multiple regression analysis was studied. Those basic soil parameters finally selected for consideration in the multiple regression on soil losses are given in Table 8 and reflect certain attributes of erodibility, i.e. the % clay and % organic matter were selected to reflect the presence of binding agents which should therefore be inversely related to soil losses, the dispersion ratio to reflect the content of easily dispersable and hence transportable clay which should be positively correlated with soil losses (Middleton, 1930) and bulk density of the topsoil which might reflect the porosity and hence the infiltration rate of the soil and would in that case be positively related to soil losses (Barnett and Rogers, 1966). The latter parameter would not however be expected to be a good index of infiltration, and hence runoff, particularly for soils with varying textures (Wischmeier and Mannering, 1969). Nevertheless in a multiple linear regression analysis, these four soil properties, viz. dispersion ratio, % clay, % organic matter and bulk density, gave a multiple correlation coefficient of 0.947*** and thus explained 90% of the variation in k_{td}. The resulting multiple regression equation which combines the effects of these four primary and interaction terms can be written as:

$$Y = 0.297 + 0.069X_{13} - 0.001X_2 - 0.011X_1 - 0.148X_9 \quad (2)$$

where Y is the predicted relative erodibility factor k_{pred}, X_{13} is the dispersion ratio, X_2 is the % clay, X_1 is % organic matter content and X_9 is bulk density in gm/c.c. In comparison, Wischmeier's soil erodibility nomograph accounted for only 71% of the variations in k_{td} for the 13 soils. This shows that the regression equation (2) developed in this study for predicting relative erodibility factors account for a greater percentage of the variation in k_{td} than Wischmeier's relationship. Table 9 summarizes the observed (k_{td}), predicted (k_{pred}) and K_{nom} relative

Table 8. Soil properties used in multiple regression analysis and multiple and partial correlation coefficients with the relative erodibility factor k_{td}.

Variables[+]	Multiple Correlation Coefficient R	Constants	Coefficients					
			X_{12}	X_{13}	X_2	X_1	X_9	df
X_{12}	.797**	0.057	0.001					11
X_{12}, X_{13}	.828***	-0.003	0.001	0.078				10
X_2, X_1, X_9	.926***	0.392			-0.002	-0.014	-0.155	9
X_{13},X_2,X_1,X_9	.947***	0.297		0.069	-0.001	-0.011	-0.148	8

Significant at: * -5%; ** -1%; *** -0.1%

\+ variable description: X_{12} = very fine sand + fine sand, X_{13} = dispersion ratio, X_2 = % clay, X_1 = % organic matter content, X_9 = bulk density (g/cc). Note that other regression equations involving one, two, or three variables can be obtained from this table.

erodibility factors while Fig. 2 shows the relationship between predicted (k_{pred}) and observed (k_{td}) relative erodibility factors.

Wischmeier's relationship and the equation (2) relationship are able to rank the soils equally well in order of their relative erodibility factors (Spearman's ranking correlation r_s = 0.88** and 0.87** respectively).

Table 9. Observed and predicted relative erodibility k factors and the erodibility K_{nom} factors estimated from Wischmeier's relationship.

Soil	$^1k_{td}$	$^1k_{pred}$	$^3K_{nom}$
Kapenguria	0.054	0.063	0.008
Thika II	0.055	0.074	0.042
Gituamba	0.065	0.060	0.033
Thika I	0.068	0.075	0.047
Siakago	0.071	0.091	0.079
Kabete	0.077	0.070	0.076
Ngenge	0.085	0.067	0.048
Masinga	0.097	0.100	0.153
Kitale	0.111	0.093	0.087
Katumani	0.135	0.134	0.075
Longonot	0.148	0.151	0.231
Kilifi - YR	0.164	0.144	0.161
Kilifi - YB	0.170	0.179	0.203

$^1k_{td}$ Relative k-values determined from trays(t) in dry(d) state.

$^2k_{pred}$ Relative k-values predicted by regression equation (2).

$^3K_{nom}$ Estimated K-values determined by Wischmeier's soil-erodibility nomograph (Wischmeier et.al., 1971).

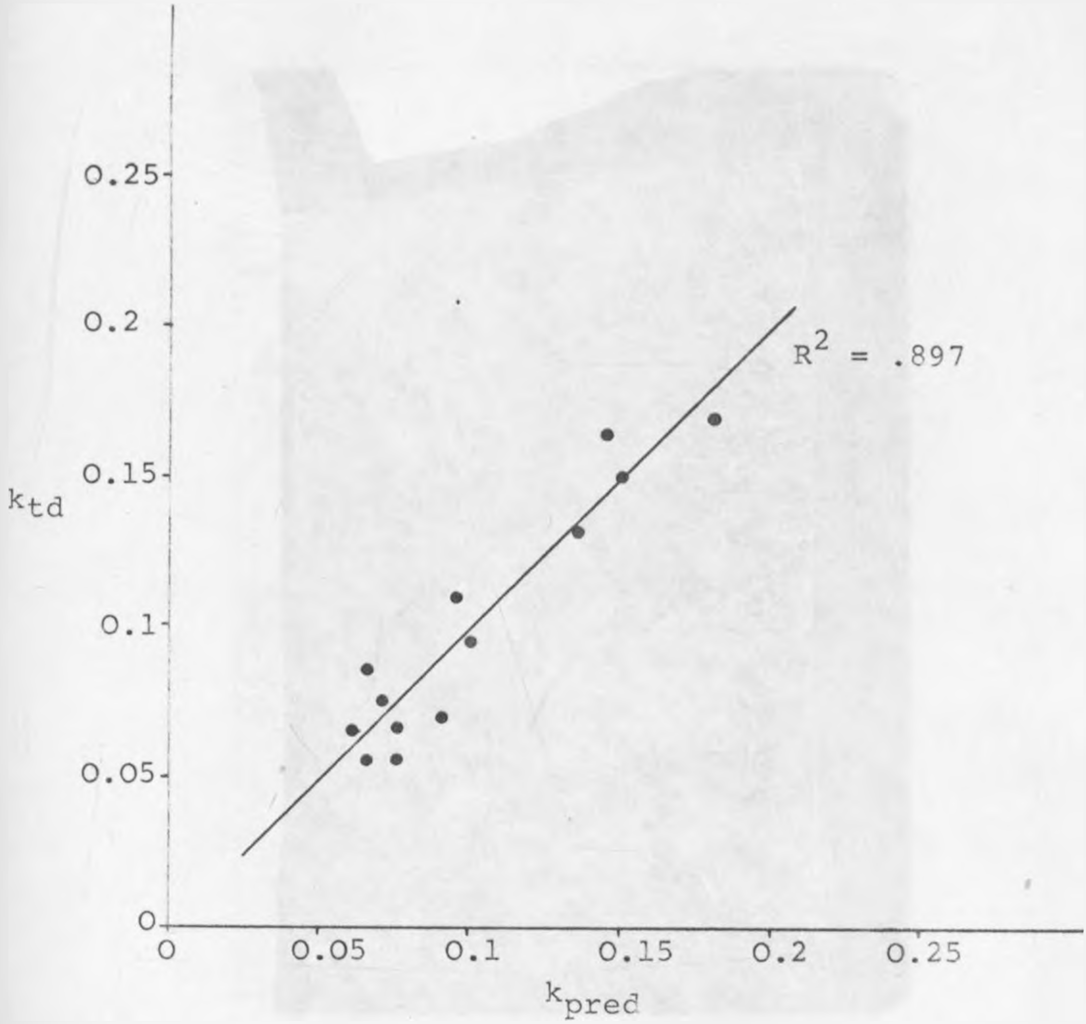
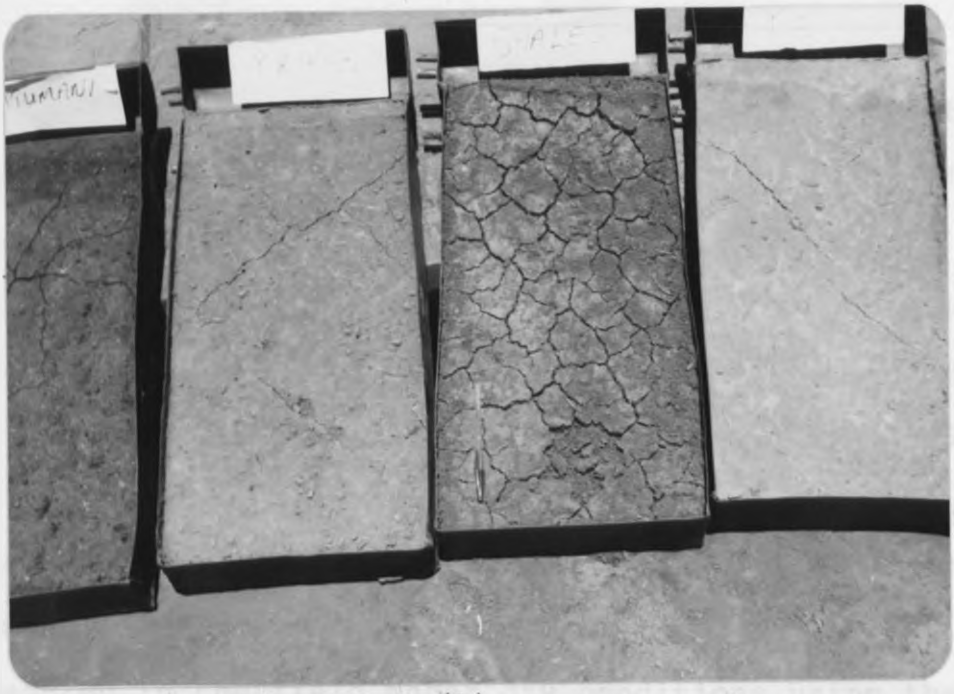


Fig. 2. Relationship between relative erodibility factors k_{pred} as predicted by equation (2) and relative erodibility factors k_{td} as measured from trays in dry state.

Plate 2. The Gituamba soil after being exposed to a 47mm/hr rainstorm of erosivity 27.3. Note the high content of stable aggregates of the surface soil despite the high silt content which is probably due to the soil's high organic matter content.



(A)

(B)

Plate 3. (A) Surface crusts formed on Kilifi-YR, Kilifi-YB, Kilifi-shales and Katumani soils following a short drying period after the simulated rainstorms. (B) Close-up of the strong crusts formed on Katumani and Kilifi-YR soils after drying.

CHAPTER 5: SUMMARY AND CONCLUSIONS

The relative erodibility of 15 Kenyan soils was determined in the laboratory by applying simulated rainstorms of 47mm/hr and 1hr duration to samples of the air-dry soils packed in metal trays. The soil losses ranged from 2.03 to 7.91g/m^2/unit of erosivity and the relative erodibility factors (k) calculated in the same way as actual K factors ranged from 0.054 to 0.210. For five of these soils, the relative k_{td} factors measured from trays in the dry state could be compared with relative soil erodibility factors (k_{fd}) measured in the field under dry conditions using the same rainfall simulator and similar rainfall intensities. The k_{td} values were found to be higher than the k_{fd} values. Nevertheless, both sets of data placed four of the five soils in the same relative order. The discrepancy due to the fifth soil could be attributed to the high level of organic manures applied between the time the field trials were conducted and the time of sampling for the laboratory study. Nevertheless the relative erodibility k_{td} factors determined in the laboratory still correlated fairly well ($r = 0.79$, NS) with the relative erodibility (k_{fd}) values measured in the field.

In an attempt to find a method of predicting relative erodibility factors, Wischmeier's nomograph was applied to the 15 soils investigated and the K_{nom} values correlated against the k_{td} values. The K_{nom} erodibility factors ranged from 0.008 to 0.231 and correlated rather poorly with the k_{td} values ($r = 0.54*$). Wischmeier's nomograph ranked the soils in order of their relative erodibility fairly well ($r_s = 0.679**$). When two soils (Mwea and Kilifi-shales) with a montmorillonite mineralogy and characterized by impeded drainage were excluded, Wischmeier's nomograph gave a correlation coefficient of $r = 0.84***$and ranked the soils in order of their relative erodibility moderately well ($r_s = 0.885**$).

In an attempt to obtain a better prediction of the relative erodibility factors, the relative erodibility k_{td} factors of the 13 well drained, non-swelling soils were statistically correlated with selected soil parameters. The best single predictive factors for the relative erodibility were the % very fine and fine sand (0.05-0.25mm) $r = 0.80***$, % fine sand (0.10-0.25mm) $r = 0.79**$, dispersion ratio $r = 0.75**$, % clay $r = -0.62*$ and % organic matter $r = -0.54$. Thus the maximum variation in k factor values accounted for was still only 65%. A further attempt to improve the precision with which k factors can be predicted was made by using multiple regression analysis. The independent variables used were dispersion ratio to reflect the content of easily dispersable and hence transportable clay, % clay and % organic matter to reflect the presence of binding agents and bulk density to reflect the porosity and hence the infiltration rate of the soil. This multiple regression gave a multiple correlation coefficient of 0.947*** and thus explained 90% of the variations in k_{td}. The multiple regression was $Y = 0.297 + 0.069X_{13} - 0.001X_2 - 0.011X_1 - 0.148X_9$, where Y is the predicted relative erodibility factor k_{pred}, X_{13} is the dispersion ratio, X_2 is % clay, X_1 is % organic matter content and X_9 is bulk density in gm/c.c. In comparison, Wischmeier's nomograph accounted for only 71% of the variations in k_{td} for the 13 soils. Nevertheless, both Wischmeier's relationship and the multiple regression relationship were able to rank the soils equally well in order of their relative erodibility factors (r_s = 0.88** and 0.87** respectively).

The fact that Wischmeier's nomograph did not correlate as well with the relative erodibility k_{td} factors as the multiple regression does not necessarily invalidate the use of Wischmeier's nomograph for estimating the real K factors for Kenyan soils. No reliable data have yet been obtained in Kenya for the erodibility K factors of different soils, and so the accuracy of using Wischmeier's nomograph to predict the erodibility of Kenyan soils is unknown. The Kenya Soil Survey's index of erodibility was found to correlate rather poorly (r = 0.68**) with the relative erodibility factors k_{td}.

The regression equation developed in this study was therefore seen to be an improvement over the Kenya Soil Survey approach for estimating the relative erodibility of Kenyan soils and until more reliable data becomes available for real K factors for Kenyan soils, it is suggested that this multiple regression can be used for predicting the relative erodibility factors of non-swelling, well drained Kenyan soils. It should therefore be useful in land evaluation exercises where the erosion hazard or erosion susceptibility of soils needs to be assessed and for selecting suitable support practices for different soils in different agricultural environments. Moreover the approach can be used to rapidly measure the relative erodibility of large number of soils since the independent variables used are all soil properties that are routinely determined in soil survey investigations.

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PART II

AN ASSESSMENT OF THE SOIL EROSION SUSCEPTIBILITY OF A SELECTED AREA IN KILIFI DISTRICT

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CHAPTER 1: INTRODUCTION

The seriousness of soil erosion in many parts of Kenya has been mentioned in Chapter 1 of Part I. Consequently there is a need to know how vulnerable soils are to erosion as this is an important land quality used in the physical evaluation of soils for different land uses, and it also affects the management and conservation practices required to reduce soil losses to acceptable values.

The vulnerability of soils to erosion depends on rainfall erosivity, soil erodibility, slope length and angle, the crop cover and management and the soil conservation practices, and this is generally referred to as the erosion hazard (Hudson, 1973; Bergsma, 1973). However crop and management practices can change markedly with time and therefore a more inherent characteristic of the potential of soils to erode is given by the rainfall erosivity, soil erodibility, slope length and angle, the combined effects of which are referred to as the erosion susceptibility (Bergsma, 1973). Erosion susceptibility of land therefore gives a measure of the soil losses likely to occur from cultivated bare land. It is interesting to note that the soil forming factors - climate, parent material, topography, vegetation, time and man are very similar to those factors determining the soil erosion hazard and soil erosion susceptibility. This relationship suggests that a soil survey forms a reasonable basis for an erosion survey. Although abundant soil surveys have been carried out in many parts of the world, relatively few attempts have been made at mapping soil erosion hazard or soil erosion susceptibility. Many research workers are now realizing the need for simultaneously combining soil survey work with erosion susceptibility or erosion hazard mapping, since similar data are required for both exercises. In Kenya, efforts have been made to assess "erosion hazard" and the Kenya Soil Survey (KSS) has developed a method of evaluating soil "erosion hazard" at a reconnaissance level (Braun and van de Weg, 1977; Braun and Muchena, 1978; Mbuvi and van de Weg, 1975; Gelens et. al., 1976; Michieka et. al., 1978). In the KSS method, an evaluation of the soil "erosion hazard" is mapped on the basis of slope length, climate, slope class and soil erodibility but according to the above definition, the KSS is actually measuring and mapping soil erosion susceptibility. These factors are rated and the individual ratings are added up. The final rating is classified to give a measure of the "erosion hazard". The study presented here attempts to evaluate and map, at a detailed scale the erosion susceptibility of a small area of 185 hectares in Kilifi District which requires first the production of a detailed soil survey. The approach used is a quantitative parametric method based on the Universal

Soil Loss Equation (USLE) (Wischmeier and Smith, 1965), and is similar, in some respects, to the method proposed by FAO (1979) for assessing the risk of soil degradation by water. This approach is rather tedious and time consuming, but is assumed to give the most accurate assessment of the comparative erosion susceptibility of land. The second part of the study is to evaluate how well a devised qualitative rating method and the Kenya Soil Survey procedure, both of which have the advantage of being simpler and quicker to carry out, compare with the more detailed and presumably more accurate quantitative parametric approach, particularly with respect to the modal slopes within the landscape. It is hoped that this detailed study may prove to be of value in developing improved procedures for erosion susceptibility mapping at smaller scales.

CHAPTER 2: LITERATURE REVIEW

2.1 Definitions

- Soil erosion hazard is a measure of the degree of soil erosion that is likely to occur. When soil erosion is already clearly in evidence, the erosion hazard expresses the intensity of the erosion processes, or the degree of soil loss, which is expected from a specific form of landuse, management and conservation practice. Soil erosion hazard therefore reflects the combined effects of all erosion factors viz. climate, topography, soil type, landuse and management practices (Bergsma, 1973).

- Soil erosion susceptibility is the vulnerability of a soil to erosion which depends only on relatively permanent factors such as climate, topography and soil properties, and is therefore an inherent and relatively permanent characteristic of the land (Bergsma, 1973; Morgan, 1979). The difference between soil erosion hazard and soil erosion susceptibility can be summarized in terms of the erosion factors:-

	Erosion factors	
Soil erosion hazard.	Climate Soils Relief	- Soil erosion susceptibility.
	Vegetation Land use	

(after Bergsma, 1973)

2.2 Assessment of soil erosion susceptibility/hazard in the field

Various research workers have mapped soil erosion susceptibility or hazard in the field using qualitative methods in which slope length and gradient, soil erodibility, climatic erosivity, crop and management practices are rated by a 'rating system' (Morgan, 1978; Arnoldus, 1974). In such systems, each of these factors is rated on a scale where the lowest number, normally taken as 1, is associated with a low risk of erosion, and the highest number with a high risk. The factor scores are multiplied or added up to give a product or total score which is compared with a chosen classification system to identify low, moderate and high erosion risks. The factor scores are mapped and areas of similar risk are delineated to give a soil erosion susceptibility/hazard map. There has not yet been a generally accepted procedure established to assess or map soil erosion susceptibility/hazard (Morgan, 1980). The FAO World Degradation Assessment (1979) Project aims to establish an internationally acceptable methodology (its aims are reviewed elsewhere within this chapter). In his review of 'Soil Erosion Processes, Assessment Techniques', Arnoldus (1974) suggests a qualitative procedure which yields two orders of soil erosion (he does not specify whether the orders are of soil erosion susceptibility or hazard). Order 1 has permissable soil erosion losses and order 2 impermissable soil erosion losses. He then subdivides the latter order into three classes viz. light, moderate and severe erosion. Arnoldus suggests the ranges of rating values for each factor to be the same i.e. equal weighting, and he suggests multiplying the rating values instead of addition since there is an interaction between the factors.

The methodology used in the mapping of soil erosion susceptibility/hazard will vary with the scale of mapping. Arnoldus (1977) estimated the maximum potential average annual soil loss due to sheet and rill erosion in Morocco at a scale of 1:5,000,000. In order to arrive at the maximum potential soil loss, the values of the cropping management factor (C-factor) and the erosion control practice factor (P-factor) were taken as unity (thus he was mapping erosion susceptibility). To obtain the erosivity map (R-factor map), Arnoldus used Fournier's $\sum P_i^2/P$-index (Fournier, 1960) in which P_i is the mean monthly precipitation and P is the mean annual precipitation (A good correlation was found between Fournier's index and known values of R-factors, r = .91, n = 178). The soil erodibility map was obtained by calculating the soil erodibility factor (K-factor) according to the nomograph developed by Wischmeier et.al., (1971). Arnoldus' topographic factor map was based upon three dominant slope classes viz. a(0-8%), b(8-30%) and c(>30%). However, average slope lengths were difficult to assess at the 1:5,000,000 scale. Therefore Arnoldus did not evaluate this factor. By superposition of the three maps and multiplication of the three values obtained for each mapping unit, a soil map was obtained. Arnoldus established five soil loss classes viz. none to slight (0-30 tons/ha/yr), moderate (30-100 tons/ha/yr), high (100-400 tons/ha/yr) and very high (400-2000 tons/ha/yr). From the final soil loss map of Morocco, Arnoldus showed topography to be the factor of overriding importance, with erosivity as a factor of secondary importance.

Bergsma (1978) carried out a reconnaissance survey of erosion hazard near Merida, Spain. Aerial photographs 1:32,000 were used, with a final map scale of 1:100,000. He made a qualitative evaluation of slope steepness, length, relative position, soil erodibility (including the effect of surface gravel and overland flow potential of the soil profiles), vegetative cover and land management. The rain-erosivity index of Wischmeier was approximated at 90 by a relationship used by Wischmeier and Smith (1962) for semi-arid to sub-humid conditions. Bergsma used the Soil Survey Manual (Soil Survey Staff, 1951) classes of slope steepness viz. level to nearly level (0-2%), undulating (2-8%), rolling (8-16%), hilly (16-30%) and steep (>30%). Three classes were used to describe the length of slope, having boundaries at 3 and 10mm on the aerial photographs (equivalent to 96 and 320m respectively). Soil erodibility was introduced at a very general level. The rain drop tests on soil samples (Low, 1967) formed a guide in this respect (a good correlation r = 0.85 existed between average drop number and the soil erodibility factor K). Bergsma mapped five classes of land use viz. bare soil, bare rock, olive and grape orchards, annual crop rotations and open forest. Due to the fragmentary land tenure system, conservation practices were very limited in extent. Bergsma indicated that the presence of a gravelly surface may lead to a reduction in soil erosion hazard by one or half a class. Short slopes (<100mm) and long slopes (>320m) made a difference of about ½ a class. Cover types had a very dominant influence on erosion hazard; steep units with a forest or grass cover were classified in the very low hazard class. The presence of conservation practices of contour farming reduced the hazard by one class. For slope position, he argued that level areas in low lying positions can give erosion hazards because of the influx of overland flow from higher areas. The absent, slight, severe to very severe erosion hazard classes recognised by Bergsma, were based on differences in parent material, relief and other hazard aspects. For instance, areas classed as absent erosion hazard class were level to nearly level and covered by valley deposits and so were areas which were steep and rocky (Bergsma argued that no soil loss was to be expected anymore from such rocky lands). Unlike many research workers, Bergsma compared the qualitative hazard classification of some mapping units with the expected soil loss values obtained from Wischmeier's method of soil loss prediction (Wischmeier et. al., 1965). The estimated soil losses of some mapping units coincided very well with Bergsma's qualitative soil erosion hazard classification. The quantitative classes of erosion susceptibility/hazard were very low, (0-5 ton/ha/yr), low (5-12 ton/ha/yr), moderate (12-25 ton/ha/yr), high (25-60 ton/ha/yr) and very high susceptibility/hazard (>60 ton/ha/yr). However, there are some disadvantages with Bergsma's work. The work involved a lot of data collection and therefore was expensive and time consuming. Downslope tillage which was the most common form of land management could not be mapped at the scale involved. Moreover where conservation practices were being practised, Bergsma reduced the hazard by one class, but if a conservation practice is effective, it should reduce soil losses to very low values even if the soil erosion susceptibility is very high.

Elwell and Stocking (1975 and 1976) used rainfall erosivity, soil erodibility, topographic, cropping and management factors to estimate soil erosion hazard in Rhodesia. They showed that, percent vegetal cover was the major factor determining the erosion hazard from crops and grassland. Elwell and Stocking analysed soil loss data from grazing trials and developed a relationship between exposed soil and soil losses. A mean seasonal exposed soil rating was evaluated by using an idealized exposed soil versus time model. Elwell and Stocking (1976) then considered the time distributions of crop cover and rainfall through the season, and developed a percent cover soil loss relationship. This approach was proposed as an alternative to a cropping management factor which required extensive testing. They used subjective ratings on the basis of field observations as there were no specific measurements of percent cover for the various crops. However, they were able to show that, soil erosion was likely to greatly increase when the total vegetal cover was below 30%.

Morgan (1978) conducted reconnaissance, semi-detailed and detailed erosion hazard surveys in Peninsular Malaysia. At a reconnaissance level (1:63,360), Morgan's aim was to give a general judgement on erosion risk in Peninsular Malaysia. He mapped drainage density (defined as the length of streams per unit area), drainage texture (defined as the number of first-order streams per unit area), and mean annual erosivity using the KE>25 index (Hudson, 1973). Morgan did not introduce any category of low erosion risk, for he argued that at least a moderate risk of erosion exists in any tropical environment. Arnoldus (1974) has argued on similar lines. The three categories of erosion risk recognized by Morgan in this reconnaissance survey were designated severe, high and moderate, where the high risk areas were divided into two groups: those where the main hazard was gullying and those where it was by overland flow and rilling. Morgan conducted a semi-detailed erosion hazard survey using aerial photographs at the scale of 1:25,000 to identify the extent and type of soil erosion taking place, and to assess the relative importance of the various factors in influencing soil loss. He took into consideration the influence of soils, drainage density, slopes and land use. First the photographs were examined stereoscopically and such information as the stream pattern, crest pattern, erosion features, e.g. rills, gullies, areas of sedimentation and the main landuse types were demarcated. The mid-slope line, which lies half-way between the divide and the drainage lines was drawn. Points along this line were selected either at random or at regular intervals, and lines (transects) were drawn from each point along the steepest part of the slope to the divide and the drainage line at right angles to the contours. On each transect, slope angles, and slope lengths were measured between breaks in slope. Soil samples were taken for analysis of particle-size distribution, organic matter and aggregate erosion exists in any tropical environment. Arnoldus (1974) has argued on similar lines. The three categories of erosion risk recognized by Morgan in this reconnaissance survey were designated severe, high and moderate, where the high risk areas were divided into two groups: those where the main hazard was gullying and those where it was by overland flow and rilling. Morgan conducted a semi-detailed erosion hazard survey using aerial photographs at the scale of 1:25,000 to identify the extent and type of soil erosion taking place, and to assess the relative importance of the various factors in influencing soil loss. He took into consideration the influence of soils, drainage density, slopes and land use. First the photographs were examined stereoscopically and such information as the stream pattern, crest pattern, erosion features, e.g. rills, gullies, areas of sedimentation and the main landuse types were demarcated. The mid-slope line, which lies half-way between the divide and the drainage lines was drawn. Points along this line were selected either at random or at regular intervals, and lines (transects) were drawn from each point along the steepest part of the slope to the divide and the drainage line at right angles to the contours. On each transect, slope angles, and slope lengths were measured between breaks in slope. Soil samples were taken for analysis of part-icle-size distribution, organic matter and aggregate stability. Records of the plant cover, such as species, percentage ground cover, decaying vegetal matter and surface litter, were made within 1x1m quadrats. Larger, 10x10m quadrats were used to record bush and tree species. Although a reasonably accurate erosion hazard map, sufficient for the purpose of a semi-detailed survey was obtained by this approach, it is very tedious and time consuming. Morgan conducted a detailed erosion hazard survey at the scale of 1:1,584 to examine the feasibility of implementing the conservation strategy defined by a semi-detailed survey, and to provide a data base for the design of mechanical protection works. He measured slopes along ten sample transects, and soil samples were taken at three points on each transect, corresponding to the convex segment on the upper slope phase, the junction between the upper and lower slope phases, and the mid-slope segment of the lower slope phase. On the slope map were shown the slope angles of the individual slope segments, the slope shape in profile and the location of convex or concave slope breaks greater than 10^{o}, the main gullies, the areas of flow convergence and the land subject to overland flow. A significant correlation (r=0.95; n=24) between the silt/clay ratio and estimates of the K-value of erodibility determined from the nomograph of Wischmeier et.al. (1971) suggested the silt/clay ratio to be a good index of erodibility. The catchment was observed regularly in the field to monitor the frequency of overland flow and gully erosion. Morgan was able to divide the catchment into three areas according to the degree of erosion hazard. These were the valley heads (with greatest risk due to continuous overland flow and gully erosion), the lower valley side slopes (with potential erosion risk) and the upper valley side slopes (with relatively low erodibility soils and gentle slope angles). Morgan observed the catchment regularly to monitor the frequency of overland flow and gully erosion. Although he was able to monitor overland flow and gully erosion, monitoring the two erosion processes required a considerable amount of time and the approach is more expensive as many automatic monitoring instruments are required. Nevertheless, by monitoring the frequency of overland flow and gully erosion, Morgan was able to obtain sufficient data to provide an indication of the frequency and magnitude of rainfall events which cause erosion. Morgan gave some disadvantages associated with the rating system. For instance, each factor is treated independently whereas there are interactions between the factors. Moreover, the factors are often combined by addition, yet there is no reason why this should be a more appropriate method of combining them than multiplication, and finally, in the rating system, each factor is generally given equal weighting.

The rating system is currently being used by the Kenya Soil Survey (Braun and van de Weg, 1977; Braun and Muchena, 1978; Muchena, 1979). The method has already been applied to three reconnaissance soil survey areas (Mbuvi and van de Weg, 1975; Gelens et. al., 1976; and Michieka et. al., 1978). Braun and van de Weg (1977) described how soil erosion 'hazard' is mapped on the basis of slope length, climate, slope class, and soil erodibility. The factors are rated and the ratings for each factor are added up. The final rating is claimed to be a measure of the erosion hazard. However, soil erosion hazard has been defined (Bergsma, 1973) as a measure of the degree of soil erosion that is likely to occur when soil erosion has already begun, thus reflecting the combined effect of all the erosion-causing factors. Since the KSS excludes landuse and management practices in their rating system, they are therefore mapping soil erosion susceptibility as defined by Bergsma (1973). In the KSS system, climate is rated on the basis of ecological zones which are defined as average annual rainfall 'r' over average annual potential evaporation 'Eo' as a ratio. The climate ratings are presented as follows:

	rating	eco zone
risk of	0	I and II (r/Eo >63%)
erosion	1	III (" 48-63%)
increases ↓	2	IV and V (" 18-48%)

The climate ratings imply that the drier the climate the greater the risk of erosion. This is contrary to the findings of Moore (1979) who found that the higher rainfall areas were associated with higher annual erosivities. The lowest erosivity hazards have been shown to occur in drier areas (R values less than 150) whereas high erosivity values (R values of over 400) occur in wet areas (Moore, 1978 and 1979; Rowntree, 1982). This therefore indicates that ecological zones IV and V have a lower risk of erosion than ecological zones I and II and therefore the climate subratings used by KSS are incorrect. Perhaps the KSS assumed that in the wetter areas there is sufficient vegetal cover to prevent soil erosion, whereas in drier areas vegetal cover is low with much more bare soil exposed. However if this concept were the basis for the KSS climate rating, then it confuses two erosion factors viz. erosivity and ground cover. Moreover, in the arable areas of Kenya, the land surface is bare when the most erosive rains occur (Fisher, 1977; Moore, 1978; Rowntree, 1982). On subrating slope length, the KSS use:

	rating	slope length
risk of	1	>200m
erosion	2	50-200m
increases ↓	3	<50m

The slope length subrating implies that there is a high risk of erosion in areas with short slopes. This is contrary to the findings of Zingg (1940) who expressed the relationship between erosion and length of slope as $X = CL^n$ where X is the total soil loss, C a constant, L is the length of slope, and n an exponent. Thus a longer slope yields more runoff and soil loss than a shorter slope. Therefore the slope length subrating as used by KSS should be in reverse. The subratings of slope gradient involve four classes viz. 0-2%, 2-5%, 5-16%, >16% (although it seems odd to place all land >16% in one slope category when land in Kenya is commonly cultivated on slopes of 55% and over; Thomas et. al., 1981) with rating classes of 1,3,5,7 respectively. The slope gradient parameter is given a higher rating of 1 to 7 because of the greater influence slope gradient is believed to exert on soil erosion (Wischmeier and Smith, 1978). The subrating of soil erodibility is based upon organic matter, flocculation index, silt/clay ratio in topsoil and bulk density in topsoil (Braun loc. cit.) When the author tested these parameters against soil losses as measured on disturbed samples using a rainfall simulator (Part I), the correlation coefficients between organic matter, flocculation index, silt/clay ratio and bulk density were found to be -.54, -.17, .37 and .37 respectively. A multiple regression analysis involving these four parameters explained 44.9% (r = 0.67; n = 13) of the variation in soil loss. Research carried out elsewhere has also shown that these parameters correlate well with soil losses (e.g. Barnett and Rogers, 1966; Dangler and El-Swaify, 1976; Mannering and Wischmeier, 1969; Young and Mutchler, 1977). In the KSS method, the subratings of slope length, slope class, climate and soil erodibility are added up. The final rating is classified to identify areas of very high, high, moderate, slight and very slight soil erosion 'hazard'. Morgan (loc.cit.) has criticised the additive rating system where each factor is treated independently since there are interactions between the factors suggesting a multiplicative method would be more appropriate.

The material so far reviewed shows that there are marked differences in the methodology of soil erosion susceptibility/hazard assessment and mapping. In an attempt to develop a universally acceptable methodology, the FAO/UNEP project (1979) on World Assessment of Soil Degradation attempted to (i) initiate a global assessment of soil degradation based on the compilation of existing data, and the interpretation of environmental factors influencing the extent and intensity of soil degradation, and (ii) to develop a methodology and select uniform criteria to measure and monitor soil degradation. "Soil degradation is a result of one or more processes which lessens the current and/or potential capability of soil to produce (quantitatively and/or qualitatively) goods or services" (FAO/UNEP, 1979). In the framework of the FAO/UNEP project, six soil degradation processes were distinguished, they are: water and wind erosion, excess of salts, chemical, physical and biological degradation. The first two occur to a larger extent in the world, although locally other processes can be dominant. In the proposed methodology, the multiplicative formula and the value range of erosion factors of the universal soil loss equation have been used, but the erosion factors have been adjusted to suit the scale of mapping. The rating attributed to each factor is chosen by comparison with the USLE. For the rainfall factor, a modified Fournier's P_i^2/P-index has been proposed as it is easier to calculate with available climatological data (Arnoldus, 1980). For determining the soil erodibility, data for the use of the nomograph published by Wischmeier et.al. (1971) are generally not available. Field plots are also rare. Therefore, an erodibility rating for each soil unit according to its texture and surface diagnostic horizon has been proposed (this is in agreement with Wischmeier's nomograph where erodibility of a soil is a function of texture, structure, permeability and humus content). The topography factor is also difficult to determine on small scale maps (1:5,000,000). Mean slope gradient in a mountaneous area and mean length of slope are meaningless. Therefore, it has been proposed to link the LS factor to the geomorphological unit or landscape classes which are defined in terms of average slope and altitude. This problem was encountered by Arnoldus (reviewed elsewhere) when he was determining the maximum potential average annual soil loss in Morocco. Average slope lengths were difficult to assess at a 1:5,000,000 scale and he had to assume that with an increase in slope gradient, the slope length will generally decline. Landuse or natural vegetation are also difficult to generalize at a small scale since the dominant vegetation or crop is generally unknown in many areas. Where natural vegetation maps exist, they do not or rarely show the state of vegetation degradation, or the vegetation cover as a percentage of ground area which are important elements in the assessment of actual erosion.

Indeed there are some disadvantages with the FAO/UNEP approach for assessing soil degradation on a global basis. Maps at the 1:5,000,000 scale will be of use in certain cases for policy-making decisions in individual nations but such maps cannot be used for planning purpose at a local level. Most of the essential data representative of large areas are lacking in many countries. The available local or site data have limited interest unless they can be safely extrapolated to the area of a mapping unit. The other problems are how soil degradation can be evaluated quantitatively and in what units should degradation be expressed. Even when qualitative degradation classifications are used, class limits need to be quantified because what may be regarded in one country or in one area as "severe" degradation, may be regarded as "moderate" in another, since qualitative classifications are generally subjective and relative. Direct field measurements and/or monitoring of the processes themselves are not possible on a global scale. Therefore data collected at a few selected locations must be extrapolated to other areas. Since the validity of extrapolation over large distances is questionable, mathematical models can be useful at this point. Thus the constraints in producing a soil erosion/degradation map at 1:5,000,000 scale are very great.

Although the 1:5,000,000 scale global erosion mapping project is of questionable, or limited use, the FAO/UNEP approaches produced methodologies for mapping erosion hazards at larger scales. The FAO/UNEP approach is very similar to the quantitative parametric method based on the USLE (Wischmeier and

Smith, 1965) for assessing the risk of soil degradation by water. The USLE approach estimates the average annual soil loss due to sheet and rill erosion and is a simple model to operate if the values of the various parameters are known. It was clear that the R factor in Wischmeier's equation cannot be calculated in most of the countries because of lack of data. For such countries, it was decided to use the Fournier's index $\sum \frac{Pi^2}{P}$ (Arnoldus, 1980). For determining the soil erodibility K factor, it was assumed that the use of nomograph (Wischmeier et.al., 1971) will give results with an acceptable accuracy in most countries. Where this may not be applicable, use of field and laboratory studies, which mostly concentrate on the estimation of aggregate stability as a major index of soil erodibility can be made. The LS factor relationship established in USA (Wischmeier and Smith, 1965) is assumed to be valid as there is no apparent reason why it should be different in another country (Foster et.al., 1979). As in the 1:5,000,000 global assessment, the values of C- and P- factors are often unknown in many countries. However, in order to arrive at the maximum potential average annual soil loss, the values of the cropping management factor (C-factor) and the erosion control practice factor (P-factor) are taken as unity.

In conclusion, the material reviewed showed the different approaches for assessing and mapping soil erosion susceptibility/hazard especially in USA and Europe. Attention was also made to the FAO/ UNEP project of trying to reach consensus on a method or methods of world wide applicability for evaluating soil degradation and thus developing methods for preventing it.

CHAPTER 3: ENVIRONMENTAL CHARACTERISTICS OF THE STUDY AREA

3.1 General features of the study area

3.1.1 Location

The study area occupies 185ha and is located between latitudes $2^{\circ}47'$ and $2^{\circ}47.6'$S and longitudes $39^{\circ}37'$ and $39^{\circ}38'$E (Mazeras sheet 198/3). The area is accessible from Kaloleni shopping centre via Kizurini Camp by all-weather roads (loose surface) and dry-weather roads.

3.1.2 Geology

The area was geologically surveyed by Caswell (1956). It is mainly composed of Mariakani sandstones of Triassic age. The sandstones are fine grained and consist largely of quartz grains with a small proportion of feldspars and micas. Outcrops are visible in areas of steeper slopes ($8-11^{\circ}$) and along the river valleys.

3.1.3 Physiography

The catchment has a low relief of less than 245m above sea level. The slopes are predominantly uniform or convex in shape. The dominantly convex slopes steepen uniformly from their crests to a maximum angle of 11° at lower slope positions. In some places at the lower slope positions, a sharp break in slope angle occurs below which the valley side has a gentle slope and grades gently into the flat valley floor (Fig. 1). The drainage is slightly incised. Three physiographic units were identified viz. uplands, bottomlands and river valleys. The uplands extend from the crest lines downslope to the break in slope, where the valley side is of gentle slope and grades gently into the flat river valley floor. The bottomlands are flat ($0-1^{o}$) and characterized by the lack of a drainage outlet and are poorly drained. The river valleys extend from the break in slope between the steeper valley sides ($5.1-11^{o}$) and the gentle slopes ($0-2^{o}$) which grade into the river valley floor where sediment deposition occurs.

3.1.4 Vegetation and present landuse

Most of the original trees and shrubs have been cleared and the land is cultivated mostly with tree crops (mainly coconuts and cashew nuts). Subsistence crops such as cassava, simsim, maize and few bananas are also grown. Rice is grown in a few flat and wet places only. Land which is not used for cultivation is generally used for grazing although very few people keep cattle.

3.1.5 Climate

The mean annual rainfall ranges from 1130mm at Chonyi Dispensary (93.39013) to 978mm at Giriama St. George's High School (93.39041). The rainfall records are taken from the East Africa Meteorological Department over a 34 year period for Chonyi Dispensary and over a 27 year period for Giriama St. George's High School. On the basis of the rainfall data from the two stations, the survey area has a mean annual rainfall of 1054mm. The distribution of the rainfall for both stations is bimodal, the highest peak occurring in May and the lowest peak in October (Fig. 2).

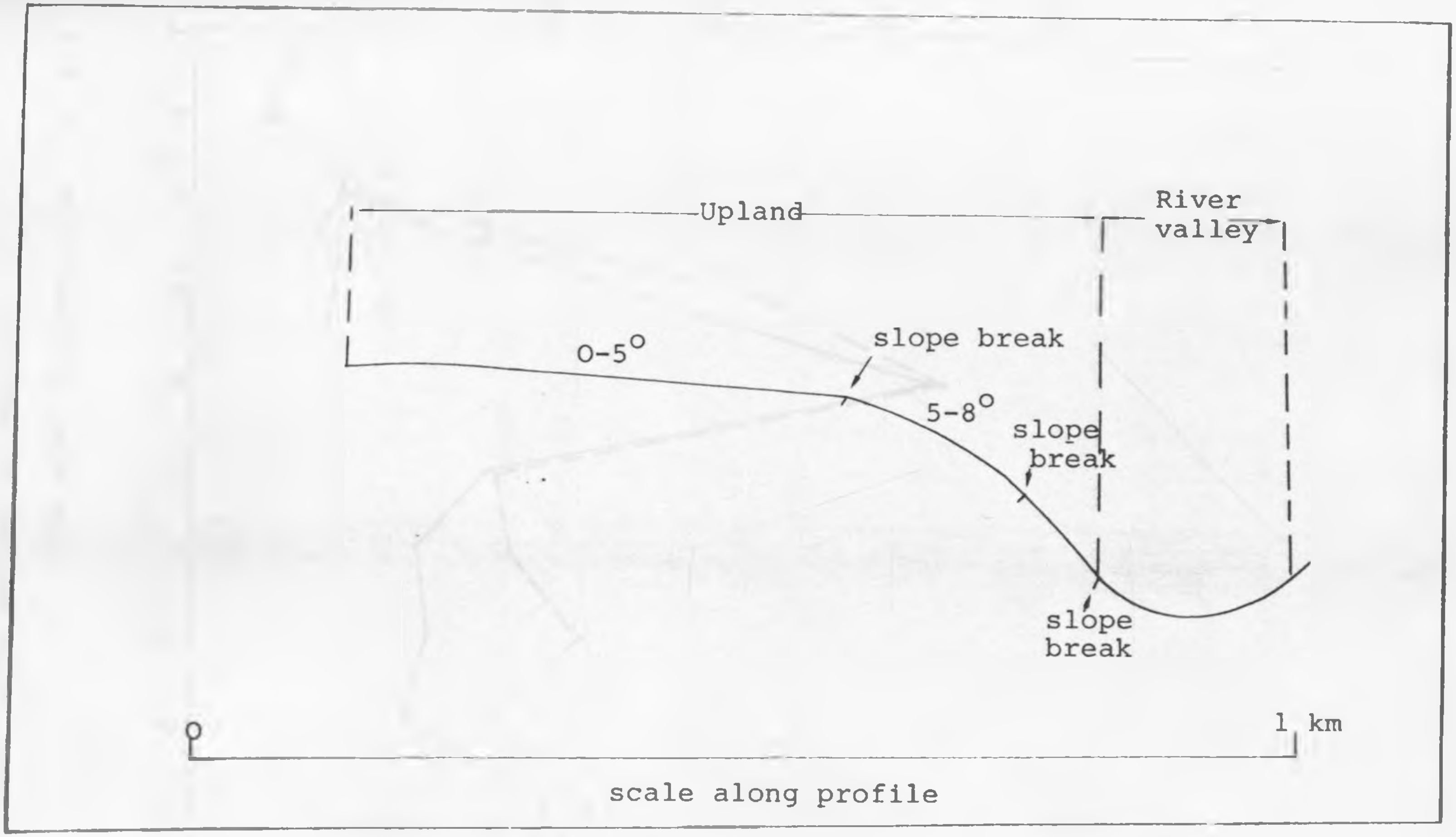

Fig. 1. Detail of a typical slope profile

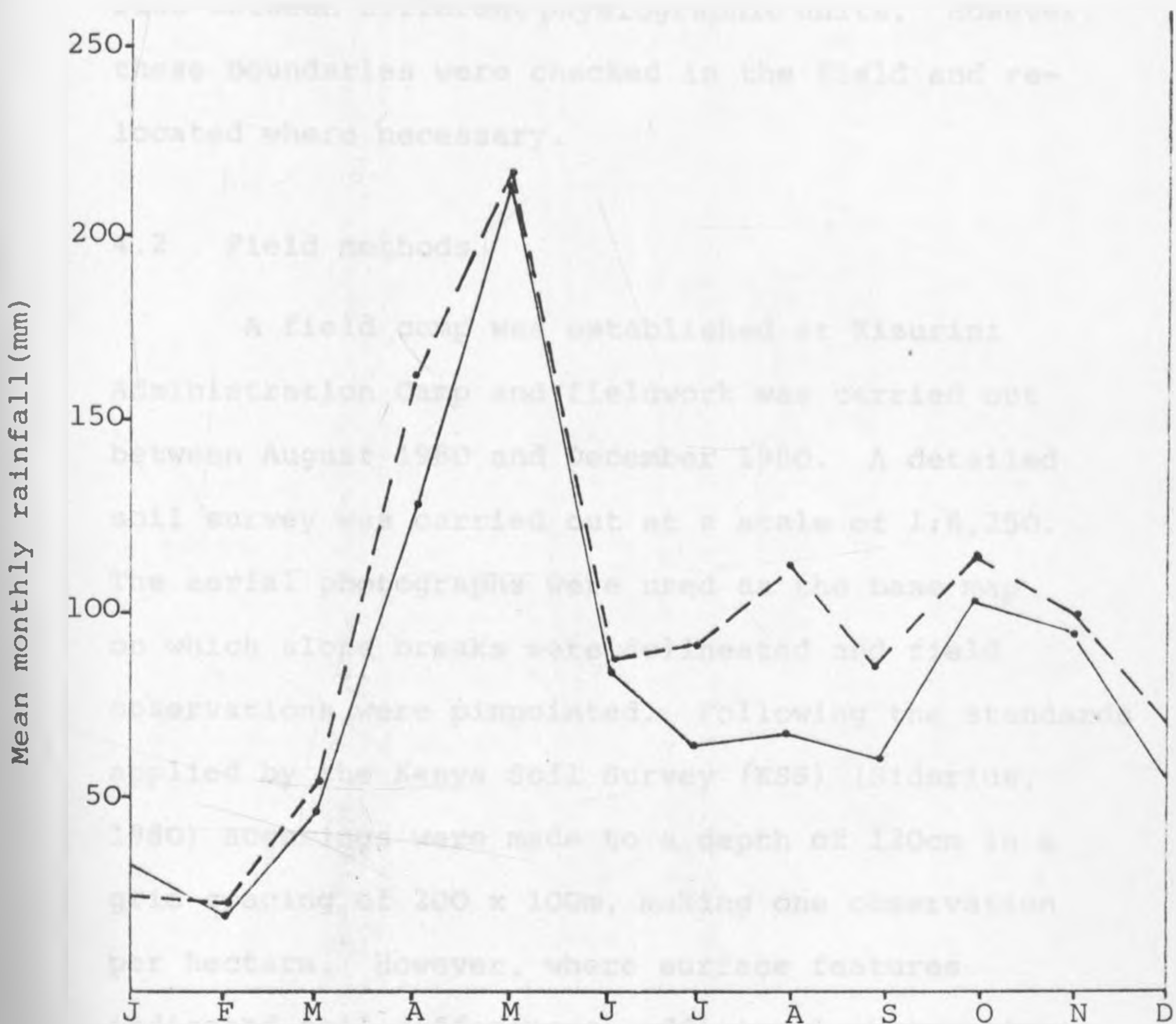

Fig. 2. Mean monthly rainfall:

——— Giriama St Georges High School (93.39041)

- - - - Chonyi Dispensary (93.39013)

CHAPTER 4: METHODOLOGIES

4.1 Office methods

Prior to the fieldwork, the aerial photographs at 1:6,250 scale were examined stereoscopically. Photo interpretation helped to identify the boundaries between different physiographic units. However, these boundaries were checked in the field and re-located where necessary.

4.2 Field methods

A field camp was established at Kizurini Administration Camp and fieldwork was carried out between August 1980 and December 1980. A detailed soil survey was carried out at a scale of 1:6,250. The aerial photographs were used as the base map on which slope breaks were delineated and field observations were pinpointed. Following the standards applied by the Kenya Soil Survey (KSS) (Siderius, 1980) augerings were made to a depth of 120cm in a grid spacing of 200 x 100m, making one observation per hectare. However, where surface features indicated soil differences, additional observations were made at points not necessarily on the traverse lines. Whilst augering, full auger profile soil descriptions and site characteristics were recorded on the standard KSS forms which are based on the FAO Guidelines for soil profile description (FAO, 1977). The soil colour was determined using Munsell soil colour charts (Munsell Colour Company, 1971). A total of 201 augerhole observations were made and described. The auger observations and land characteristics helped to identify different mapping units. These were identified on the basis of soil depth, colour, mottling, texture, consistence, concretions, landform, slope class, etc. A code method was used to identify each mapping unit in which the first two symbols denoted the soil classification at first and second levels according to the legend of the FAO-Unesco Soil Map of the World (FAO, 1974). The third symbol also in the numerator denoted the slope class where the symbols A,B,C,D and E represent gradients of 0-1°, 1.1-3°, 3.1-5°, 5.1-8°, 8.1-11° respectively. The symbol in the denominator denoted physiography where U, V and B are used to represent uplands, valleys and bottomlands respectively. The author did not find it necessary to include a symbol for geology as all the soils were developed on the same parent rock. The example given below shows how the coding system was used.

Mapping unit $\frac{Qc\text{-}C}{U}$

- Q → Arenosols
- c → cambic Arenosols
- C → slope class (3.1-5°)
- U → physiography (uplands)

Representative profile pits were dug for each mapping unit. The pits varied from 130-220cm deep depending on the soil depth. A total of 21 profile pits were dug, described and sampled. Soil samples from each horizon were taken for laboratory analysis, and in addition, samples for bulk density of the topsoils were collected randomly from the mapping units within the survey area. The bulk density values were used in the assessment of soil erodibility.

The slope gradient and slope length parameters were also mapped. Slope gradients were measured with an Abney level while the slope length were measured directly in the field using a 100meter chain and from the base map where a good relationship had been established between the field and base map measurements. The slope lengths were measured from crest lines downslope at right angles to the contours for each slope segment. Slope segments were delineated by a change in soil type, a break in slope gradient, a change in slope category or by a drainage channel or a gradient sufficiently shallow for sediment deposition to occur.

4.3 Evaluation and mapping of the erosion factors

The erosion factors and hence the erosion susceptibility were evaluated by a quantitative parametric approach based on the USLE (Wischmeier and Smith, 1965), a devised qualitative rating method and the Kenya Soil Survey rating procedure (Braun and van de Weg, 1977).

4.3.1 Evaluation and mapping of the erosion factors by the quantitative parametric approach

English rather than metric units have been used for R, K and L factors since they are derived from the USLE which is based on English units.

4.3.1.1 Erosivity evaluation

The erosivity R factors in ft tons in/acre per year were calculated from the following regression on kinetic energy (KE), where KE is the kinetic energy of rain falling at intensities greater than 25mm/hr for 15 minute periods (Moore, 1979).

$$R = 0.029KE - 26.0 \qquad r = 0.95^{***}$$

The KE values for coastal areas, within which Kizurini occurs, were obtained from the following regression on mean annual rainfall (x) in mm/yr (Moore, 1979).

$$KE = 22.82x - 15795 \qquad r = 0.84^{*}$$

4.3.1.2 Erodibility evaluation

A regression equation developed in Part I for predicting the relative erodibility factors (k) of well drained, non-swelling soils was used.

$$Y = 0.297 + 0.069X_{13} - 0.001X_2 - 0.011X_1 - 0.148X_9 \qquad r = .95^{***}$$

where Y is the predicted relative erodibility factor k, X_{13} is the dispersion ratio, X_2 is the % clay, X_1 is organic matter percent and X_9 is bulk density in gm/c.c.

4.3.1.3 Topography evaluation

The LS factors were evaluated for each slope segment by the method of Foster and Wischmeier (1974). For slope segment 'i' in a sequence of segments from crest line to drainage line or the lowest point of the slope segment, the LS factor is given by the following relationship:

$$LS_i = S_i \frac{(\lambda_i^{m+1} - \lambda_{i-1}^{m+i})}{72.6^m(\lambda_i - \lambda_{i-1})}$$

where S_i is the slope factor for segment 'i' given by

$$S_i = \frac{(0.034S^2 + 0.30S + 0.45)}{6.613}$$

where S = % slope of segment'i'

λ_i = distance from crest line to bottom of segment 'i' (ft)

λ_{i-1} = distance from crest line to bottom of segment 'i-1' (ft)

m = exponent, assumed = 0.5

In this evaluation procedure, soil loss increases logarithmically with both increasing slope gradient and slope length. The R,k and LS factors were multiplied together and then rated as follows:

Rating		Erosion susceptibility
1	0 - 150	very low susceptibility to erosion
2	150 - 300	low " " "
3	300 - 450	moderate " " "
4	450 - 600	high " " "
5	>600	very high " " "

4.3.2 Evaluation and mapping of the erosion factors by the devised qualitative rating method

4.3.2.1 Erosivity evaluation

The erosivity R factor was calculated by the regression given by Moore (1979) (see page 96) and was rated at 3 for the Kizurini area according to the following rating system:

Subrating	R factor (English units)
1	<100
2	101 - 200
3	201 - 300
4	301 - 400
5	>400

4.3.2.2 Erodibility evaluation

The relative erodibility k factor values obtained in Part I were rated from 1 to 5 according to the following criteria:

subrating	k_{td} factor (English units)
1	≤0.12
2	0.13 - 0.24
3	0.25 - 0.36
4	0.37 - 0.48
5	>0.48

The relative erodibility k values were calculated from the regression equation given on page 96. These are k values obtained from trays(t) in dry(d) state. See also Part I, page 45.

4.3.2.3 Topography evaluation

The slope gradients used in the evaluation were the modal slope gradients for the whole slope length. The slopes were not divided into slope segments as in the quantitative method. Rating of the slope gradients is as follows:

Subrating	Modal slope gradient (%)
1	0 - 5
3	5 - 8
5	8 - 16
7	16 - 30
9	>30

The slope length parameter referred to the distance from crest line to the drainage channel and was rated:

Subrating	Slope length (m)
1	⩽50
2	51 - 100
3	101 - 200
4	201 - 300
5	>300

The subratings for erosivity, erodibility, slope gradient and slope length were multiplied together to give a product score which was then rated from 1 to 5 as follows

Rating	Erosion susceptibility	Subrating product
1	very low	0 - 50
2	low	50 - 100
3	moderate	100 - 150
4	high	150 - 200
5	very high	>200

4.3.3 Evaluation and mapping of the erosion factors by the Kenya Soil Survey rating method (Braun and van de Weg, 1977)

4.3.3.1 Climate evaluation

Climate is rated on the basis of ecological zones which are defined as average annual rainfall 'r' over average annual potential evaporation 'Eo' as a ratio. The climate was rated at 1 for the Kizurini area.

Subrating	Eco-zone
0	I and II (r/Eo >63%)
1	III (" 48 - 63%)
2	IV and V (" 18 - 48%)

4.3.3.2 Topography evaluation

The slope gradients used in the evaluation were the modal slope gradients for the whole slope length. The slopes were not divided into slope segments as in the quantitative method. Rating of the slope gradients is as follows:

Subrating	Modal slope gradient (%)
1	0 - 5
3	5 - 8
5	8 - 16
7	16 - 30
9	>30

According to the KSS method, the risk of erosion increases with decrease in slope length. The slope lengths therefore were rated as:

Subrating	Slope length (m)
1	>300
2	201 - 300
3	101 - 200
4	51 - 100
5	≤50

The slope lengths refer to the distances from crest line to the drainage channel.

4.3.3.3 Erodibility evaluation

This was based on laboratory data of certain soil parameters viz. organic matter content, flocculation index, silt/clay ratio in topsoil and bulk density of the topsoil. The individual soil parameters were then rated as:

(a)

Subrating	% Carbon
1	>2%
2	1-2%
3	<1%

(b)

Subrating	Flocculation index
1	>70%
2	50-70%
3	<50%

(c)

Subrating	Silt/clay ratio
1	<0.20
2	0.20-0.40
3	>0.40

(d)

Subrating	Bulk density (gm/c.c)
1	<1.2
2	1.2-1.5
3	>1.5

The subratings for climate, slope gradient, slope length and erodibility were added up to give a total score which was then rated from 1 to 5 as follows:

Rating	Total score	Susceptibility to erosion
1	≤15	very low
2	16 - 18	low
3	19 - 21	moderate
4	22 - 24	high
5	>24	very high

4.4 Laboratory methods

4.4.1 Physical methods

These involved the bulk density determination and particle size distribution. The bulk density was determined by the oven dry ($105^{o}C$) weight of a soil core of known volume (Richards, 1954). Both hydrometer and pipette methods were used to determine the particle size distribution. For the hydrometer method, a soil sample was placed in an end-over-end shaker with added sodium hexametaphosphate and left shaking overnight. Measurement of silt plus clay (0-50μ) and clay (0-2μ) was taken at 40 seconds and 2 hours after the cessation of shaking respectively. The sand fraction was obtained by difference (Day, 1956). For the pipette method, soil samples were treated with hydrogen peroxide and left shaking overnight with a dispersing agent (sodium hexametaphosphate). A 0.05mm sieve was used to separate out the sand fraction which was further sieved into very coarse (2-1mm), coarse (1-0.50mm), medium (0.5-0.25mm), fine (0.25-0.10mm) and very fine (0.10-0.05mm) sand fractions. Determination of the silt (0.05-0.002mm) and clay <0.002mm) fractions was by the pipette method (Soil Survey Staff, 1951).

4.4.2 Chemical analysis

Soil pH and electrical conductivity were determined in a 1:2.5 soil-water and 1:2.5 soil-NKCl suspensions (Hinga et.al., 1980). The % carbon was determined by Walkley and Black method (Black, 1965). The % nitrogen was carried out for the A-horizons only (Black, 1965). The cation exchange capacity (CEC) was determined by subsequent leachings of the soil with 1N ammonium acetate of pH 7.0, 95% ethyl alcohol and 1N-sodium acetate of pH 8.2. The determination of sodium, potassium and calcium was accomplished by flame photometry and magnesium on the Atomic Absorption Spectrophotometer. The sum of the cations Ca, Mg, K and Na multiplied by 100 and divided by the CEC gave the percent base saturation. The amount of sodium (in m.e) multiplied by 100 divided by CEC gave the exchangeable sodium percent (Mehlich, 1962; Hinga et.al., 1980).

4.5 Cartographic methods

The contour and drainage patterns shown on the 1:50,000 scale topographical map sheet covering the area (Mazeras sheet 198/3) were redrawn at 1:6,250 scale to provide a base on which to copy the information contained on the aerial photographs. The soil erodibility maps, slope category maps and slope length maps were then fair-drawn at a scale of 1:10,000.

CHAPTER 5: RESULTS AND DISCUSSIONS

5.1 General properties of the soils

The distribution of the soils in the survey area is shown in the soil map (Fig. 3). Although surface soil properties such as texture, depth of A horizon, stoniness, etc. were examined so that the soils could be mapped at the type or phase level, the soils appeared to be remarkably uniform in their topsoil as well as subsoil characteristics. Therefore the soils could have been classified at a low category level compatible with the detailed scale of mapping, but because of the lack of lower categories in the FAO/Unesco System (1974), most of the soils are only classified at the subgroup level. Where classification for some of the soils was possible according to the 'Kenya Concept' (Siderius and van der Pouw, 1980), the derived third level terminology ("unit") is shown within brackets in the text. However, the third level terminologies are still awaiting international agreement on nomenclature for intergrading soil units. The soils identified were chromic Luvisols, plinthic Luvisols, gleyic Luvisols (rimic+-gleyic Luvisols), cambic Arenosols, luvic Arenosols, Lithosols (stony phase), and eutric Fluvisols (rimic-eutric Fluvisols).

+ rimic = fissure, crack. Derived from the Latin word rima.

eutric FLUVISOLS (rimic-eutric Fluvisols)

These are shown on the soil map by the mapping unit Je-A/V. The soils are poorly drained, very deep, light yellowish brown to greyish brown, mottled, friable sandy loams, showing fine stratifications of sand.

Description and range of soil characteristics:

The soils vary in depth, from shallow to very deep, very poorly to imperfectly drained. The colour of the topsoil is light yellowish brown (10YR 6/4, moist) while that of the subsoil varies from very pale brown (10YR 3/4, moist) to greyish brown (10YR 5/2, moist). Consistence for both the topsoil and subsoil varies from friable to firm when moist and slightly sticky to slightly plastic when wet. The surface texture varies from sandy loam to sandy clay loam. The bulk density for the topsoil varies from 1.34 to 1.50 gm/cc. The topsoil structure is porous massive to weak, fine subangular blocky. The soils are relatively highly erodible due to low % clay, low organic matter content and high bulk density. The soils have a tendency to form surface crusts (5mm thick) while surface cracking (8-10mm in width and 16cm in depth) and sand overwash are common. The pH ranges from 5.5 in the topsoil to 7.0 in the subsoil. The CEC is low to moderate (7-12 me/100g) in both the topsoil and subsoil. The base saturation is high, about 85% in the topsoil and subsoil. The organic matter content is less than 1.5% and this decreases irregularly with depth. A representative profile is described in Appendix 1.

Environmental characteristics:

The eutric Fluvisols (rimic-eutric Fluvisols) occurred entirely within the 0-1^{o} slope category in valley bottoms. The slopes were mainly concave in shape and evidence of erosion was by sand over-wash (deposition). Landuse of the minor river valleys consisted mainly of rice and in places coconut palm trees.

<u>LITHOSOLS</u>

These are shown on the soil map by the mapping unit I-E/U. The soils are well drained, shallow, strong brown, friable sandy clays with rock outcrops.

Description and range of soil characteristics:

The soils are shallow, with pockets of moderately deep to deep soils. The colour of the topsoil is strong brown and in other places yellowish brown (7.5YR 5/6 and 10YR 5/4 respectively , when moist). Consistence is friable to firm when moist and slightly sticky to sticky and slightly plastic when wet. The surface texture varies from sandy loam to sandy clay. The topsoil bulk density varies from 1.30 to 1.46

g/c.c. The structure is weak to moderate, fine to medium subangular blocky. The soils are highly erodible due to low % clay, low % organic matter and the tendency to form surface crusting which is 5mm-8mm thick. The pH ranges from 5.8 to 6.2. The organic matter content is very low (<0.9%).

Environmental characteristics:

The Lithosols were largely found in the uplands, mainly within the 8-11^{o} slope category. The slopes were entirely convex and were less than 100m in length. Exposed tree roots and gully erosion signs (Plate 1) were common erosion features. At the time of the survey, most of the area under Lithosols was left uncultivated and was characterized by outcrops of rocks (Mariakani Sandstones).

<u>luvic ARENOSOLS</u>

These are shown on the map by the mapping units Ql-A/U, Ql-B/U, Ql-C/U, and Ql-D/U. The soils are somewhat excessively drained, very deep, yellowish brown, friable loamy sands.

Description and range of soil characteristics:

The soils are well to somewhat excessively drained. The depth of the soil to the parent material is over 200cm. The texture of the topsoil is sandy loam while the subsoil has a loamy sand though in places a sandy clay loam texture. The topsoil colour is very dark greyish brown (10YR 3/2, moist) while that of the subsoil is yellowish brown (10YR 5/6, moist). The topsoil and subsoil are both friable when moist, non sticky to slightly sticky and non plastic when wet. The bulk density for the topsoil varies from 1.30 to 1.45 g/c.c. The topsoil structure is porous massive to weak, fine to medium subangular blocky. Like the Lithosols, these soils are highly erodible due to low organic matter content, low % clay and their tendency to form surface crusting. The pH ranges from 6.5 in the topsoil to 6.1 in the subsoil. The CEC is very low to low (<5 me/100g) in both the topsoil and subsoil and the base saturation is high (>75%) both in the topsoil and subsoil. The organic matter content is less than 1.8%. For detailed description of a representative soil profile and analytical data, see Appendix 2.

Environmental characteristics;

The luvic Arenosols wholly occur in the uplands within the slopes ranging from $0-8^{o}$. The slopes occurring on the crest lines are flat to very gently undulating ($0-3^{o}$) and are convex to linear in shape and generally less than 80m in length. The mapping units are characterized by coconut palm trees, maize, simsim and cassava cultivations.

cambic ARENOSOLS

These are shown on the soil map by the mapping unit Qc-C/U. The soils are well drained, moderately deep, yellowish brown, friable sandy loams.

Description and range of soil characteristics:

The soils are well drained to somewhat excessively drained, moderately deep. The texture of the topsoil is sandy loam to loamy sand while the subsoil has a sandy loam texture. Topsoil colour is dark brown (10YR 3/3, moist) while that of the subsoil is yellowish brown (10YR 5/4, moist). Both topsoil and subsoil are friable when moist and non sticky and non plastic when wet. The topsoil structure is porous massive to weak, fine subangular blocky. The bulk density for the topsoil varies from 1.25 to 1.40 gm/c.c. The soils are relatively highly erodible, and have tendency of forming surface crusting. The pH ranges from 6.0 in the topsoil to 5.5 in the subsoil. The CEC is low (4-7 me/100g) in both the topsoil and subsoil while base saturation varies from 50% to 80%. The organic matter content is less than 1.5% for both topsoil and subsoil. A representative profile and analytical data are given in Appendix 3.

Environmental characteristics:

The mapping unit occurs in the uplands within the 3.1-5^{o} slope class. The slopes are slightly concave in shape and 50-100m in length. At the time of the survey, most of the area was cultivated with cassava, a few bananas and simsim.

chromic LUVISOLS

These are represented by mapping units Lc-A/U, Lc-B/U, Lc-C/U, Lc-D/U and Lc-E/U. The soils are well drained, very deep, reddish brown, friable sandy clay loams.

Description and range of soil characteristics:

The soils are well drained. The depth of the soil to the parent material is in general over 200cm. Moderately deep to deep soils only occur in the 8-11^{o} slope phase. The texture of the topsoil is sandy clay loam to sandy loam while the subsoil is sandy clay. The colour of the topsoil is brown to dark brown (10YR 4/3, moist) while the subsoil is yellowish red (5YR 4/6, moist). Both the subsoil and topsoil are friable when moist and slightly sticky and slightly plastic when wet. The bulk density for the topsoil varies from 1.25 to 1.50 gm/c.c. while the structure is porous massive to weak and moderate, fine to medium subangular blocky. The soils are highly erodible due to the low organic matter content, low % clay and tendency to form surface crusting. The pH ranges from 6.9 in the topsoil to 5.5 in the subsoil. The CEC is low (4.0-7.0 me/100g) for both topsoil and subsoil while the base saturation is above 60% in the topsoil and subsoil. The organic matter content is below 1.5%. For a detailed description of a representative soil profile and analytical data, see Appendix 4.

Environmental characteristics:

The chromic Luvisols occur in the uplands within the slopes ranging from 0-11^{o}. Where the slopes are 0-1^{o}, the slope shape is linear and generally with lengths ranging from 0-80m. The slopes having gradients above 3^{o} are convex in shape and the length varies from 50 to >300m. Lack of ground cover and exposed tree roots are evidences of sheet and gully erosion occurring in the steeper areas of 8-11^{o}. The crops grown were mainly cashew nuts, maize and a few coconut palms.

plinthic LUVISOLS

These are shown on the map by the mapping unit Lp-B/U. The soils are moderately drained, deep, yellowish brown, mottled, firm clay loams.

Description and range of soil characteristics:

The soils are moderately drained. The depth of the soils to the parent material is generally over 90cm. The texture of the topsoil is clay loam while that of the subsoil is clay. Colour of the topsoil is very dark greyish brown (10YR 3/2, moist) and that of the subsoil is yellowish brown (10YR 5/6, moist). The topsoil is friable to firm when moist while the subsoil is firm. The bulk density of the topsoil varies from 1.20 to 1.35 gm/c.c. The topsoil structure is weak to moderate, medium, subangular blocky. The relative erodibility is high and surface crusting is 8-11mm thick while surface cracking (<5mm in width and 4cm in depth) is common. Soil pH ranges from 5.5 in the topsoil to 6.0 in the subsoil. The CEC ranges from 12 to 16 me/100g while the base saturation ranges from 50% to 70%. The organic matter is less than 1.60%. A description of a representative profile and analytical data is given in Appendix 5.

Environmental characteristics:

Soils of the mapping unit Lp-B/U are confined to the 1-3^{o} slope category. The slopes are linear to slightly convex and are in general over 150m in length. Unlike the other units, the unit lacked coconut palm trees and was wholly cultivated with maize.

<u>plinthic LUVISOLS - greyic LUVISOLS (rimic-greyic LUVISOLS)</u>

Mapping unit Lp-Lg-A/B represents a complex of plinthic Luvisols and greyic Luvisols (rimic-greyic Luvisols).

- plinthic Luvisols: The soils are imperfectly drained, deep, yellowish brown, mottled, firm, clay loams.

Description and range of soil characteristics;

The range of soil characteristics is similar to that of the plinthic Luvisols i.e. mapping unit Lp-B/U described above (page 113) except for the depth which is over 120cm.

Environmental characteristics:

These soils occur in the bottomlands. The slopes are flat (0-1^{o}) and linear in shape and are 50-100m in length. A lot of sand overwash was evident due to deposition. At the time of the survey, the unit was largely under rice cultivation.

- greyic Luvisols (rimic-greyic Luvisols): The soils are poorly drained, deep, grey, mottled, firm sandy clay loams.

Description and range of soil characteristics:

The soils are deep, very poorly drained. The texture of the topsoil is sandy loam to sandy clay loam while that of the subsoil is loamy sand but in places sandy clay to clay. The colour of the topsoil and subsoil ranges from dark greyish brown (10YR 4/2, moist) to light brownish grey (10YR 6/2, moist) to grey (10YR 5/1, moist). Consistence of both topsoil and subsoil ranges from friable to firm when moist. The bulk density of the topsoil varies from 1.23 to 1.38 gm/c.c. The topsoil structure is weak, medium subangular blocky. Surface crusting is 7-9mm thick while surface cracking (12mm wide and 18 to 26cm deep) is common. The pH ranges from 5.3 in the topsoil to 5.8 in the subsoil. The CEC is 12-15 me/100g in both topsoil and subsoil. The base saturation varies from 40 to 75%. The organic matter content is less than 1.5%. A detailed description of a representative profile and analytical data is given in Appendix 6.

Environmental characteristics:

The soils occur in a bottomland. The slopes are linear, very flat (0-1^{o}) and are 50-100m in length. At the time of survey, the complex unit was under rice cultivation.

5.2 Soil erosion susceptibility

5.2.1 Erosion susceptibility by the quantitative parametric approach

The slope gradient map (Fig. 4) was combined with the soil map to produce a +slope gradient - soil map (Fig. 3). The LS factors were then evaluated for each soil/slope segment unit in a series of "traverses", selected to cover the whole of the area,

+ Initially the slope classes had been used to identify the mapping units. See also page 94.

from ridge tops to valley bottoms at right angles to the contour lines. The LS, k and R factors were evaluated by methods given in section 4.3.1 and were multiplied together to obtain the erosion susceptibility values. These values were then assigned to five erosion susceptibility classes as shown in Fig. 6. It is assumed that this quantitative parametric method gives the best index of erosion susceptibility since it is a much more detailed method that considers the erosion susceptibility of each slope segment and by this way, takes account of slope position. The R factor used seems to be the best index of erosivity presently available for this area. The k factors, though probably unrealistic in absolute terms are probably reasonably valid in relative terms. The LS factors are presumably valid, as there is no reason to believe the LS relationship established in one country, i.e. USA, should be different in another country (Foster et.al., 1979), since the LS merely reflects the influence of slope and relief on the detaching and transporting capacity of overland flow and splash which is basically determined by energy-force relationships.

When comparing the soil and slope maps with the quantitative erosion susceptibility map, it can be seen that most of the least susceptible areas are associated with the luvic Arenosols and the plinthic from ridge tops to valley bottoms at right angles to the contour lines. The LS, k and R factors were evaluated by methods given in section 4.3.1 and were multiplied together to obtain the erosion susceptibility values. These values were then assigned to five erosion susceptibility classes as shown in Fig. 6. It is assumed that this quantitative parametric method gives the best index of erosion susceptibility since it is a much more detailed method that considers the erosion susceptibility of each slope segment and by this way, takes account of slope position. The R factor used seems to be the best index of erosivity presently available for this area. The k factors, though probably unrealistic in absolute terms are probably reasonably valid in relative terms. The LS factors are presumably valid, as there is no reason to believe the LS relationship established in one country, i.e. USA, should be different in another country (Foster et.al., 1979), since the LS merely reflects the influence of slope and relief on the detaching and transporting capacity of overland flow and splash which is basically determined by energy-force relationships.

When comparing the soil and slope maps with the quantitative erosion susceptibility map, it can be seen that most of the least susceptible areas are associated with the luvic Arenosols and the plinthic

Luvisols in the most gently sloping areas, generally less than 3°. On the other hand, most of the areas with a very high erosion susceptibility are associated with chromic Luvisols and chromic Luvisols with pockets of Lithosols which occur on slopes ranging from 3° to 11°. In some areas, where the chromic Luvisols were associated with slopes of 3-5°, the erosion susceptibility was moderate to high. Thus slope gradient appears to have an important influence on the erosion susceptibility as would be expected. Bergsma (1973) found slope steepness to be the dominant cause of soil erosion hazard in the area in which he worked.

The quantitative erosion susceptibility map also reflects the importance of slope position as shown in Fig. 6 i.e. there is a trend of increasing erosion susceptibility from crest line to drainage channel. The vast majority of the slopes in this area, with the exception of the concave slopes associated with the cambic Arenosols and the luvic Arenosols in the north east, are uniform or, more commonly, convex in shape. Thus it is the slope segments occupying the lowest position in convex sloping areas and hence with the steepest slopes, often 5-11°, which were generally most susceptible to erosion. The other factor giving high erosion susceptibility values was the long slope length often in excess of 300m, which encouraged the accumulation of increasing volumes of runoff in a downslope direction.

Field observations supported in general the erosion susceptibility rating map produced by this method. Thus on the steep lower convex slope positions, there were frequent signs of tree root exposures and gully erosion (see also chromic Luvisols description page . Stout (1965), Morgan (1978) and Bergsma (1973) have also observed that on uniform or convex slopes, more soil is lost from the lower lying slope segments than from the upper lying segments, while Foster and Wischmeier (1974) have shown that soil loss increases logarithmically with both increasing slope gradient and slope length.

Although this method is presumed to have given a reasonably detailed and accurate indication of the relative erosion susceptibility of the area, the method is tedious and time consuming. It does however, pin-point the critical or most erosion sensitive areas viz. the valley sides with steep slopes at the foot of long convex or uniform slopes. Thus great attention should be paid to these areas when advising farmers on the need for conservation measures. Alternatively, or preferably, these areas should be left in pasture, bush or woodland.

5.2.2 Erosion susceptibility by the devised qualitative rating method

The slope length map (Fig. 5) was superimposed on the slope gradient-soil map (Fig. 3) and the ratings were then determined for the whole slope lengths or for slope segments that were occupied by different soil units. The subratings for erosivity, relative erodibility, slope gradient and slope length (as evaluated by methods given in section 4.3.2) were multiplied together to give a product score which was then rated from 1 to 5 to identify areas of very low (<50), low (50-100), moderate (100-150), high 150-200) and very high (>200) erosion susceptibility. The erosion susceptibility map by this method is given in Fig. 7.

The erosion susceptibility map (Fig. 7) shows that, susceptibility to erosion generally increased from crest line down-slope and in some places then decreased before the drainage channel is reached even though the slope gradient was greater in the lower-slope positions. This suggests that either deposition was occurring on the valley side slopes (where signs of rill and gully erosion were observed - see Plate 1) or that the lower slope segments were not influenced by overland flow from the upper segments. The distribution of erosion susceptibility ratings especially in the south-west part of the area is rather contradictory to field observations since the chromic Luvisols with pockets of Lithosols showed evidence of soil erosion (see description of chromic Luvisols and Lithosols in section 5.1) whereas these signs were not visible on the chromic Luvisols occurring upslope. Nevertheless, in many areas the classification of the modal slopes by the qualitative rating method coincided fairly well with the quantitative parametric method. This is mainly in the north-eastern part of the map having slopes 5 to 8^{o} and along the crest lines. The extent to which the devised qualitative rating of erosion susceptibility distribution (Fig. 7) coincided with that given by the quantitative parametric method (Fig. 6) was examined by superimposing the two maps together (Fig. 7 and Fig. 6). This showed a reasonably good degree of coincidence where 55% of the total area of Fig. 7 coincided with the erosion susceptibility distribution of Fig. 6. The coincidence was particularly good for areas of very high and very low erosion susceptibility but moderately poorer for intermediate erosion susceptibility classes.

The main deficiencies in this approach appear to be the inability of this method to indicate the existence of, albeit relatively short, but highly erosion susceptible lower-slope sites. Perhaps this could be overcome to some extent by including slope shape and slope position as additional parameters within the rating method. Thus landscape with pronounced convex slopes would be expected, other factors being constant, to be characterized by relatively higher erosion susceptible lower slope positions, compared to the upper slopes. Moreover these differences would be further accentuated in a topography with very long slopes.

5.2.3 Erosion susceptibility by the Kenya Soil Survey qualitative rating method

As for the devised qualitative method, the slope length map was superimposed on the slope gradient- soil map and ratings were determined for the whole slope length or for slope lengths occupied by a single soil type. The subratings for climate, erodibility, slope gradient and slope length (evaluated by the methods given in section 4.3.3) were added up to give a total score which was then rated from 1 to 5 to identify areas of very low, low, moderate, high and very high erosion susceptibility as is shown in Fig. 8.

The erosion susceptibility map (Fig. 8) showed that, susceptibility to erosion generally increased from crest lines down slope to the drainage channel. This result was unexpected, since the KSS method does not take slope positions into account, and probably reflects the fact that the lower slopes were generally short and steep, and both short and steep slopes are given a high rating in the KSS method, hence a high erosion susceptibility rating. However, the KSS rating method underestimated the erosion susceptibility class of the lower slope positions. Unlike the quantitative and the devised qualitative methods, the KSS qualitative method failed to show the low erosion susceptibility in the cambic Arenosols which are associated with concave slopes. Furthermore, the distribution of erosion susceptibility ratings by this method in the north west part of the area covered by plinthic Luvisols shows the susceptibility to erosion is higher on the crest line and decreases downslope, even though the slope gradient is increasing with slope length.

Whereas the quantitative parametric map shows an appreciable part of the area to be very highly susceptible to erosion, only a very small area is indicated as very highly susceptible to erosion by the KSS method. The deficiencies in this approach appear to be the inability of this method to account for slope position and the influence of long slopes on erosion susceptibility. Areas having the longest slopes (>300m) are classified as possessing low erosion susceptibility by the KSS method whereas the quantitative and the devised qualitative methods have shown these areas to be very highly susceptible to erosion. This can be attributed to the incorrect

rating of slope length in the KSS method as discussed previously (section 4.3.3.2).

In many areas, the classification of the modal slopes by the KSS qualitative rating method coincided rather poorly with the quantitative parametric method. The extent to which the KSS qualitative rating method of erosion susceptibility distribution (Fig. 8) coincided with that given by the quantitative parametric method (Fig. 6) was examined by superimposing the two maps together (Fig. 8 and Fig. 6). This showed a poorer coincidence where only 17% of the total area of Fig. 8 coincided with the erosion susceptibility distribution of Fig. 6. The coincidence was poor for all erosion susceptibility classes.

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In many areas, the classification of the modal slopes by the KSS qualitative rating method coincided rather poorly with the quantitative parametric method. The extent to which the KSS qualitative rating method of erosion susceptibility distribution (Fig. 8) coincided with that given by the quantitative parametric method (Fig. 6) was examined by superimposing the two maps together (Fig. 8 and Fig. 6). This showed a poorer coincidence where only 17% of the total area of Fig. 8 coincided with the erosion susceptibility distribution of Fig. 6. The coincidence was poor for all erosion susceptibility classes.

Plate 1: Exposed tree roots and gully erosion signs are common erosion features in areas under the 8.1-11^{o} slope category.

Fig. 3 DETAILED SOIL MAP OF THE KIZURINI AREA (MAP SHEET 198/3)

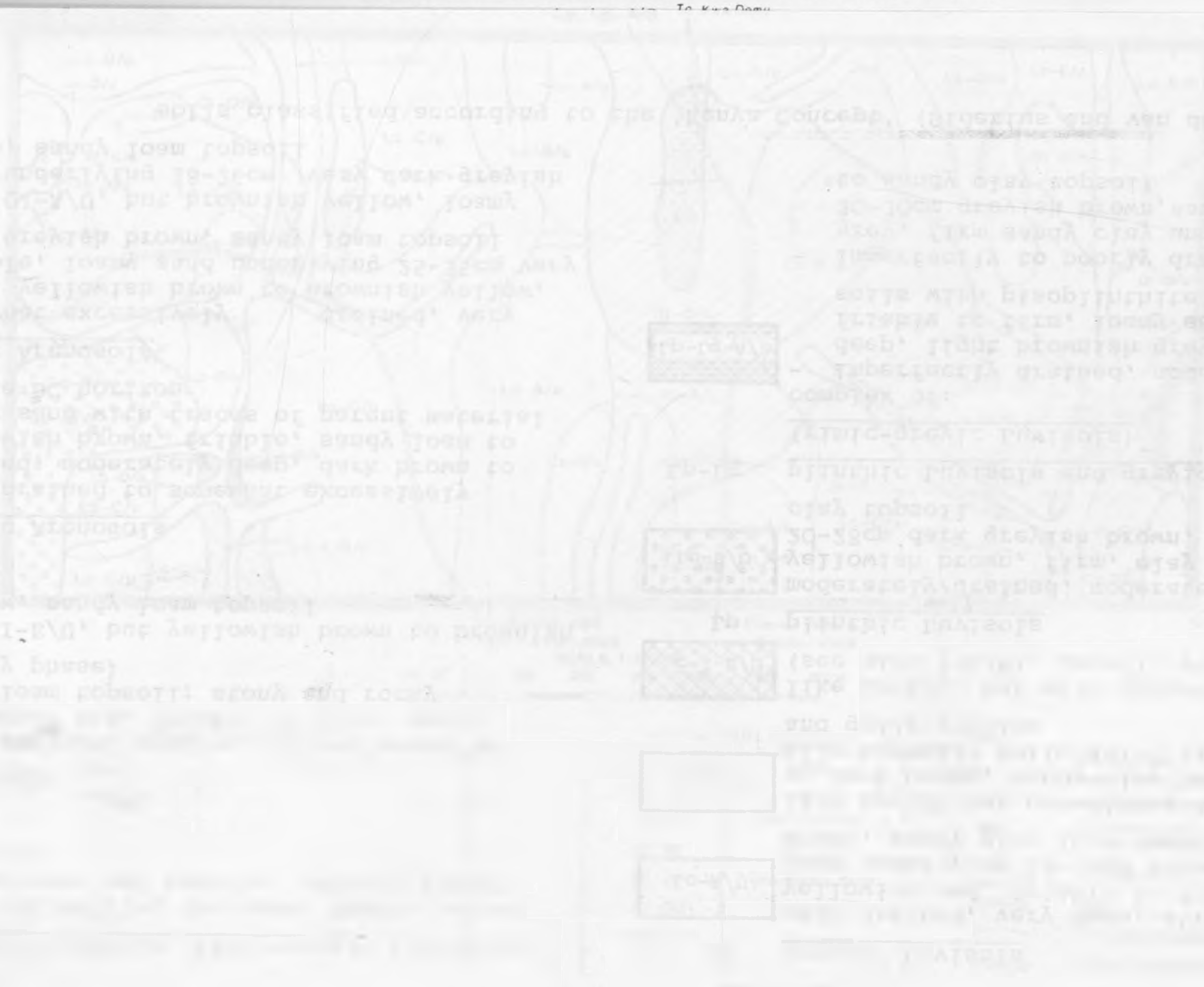

Fig. 3 DETAILED SOIL MAP OF THE KIZURINI AREA (MAP SHEET 198/3)

slope	slope class symbol
0–1°	A
1.1–3°	B
3.1–5°	C
5.1–8°	D
8.1–11°	E

SOIL MAP LEGEND

J FLUVISOLS

Je eutric Fluvisols (rimic-eutric Fluvisols)+

Je-A/V — soils of varying drainage, depth, colour consistence and texture; showing stratification

I LITHOSOLS

I Lithosols

I-E/U — well drained, shallow, strong brown to yellowish red, friable to firm, sandy clay loam topsoil; stony and rocky (stony phase)

I-C/U — like I-E/U, but yellowish brown to brownish yellow, sandy loam topsoil

Q ARENOSOLS

Qc cambic Arenosols

Qc-C/U — well drained to somewhat excessively drained, moderately deep, dark brown to yellowish brown, friable, sandy loam to loamy sand with traces of parent material in the BC horizon

Ql luvic Arenosols

Ql-A/U — somewhat excessively drained, very deep, yellowish brown to brownish yellow, friable, loamy sand underlying 25-35cm very dark greyish brown, sandy loam topsoil

Ql-D/U — like Ql-A/U, but brownish yellow, loamy sand underlying 18-26cm very dark greyish brown, sandy loam topsoil

+ soils classified according to

thickness in cm	name
0-25	very shallow
25-50	shallow
50-80	moderately deep
80-120	deep
more than 120	very deep

Lc-A/u	soil mapping slope class symbol physiography symbol
● S	profile pit number as described in the appendices
	soil boundary
	road
	soil slope boundary
	survey area boundary

L LUVISOLS

Lc chromic Luvisols

Lc-A/U — well drained, very deep, strong brown to yellowish red, friable to firm, sandy clay loam underlying 14-20cm brown to dark brown, sandy clay loam topsoil

Lc-E/U — like Lc-A/U but underlying 10-15cm brown to dark brown, sandy clay loam to sandy clay topsoil; soils having signs of sheet and gully erosion

Lc-I-E/U — like Lc-E/U, but with pockets of Lithosols (see also I-E/U), locally stony

Lp plinthic Luvisols

Lp-B/U — moderately well drained, moderately deep to deep, yellowish brown, firm, clay underlying 20-28cm dark greyish brown, sandy clay to clay topsoil

Lp-Lg plinthic Luvisols and greyic Luvisols (rimic-greyic Luvisols)+

Lp-Lg-A/B — complex of:

- imperfectly drained, moderately deep to deep, light brownish grey to pale brown, friable to firm, loamy sand topsoil; soils with pisoplinthite within 125cm
- imperfectly to poorly drained, deep, grey, firm sandy clay underlying 20-30cm greyish brown, sandy clay loam to sandy clay topsoil

+ the 'Kenya Concept' (Siderius and van der Pouw, 1980)

Plate 1: Exposed tree roots and gully erosion signs are common erosion features in areas under the 8.1-11^{o} slope category.

rating of slope length in the KSS method as discussed previously (section 4.3.3.2).

In many areas, the classification of the modal slopes by the KSS qualitative rating method coincided rather poorly with the quantitative parametric method. The extent to which the KSS qualitative rating method of erosion susceptibility distribution (Fig. 8) coincided with that given by the quantitative parametric method (Fig. 6) was examined by superimposing the two maps together (Fig. 8 and Fig. 6). This showed a poorer coincidence where only 17% of the total area of Fig. 8 coincided with the erosion susceptibility distribution of Fig. 6. The coincidence was poor for all erosion susceptibility classes.

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Plate 1: Exposed tree roots and gully erosion signs are common erosion features in areas under the $8.1-11^{\circ}$ slope category.

Fig. 3 DETAILED SOIL MAP OF THE KIZURINI AREA (MAP SHEET 198/3)

Fig. 4 SLOPE GRADIENT MAP OF THE KIZURINI AREA (MAP SHEET 198/3)

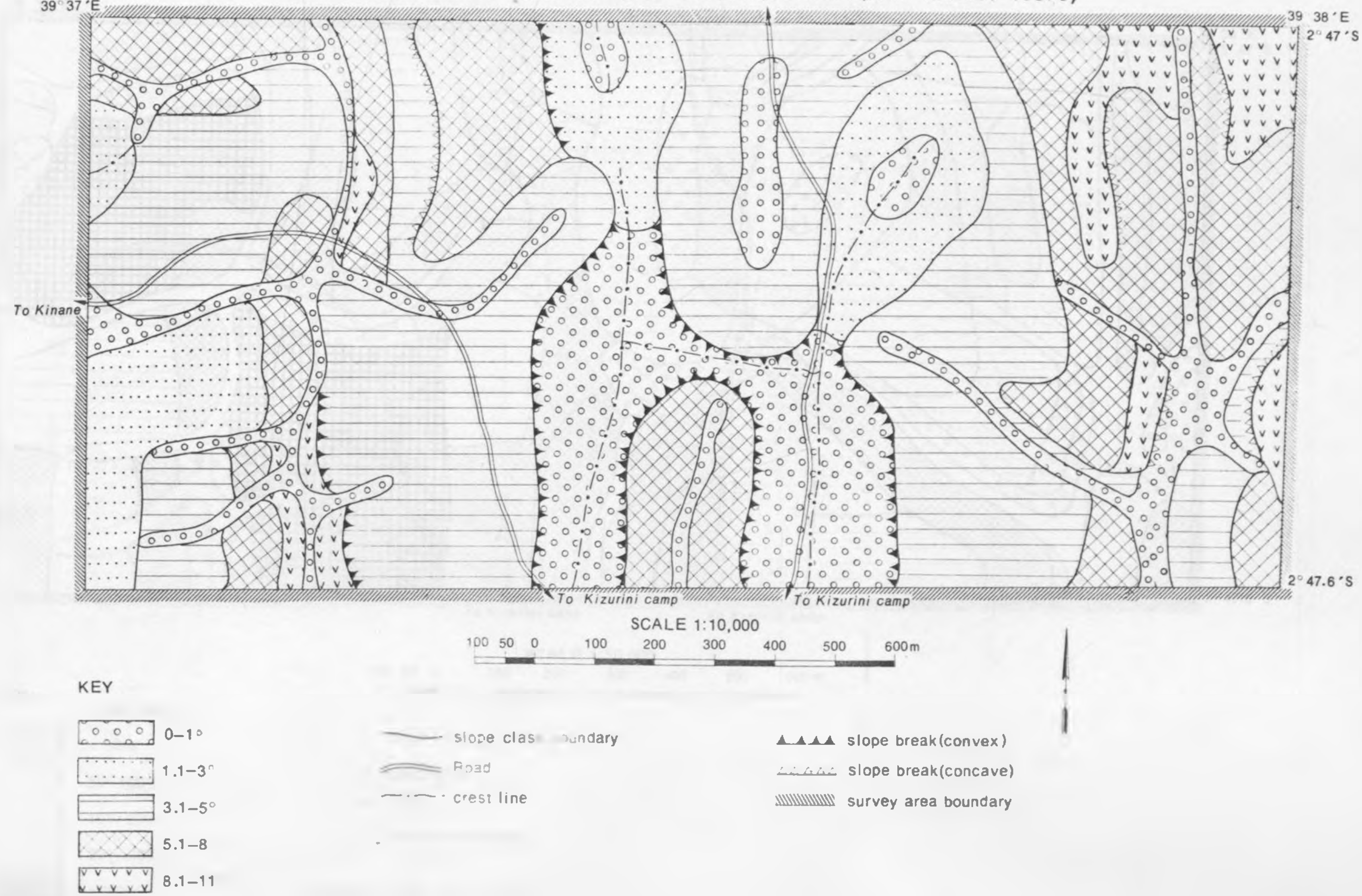
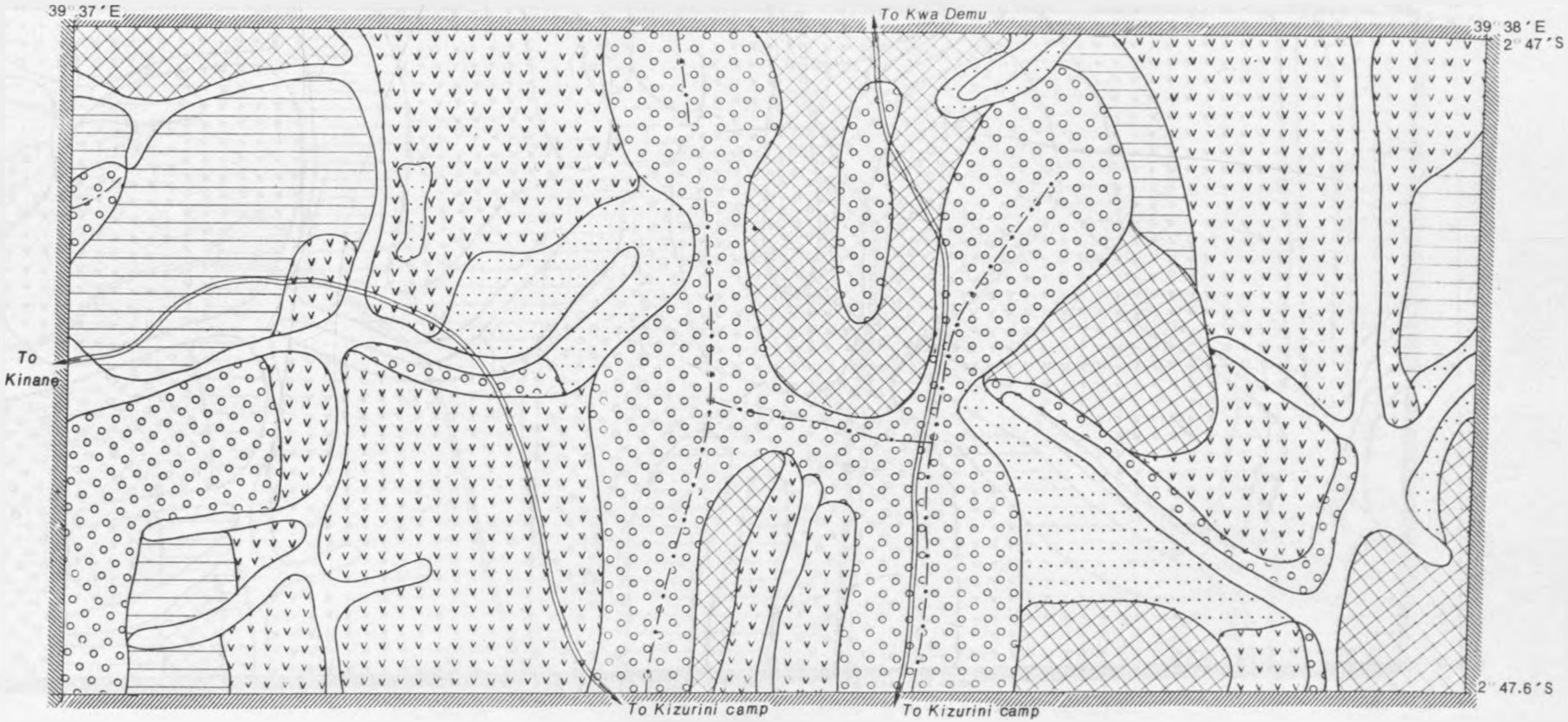


Fig. 5 SLOPE LENGTH MAP OF THE KIZURINI AREA (SHEET 198/3)

Fig. 6 SOIL EROSION SUSCEPTIBILITY MAP OF THE KIZURINI AREA (SHEET 198/3) AS EVALUATED BY THE QUANTITATIVE PARAMETRIC METHOD



SCALE 1:10,000

100 50 0 100 200 300 400 500 600 m

KEY

	Erosion Susceptibility value	Susceptibility to erosion
	0–150	very low
	150–300	low
	300–450	moderate
	450–600	high
	> 600	very high

Soil erosion Susceptibility boundaries

crest lines

Roads

Drainage channels

survey area boundary

Fig. 7 SOIL EROSION SUSCEPTIBILITY MAP OF THE KIZURINI AREA (SHEET 198/3) AS EVALUATED BY THE DEVISED QUALITATIVE RATING METHOD

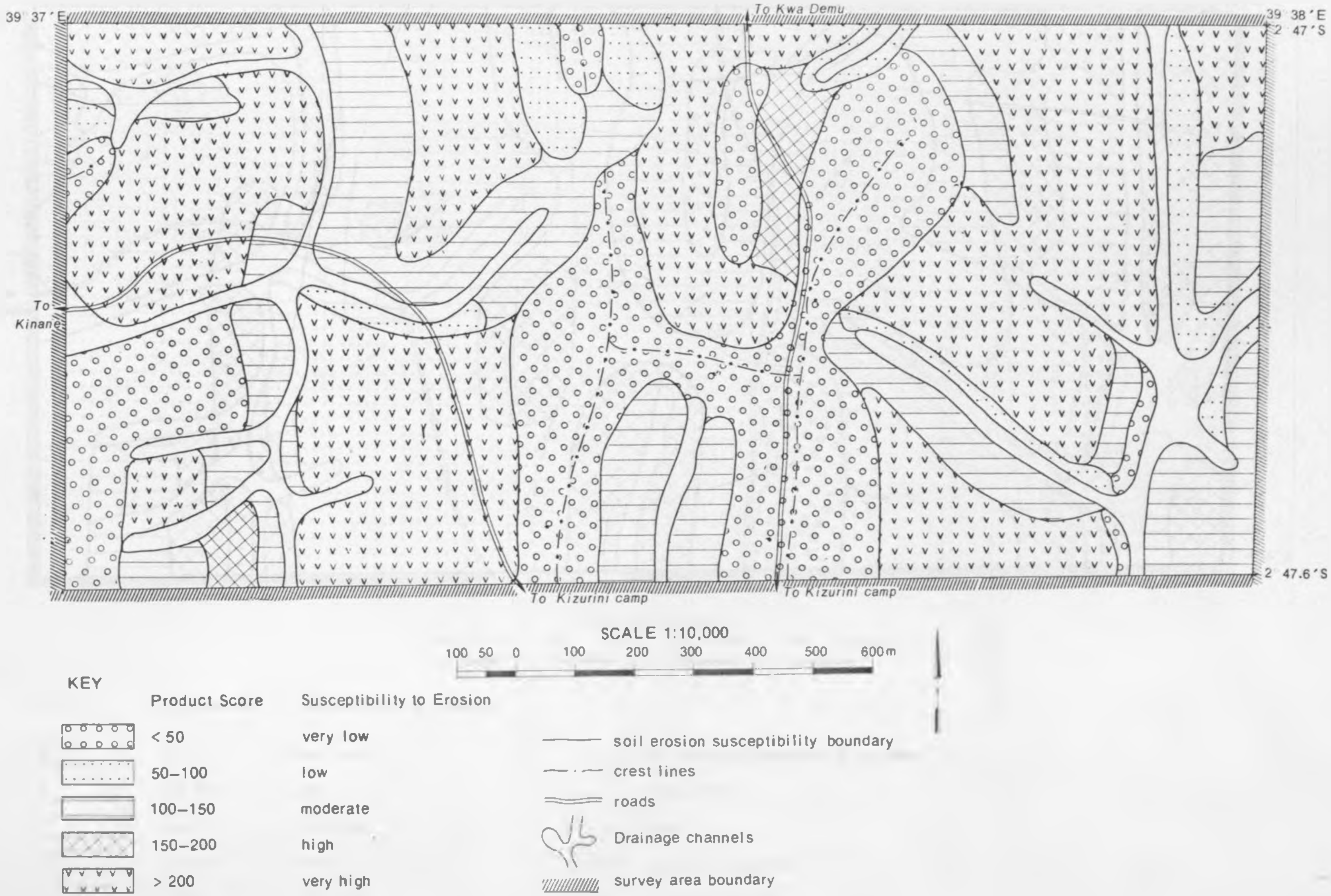
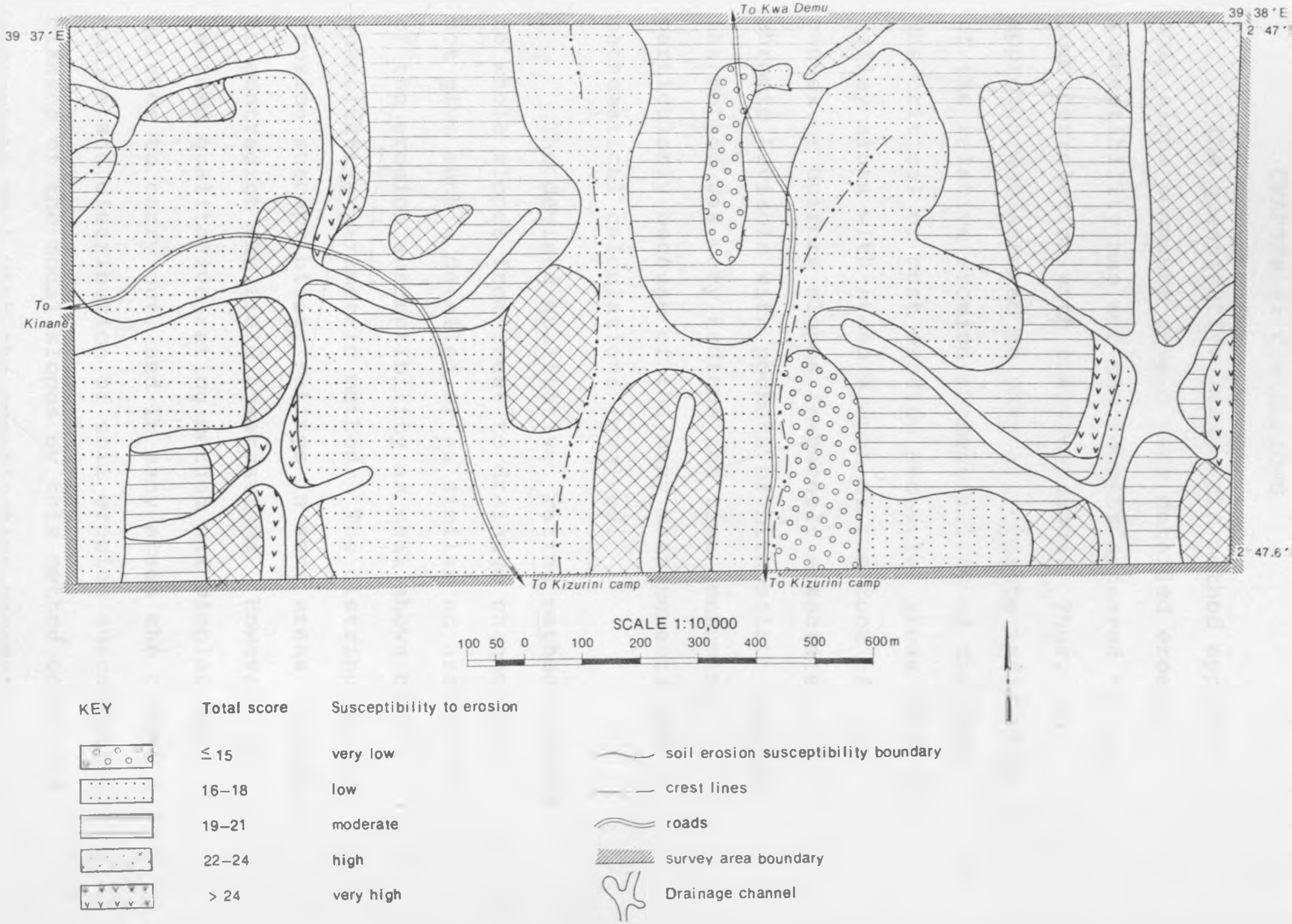


Fig.8 SOIL EROSION SUSCEPTIBILITY MAP OF THE KIZURINI AREA (MAP SHEET 198/3) AS EVALUATED BY THE KENYA SOIL SURVEY QUALITATIVE RATING METHOD



CHAPTER 6: CONCLUSIONS

The quantitative parametric method applied to soil slope segments gave a very detailed erosion susceptibility map and the results appeared to show some correlation with field evidence. Thus, this approach was assumed to give an accurate indication of the relative erosion susceptibility of the area. The critical or most erosion sensitive areas were the valley sides with steep slopes at the foot of long convex or uniform slopes frequently associated with chromic Luvisols with pockets of Lithosols. However, the method was very tedious and time consuming, particularly because of the many measurements and mathematical calculations involved.

The devised qualitative rating method applied to whole slopes from crest to drainage channel did not give such a detailed or as similar an assessment of the erosion susceptibility as that shown by the quantitative parametric method. The distribution of erosion susceptibility ratings in some areas appeared to contradict the field observations. However, the devised qualitative rating method was simpler and quicker to carry out, and in many areas the classification and distribution of soil erosion susceptibility classes of the modal slopes by this method coincided moderately well with the quantitative parametric method.

The Kenya Soil Survey qualitative rating method gave a less detailed assessment of erosion susceptibility and the distribution of the erosion susceptibility classes coincided poorly with those given by the quantitative parametric approach. In particular the KSS method underestimated the erosion susceptibility of those areas with long slope lengths. Thus, of the two simpler qualitative rating methods, the devised qualitative method was found to be superior to the KSS method.

The detailed quantitative method showed the importance of slope shape and particularly slope position on erosion susceptibility, suggesting that these two parameters should also be included in the simpler rating methods when mapping and evaluating erosion susceptibility. The study also supports the practice of giving slope gradient a higher weighting than the other parameters in erosion susceptibility rating methods.

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Appendix 1. Soil profile description of mapping unit Je-A/V

Site Observation No. 198/3-W

Soil classification	:	eutric Fluvisols (rimic-eutric Fluvisols)
Physiography	:	river valley
Relief, macro	:	very gently undulating
Slope gradient	:	0-2°
Landuse	:	rice, coconut palm trees
Surface stoniness	:	nil
Erosion	:	nil
Surface crusting	:	weak (<5mm)
Surface cracking	:	<10mm, wide; 12-16cm, deep
Drainage class	:	poorly to imperfectly drained

Ap	0-10cm	Light yellowish brown (10YR 6/4, moist); sandy loam; porous massive breaking to weak, fine subangular blocky structure; friable when moist, non sticky and non plastic when wet; few, fine, faint mottles; common fine and common medium pores; few fine and few medium roots; clear and smooth transition to:
Au_1	10-14cm	Very pale brown (10YR 7/4, moist); sandy loam to loamy sand; porous massive breaking to very weak, fine subangular blocky structure; friable when moist, non sticky and non plastic when wet; common, fine, faint mottles, many fine, many medium pores; clear and smooth transition to:
Bg_1	14-23cm	Greyish brown (10YR 5/2, moist); sandy loam; weak, medium subangular blocky structure; friable to firm when moist, non sticky and non plastic when wet; common, fine faint mottles; common fine, common medium pores; clear and smooth transition to:
Bg_2	23-58cm	Grey (10YR 5/1, moist) sandy loam; weak, medium subangular blocky structure; friable to firm when moist, slightly sticky and non plastic when wet; common, fine to medium, distinct mottles; common fine, common medium pores; clear and smooth transition to:
Bg_3	58-130cm	Dark grey (4N, moist); sandy clay loam to sandy clay; moderate, medium angular blocky structure; firm when moist, slightly sticky and slightly plastic when wet; common, medium, distinct mottles; few fine, few medium pores.

Analytical Data to Appendix 1 of Soil profile description of mapping unit Je-A/V, Site Observation No. 198/3-W

Horizon	Ap	Au_1	Bg_1	Bg_2	Bg_3
Depth (cm)	0-10	10-14	14-23	23-58	58-130
pH-H_2O	5.7	6.5	6.7	7.0	7.0
pH-KCl	5.6	5.9	6.0	5.9	5.8
EC (mmho/cm)	0.05	0.35	0.50	0.35	0.30
C (%)	0.69	0.26	0.41	0.18	0.20
N (%)	0.03				
C/N	23				
CEC(me/100g),pH 8.2	11	7.0	7.6	7.6	9.6
Exch. Ca(me/100g)	5.0	2.9	4.0	3.6	5.2
" Mg	2.4	1.4	2.1	2.0	2.8
" K	0.12	0.06	0.07	0.07	0.14
" Na	1.49	0.88	1.40	1.00	1.18
Sum of cations	9.01	5.24	7.57	6.67	9.32
Base sat. %, pH 8.2	81.9	74.9	99.6	87.8	97.1
ESP at pH 8.2	13.5	12.6	18.4	13.2	12.3
Texture:					
Gravel % (>2.0mm)	-	-	-	-	-
Sand% (2.0-0.05mm)	58	80	74	76	64
Silt% (0.05-0.002mm	24	10	14	12	16
Clay % (0.002-0mm)	18	10	12	12	20
Texture class	SL	SL/LS	SL	SL	SCL/SL

Topsoil:	
Bulk density (g/c.c)	1.35
Flocculation index	38
Relative erodibility k values	0.46

Appendix 2. Soil profile description of mapping unit Q1-A/U

Site Observation No. 198/2-D

Soil classification	:	luvic Arenosols
Physiography	:	uplands
Relief, macro	:	very gently undulating
Slope gradient	:	0-2^{o}
Surface stoniness	:	nil
Landuse	:	coconut palm trees, maize, simsim, cassava
Erosion	:	nil
Surface crusting	:	weak (<5mm thick)
Surface cracking	:	nil
Drainage class	:	somewhat excessively well drained

A_1	0-26cm	Brown to dark brown (10YR 4/3, moist); loamy sand; porous massive to weak, fine subangular blocky structure; friable when moist, non sticky and non plastic when wet; many fine, many medium roots; clear and smooth transition to:
AB	26-53cm	Dark yellowish brown (10YR 4/4, moist); loamy sand; porous massive to weak, medium subangular blocky structure; friable when moist, non sticky and non plastic when wet; many very fine, few fine, very few medium roots; clear and smooth transition to:
Bu_1	53-99cm	Yellowish brown (10YR 5/6, moist); sandy loam; porous massive to weak, medium subangular blocky structure; friable when moist, slightly sticky and slightly plastic when wet; many fine, many medium pores; few very fine, few fine, common medium roots; thin lamellae of clay accumulation; clear and smooth transition to:
Bu_2	99-160cm	Brownish yellow (10YR 6/8, moist); sandy loam, porous massive to weak, medium to fine subangular blocky structure; friable when moist, non sticky and non plastic when wet; many fine, many medium pores; very few fine roots; thin lamellae of clay accumulation are common.

Analytical data to Appendix 2 of Soil profile description of mapping unit Q1-A/U, Site Observation No. 198/3-D.

Horizon	A_1	AB	Bu_1	Bu_2
Depth (cm)	0-26	26-53	53-99	99-160
$pH-H_2O$	6.8	5.9	5.6	5.8
pH-KCl	5.8	4.3	4.0	4.3
EC (mmho/cm)	0.08	0.03	0.02	0.03
C (%)	0.40	0.36	0.33	0.33
N (%)	0.04			
C/N	10			
CEC(me/100g),pH 3.2	4.8	1.8	1.8	4.0
Exch. Ca(me/100g)	2.8	1.0	0.4	1.5
" Mg	1.1	0.4	0.8	1.0
" K	0.36	0.14	0.11	0.11
" Na	0.25	Trace	Trace	0.08
Sum of cations	4.51	1.54	1.31	2.69
Base sat. %, pH 8.2	94	85.6	72.8	67.25
ESP at pH 8.2	5.2	-	-	2.0
Texture:				
Gravel % (>2.0mm)	-	-	-	-
Sand% (2.0-0.05mm)	80	78	78	78
Silt% (0.05-0.002mm	14	16	16	4
Clay % (0.002-0mm)	6	6	6	18
Texture class	LS	LS	LS	SL
Topsoil:				
Bulk density (g/c.c)	1.30			
Flocculation index	34			
Relative erodibility k values	0.49			

Appendix 3. Soil profile description of mapping unit Qc-C/U

<u>Site Observation No. 198/2-R</u>

Soil classification	:	cambic Arenosols
Physiography	:	uplands
Relief, macro	:	gently undulating
Slope gradient	:	3-5^{o}
Landuse	:	cassava, bananas, simsim
Surface stoniness	:	locally stony
Erosion	:	nil
Surface crusting	:	weak (<5mm, thick)
Surface cracking	:	nil
Drainage class	:	well drained

Ap	0-30cm	Dark brown (10YR 3/3, moist); sandy loam; porous massive to weak, fine subangular blocky structure; friable when moist, non sticky and non plastic when wet; few termite channels; many fine and many medium pores; common fine and few medium roots; clear and smooth transition to:
Bu_1	30-65cm	Yellowish brown (10YR 5/4, moist); sandy loam; porous massive; friable when moist; non sticky and non plastic when wet; common fine and common medium pores; very few fine, very few medium roots; clear and wavy transition to:
BC	65-83cm	Yellowish brown (10YR 5/6, moist); sandy loam; porous massive; friable when moist, non sticky and non plastic when wet; few, hard iron and manganese nodules (5%, 5-10mm); very few medium roots, in places showing pieces of weathering rock.

Analytical Data to Appendix 3 of Soil profile description of mapping unit Qc-C/U, Site Observation No. 198/3-R.

Horizon	Ap	Bu_1	BC		
Depth (cm)	0-30	30-65	65-83		
$pH-H_2O$	6.1	5.9	6.0		
pH-KCl	5.3	4.4	4.1		
EC (mmho/cm)	0.08	0.03	0.03		
C (%)	0.60	0.20	0.23		
N (%)	0.03				
C/N	20				
CEC(me/100g),pH 8.2	6.6	4.4	4.5		
Exch. Ca(me/100g)	2.5	2.0	1.8		
" Mg	0.8	1.0	1.2		
" K	0.27	0.24	0.12		
" Na	Trace	0.15	0.25		
Sum of cations	3.57	3.39	3.37		
Base sat. %, pH 8.2	54.1	77.0	74.9		
ESP at pH 8.2	-	3.4	5.6		
Texture:					
Gravel % (>2.0mm)	-	-	-		
Sand% (2.0-0.05mm)	78	78	78		
Silt% (0.05-0.002mm)	12	10	12		
Clay % (0.002-0mm)	10	12	10		
Texture class	SL	SL	SL		

Topsoil:	
Bulk density (g/c.c)	1.29
Flocculation index	36
Relative erodibility k values	0.49

Appendix 4. Soil profile description of mapping unit Lc-A/U

Site Observation No. 198/3-S

Soil classification	:	chromic Luvisols
Physiography	:	uplands
Relief, macro	:	very gently undulating
Slope gradient	:	$0-2^{o}$
Landuse	:	cashew nuts, coconut palm trees, maize
Surface stoniness	:	nil
Erosion	:	nil
Surface crusting	:	weak (4mm, thick)
Surface cracking	:	nil
Drainage class	:	well drained

Ap	0-19cm	Brown to dark brown (10YR 4/3, moist); sandy loam; porous massive to weak, fine to medium subangular blocky structure; friable when moist, slightly sticky and non plastic when wet; many fine and many medium pores; many fine, many medium roots; many termite channels; clear and smooth transition to:
BA	19-44cm	Reddish brown (5YR 4/4, moist); sandy loam; porous massive to weak, medium subangular blocky structure, friable when moist, slightly sticky and non plastic when wet; many fine, common medium pores; common fine, common medium roots; clear and smooth transition to:
Bt_1	44-93cm	Reddish brown (2.5YR 4/4, moist); sandy clay loam; weak, medium to coarse subangular blocky structure;friable to firm when moist, slightly sticky and slightly plastic when wet; common fine, common medium pores; patchy, thin clay cutans; common medium roots along the cracks; clear and smooth transition to:
Bt_2	93-170cm	Red (2.5YR 4/6, moist); sandy clay loam; moderate, medium to coarse subangular blocky structure; friable to firm when moist, sticky and plastic when wet; common fine, few medium pores; patchy, thin clay cutans; very few medium roots.

Analytical Data to Appendix 4 of Soil profile description of mapping unit Lc-A/U, Site Observation No. 198/3-S.

Horizon	Ap	BA	Bt_1	Bt_2	
Depth (cm)	0-19	19-44	44-93	93-170	
$pH-H_2O$	6.9	6.2	5.6	5.5	
pH-KCl	5.8	4.1	4.0	4.2	
EC (mmho/cm)	0.06	0.04	0.04	0.04	
C (%)	0.68	0.26	0.29	0.23	
N (%)	0.05				
C/N	13.6				
CEC(me/100g),pH 8.2	6.4	5.6	6.4	4.2	
Exch. Ca(me/100g)	3.3	2.0	2.9	1.5	
" Mg	1.5	2.5	1.3	0.9	
" K	0.52	0.09	0.27	0.08	
" Na	0.13	0.38	0.40	0.13	
Sum of cations	5.45	4.97	4.87	2.61	
Base sat. %, pH 8.2	85.2	88.75	76.1	62.1	
ESP at pH 8.2	2.0	6.8	6.3	3.1	
Texture:					
Gravel % (>2.0mm)	-	-	-	-	
Sand% (2.0-0.05mm)	76	78	68	65	
Silt% (0.05-0.002mm	16	10	10	10	
Clay % (0.002-0mm)	8	12	22	25	
Texture class	SL	SL	SCL	SCL	

Topsoil:	
Bulk density (g/c.c)	1.27
Flocculation index	34
Relative erodibility k values	0.57

Appendix 5. Soil profile description of mapping unit Lp-B/U

<u>Site Observation No. 198/3-H</u>

Soil classification	:	plinthic Luvisols
Physiography	:	uplands
Relief, macro	:	gently undulating
Slope gradient	:	2-3^{o}
Landuse	:	maize
Surface stoniness	:	nil
Erosion	:	nil
Surface crusting	:	moderate (8mm, thick)
Surface cracking	:	<5mm, wide; 4cm deep
Drainage class	:	moderately drained

A_1	0-31cm	Very dark greyish brown (10YR 3/2, moist); clay loam; weak, medium subangular blocky structure; friable to firm when moist, sticky and plastic when wet; common fine, common medium pores; common fine, common medium roots; clear and smooth transition to:
Bt_1	31-70cm	Yellowish brown (10YR 5/6, moist); clay to clay loam; moderate, medium subangular blocky structure; firm when moist, sticky and plastic when wet; common, fine, faint mottles; common fine, few medium pores; patchy, thin clay cutans; few medium, common coarse roots; clear and smooth transition to:
Bt_2	70-115cm	Light olive brown (2.5Y 5/4, moist); clay; moderate, coarse subangular blocky structure; very firm when moist, sticky and plastic when wet; common, fine to medium, distinct mottles; few fine, few medium pores; broken, moderately thick clay cutans; few iron and manganese concretions (5%, <6mm); very few coarse roots; abrupt and wavy transition to:
Bcn	115cm+	piso-plinthite.

Analytical Data to Appendix 5 of Soil profile description of mapping unit Lp-B/U, Site Observation No. 198/3-H

Horizon	A_1	Bt_1	Bt_2		
Depth (cm)	0-31	31-70	70-115		
pH-H_2O	5.6	5.8	6.0		
pH-KCl	4.1	3.9	4.3		
EC (mmho/cm)	0.05	0.09	0.09		
C (%)	0.42	0.66	0.58		
N (%)	0.10				
C/N	4.2				
CEC(me/100g),pH 3.2	13.4	15.6	15.6		
Exch. Ca(me/100g)	2.3	2.3	3.0		
" Mg	4.2	6.0	7.3		
" K	0.19	0.21	0.30		
" Na	0.05	0.40	0.45		
Sum of cations	6.74	8.91	11.05		
Base sat. %, pH 8.2	50.3	57.1	70.8		
ESP at pH 8.2	0.4	2.6	2.9		
Texture:					
Gravel % (>2.0mm)	-	-	-		
Sand% (2.0-0.05mm)	36	32	24		
Silt% (0.05-0.002mm	34	28	28		
Clay % (0.002-0mm)	30	40	48		
Texture class	CL	C/CL	C		

Topsoil:	
Bulk density (g/c.c)	1.22
Flocculation index	41
Relative erodibility k values	0.46

Appendix 6. Soil profile description of mapping unit Lp-Lg-A/B

Site Observation No. 196/3-C

Soil classification	:	gleyic Luvisols (rimic-gleyic-Luvisols)
Physiography	:	bottomland
Relief, macro	:	flat
Slope gradient	:	$0-1^{\circ}$
Landuse	:	rice
Surface stoniness	:	nil
Erosion	:	nil
Surface crusting	:	moderate (9mm, thick)
Surface cracking	:	12mm wide, <20cm deep
Drainage class	:	poorly drained

Ap	0-33cm	Greyish brown (10YR 5/2, moist); sandy clay loam; weak, medium subangular blocky structure; friable to firm when moist; slightly sticky and slightly plastic when wet; many fine, common medium pores; few, fine, faint mottles; many very fine, common fine roots; clear and smooth transition to:
Bt_1g	33-75cm	Grey (10YR 5/1, moist); clay to clay loam; moderate, medium subangular blocky structure; firm when moist, sticky and plastic when wet; common, medium, distinct mottles; patchy, thin clay cutans; common fine, common medium, very few coarse roots; clear and smooth transition to:
Bt_2g	75-128cm	Light grey (5YR 7/1, moist); clay to clay loam; moderate, medium subangular blocky structure; very firm when moist, sticky and plastic when wet; common, medium, distinct mottles; common fine, few medium pores; patchy, thin clay cutans; very few fine roots.

Analytical Data to Appendix 6 of Soil profile description of mapping unit Lp-Lg-A/B, Site Observation No. 198/3-C.

Horizon	Ap	Bt_1g	Bt_2g		
Depth (cm)	0-33	33-75	75-128		
$pH-H_2O$	5.3	5.3	5.6		
pH-KCl	3.7	3.5	3.8		
EC (mmho/cm)	0.04	0.10	0.12		
C (%)	0.57	0.33	0.31		
N (%)	0.05				
C/N	11.4				
CEC(me/100g),pH 8.2	4.8	11.6	12.0		
Exch. Ca(me/100g)	1.4	3.3	5.2		
" Mg	1.0	1.4	3.7		
" K	0.04	0.12	0.14		
" Na	Trace	0.30	0.03		
Sum of cations	2.44	5.12	9.07		
Base sat. %, pH 8.2	50.8	44.1	75.6		
ESP at pH 8.2		2.6	0.3		
Texture:					
Gravel % (>2.0mm)	-	-	-		
Sand% (2.0-0.05mm)	76	58	58		
Silt% (0.05-0.002mm	2	12	16		
Clay % (0.002-0mm)	22	30	26		
Texture class	SCL	SCL	SCL		
Topsoil:					
Bulk density (g/c.c)	1.29				
Flocculation index	43				
Relative erodibility k values	0.42				