Empirical Evaluation and Comparative Study of Use of Erosion Modelling in Small Catchments in Naivasha, Kenya

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Empirical Evaluation and Comparative Study of Use of Erosion Modelling in Small Catchments in Naivasha, Kenya

By

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Dedicated

To My Dear Parents

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Abstract

Soil erosion is a widely recognized problem. For conservation planning, targeting high-risk areas, assessment and mapping of erosion is essential. Many methods are available to assess and map the diffused process of erosion. Erosion surveys are used to review erosion qualitatively. Assessing overall erosion can be done by using aerospace images and expert knowledge, applying a rule-based system. Because of the interaction between rainfall, soil and cultivation practices, to estimate or to classify erosion intensity is not a simple matter. Therefore use of simulation modelling could be of help. Generally for complex catchments, models alone seldom yield satisfactory results. Model suitability for different land conditions may differ according to inherent behaviour of model, parameters considered in modelling and parameter sensitivity.

In this research, potentials and limitations for erosion surveys using aerospace images and field observations are studied with three of widely used erosion models; Universal Soil Loss Equation, the Morgan model and EUROSEM, are assessed to evaluate the role of erosion modelling in erosion surveys using aerospace data. Model support, to merge quantitative approaches with qualitative criteria for assessing and mapping erosion, are discussed together with the behaviour of field input parameters in the model process. The 3 models are evaluated empirically, by comparing with field observed erosion rates and by parameter sensitivity, for their support for mapping erosion risk, using selected land units in Naivasha basin in rift valley of Kenya.

Seven sites from four locations have been selected for the model evaluation. Sites varied in aspects of slope-length, slope steepness, crop cover and surface rilling. Permeability tests demonstrated very high rates in some land units. The saturated hydraulic conductivity ranges between 0.33 cm/hr in *Kinangop* Grasslands to 24 cm/hr in the maize cultivated lands in *Longonot* area. Despite high permeability, signs of high erosion rates could be observed in many sites with strong surface sealing. But the effect of surface sealing is seldom considered in modeling. Correlation analysis showed that spatial distribution of rainstorms in the area is very low even within 2km radius. Temporal rain distribution pattern in the area showed infrequent large rain events and instantaneous high intense peaks within small rainstorms, but data scarcity in most areas limits the use of event-based models. For the areas where rainfall data is available in 24hour increments, regression equations are developed using past rainfall records for estimation of kinetic energy and rain erosivity.

According to the results of *Kinangop* (K1) site, for land units with longer slope-lengths, USLE over-estimates erosion rates and the Morgan model estimates seems to be reasonable. EUROSEM model revealed that 75% of annual erosion is from 2 rainstorms in *Kinangop*. Erosion estimates for *Ndabibi* N1 site gives very close values for both models, when slope-length is close to 90m. As evident from the estimation of erosion for *Longonot* (L) site, for land units with high moisture holding capacity or highly permeable, application of USLE is better than the Morgan model. The Morgan model gives lower estimation for *Longonot* than the minimum actual soil loss. For sites with less crop cover, the Morgan model seems to be over estimating erosion rates, but evidences not enough to confirm that.

Studying the parameter behaviour within the modelling process revealed that, 50% change in slope steepness results nearly 100% change in USLE estimated soil erosion. Sensitivity of slope change for

higher slope classes is high in USLE. Effect of slope change for the Morgan model is less for the transport capacity. For higher slopes it will limit the further increase due to detachment limitation. Detection of soil structure is important in USLE, a change in structural code results in more than 100% change in estimated erosion. Organic matter content is the most important component in USLE erodibility factor. A 50% change in organic matter content results 100% change of erodibility and predicted erosion. Other textural components have less effect on USLE soil erodibility estimation. Length of slope change will effect at a decreasing rate for USLE but has no effect in the Morgan model because this factor do not included. Cover factor is more sensitive to surface cover or mulch cover than the other sub factors for both models. But the effect of cover factor change on estimated erosion is less in the Morgan model than in USLE.

The EUROSEM Model was applied to two adjoining parts of a small catchment, one with grass cover and one with rain-fed crops. The model simulated large differences in erosion, which are in agreement with what was observed in the field.

Qualitative criteria can be used to classify land units according to their erosion status if one has local field knowledge. Land units with very low or no erosion can easily be identified using land cover and landform. Land units which exhibit high variability due to frequent change in cultivation conditions, model support is needed for further classification. Selection of a suitable model for each land unit category is critical because different types of models give varied results for the same land unit. Evaluation of models with respect to the parameter behaviour and land conditions may help for better erosion assessment.

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Symbol	Description	Unit
A	Average annual soil loss	(ton/ac)
A_s	Surface area	(mm^2)
C	Cover and management factor	
CC	Crop Canopy sub factor	
CC_e	Canopy cover fraction	
D_{50}	Median particle size of soil	(μm)
D_p	Storm duration	(hours)
D_r	Top soil rooting depth	(mm)
E	Kinetic energy of rainfall	(kJ/m^2)
EI_{30}	Erosivity index in USLE	($kJ\ m^{-2}\ mm\ h^{-1}$)
ET_0	Potential evapotranspiration	(mm/day)
ET_a	Actual evapotranspiration	(mm/day)
F	Rate of splash detachment	(kg/m^2)
G	Transport capacity	($kg/m^{2)}$
h	Water level	(mm)
H_e	Effective plant height	(m)
I	Rainfall intensity of erosive rain	(mm/h)
I_{30}	Maximum 30 minute storm intensity	(mm/h)
K	Soil erodibility	($t.ha.MJ^{-1}.ha.mm^{-1}.h$)
K_{det}	Soil detachability	(g/J)
K_s	Saturated hydraulic conductivity	(mm/hr)
L	Slope-length factor	
l	Slope-length(m)	
m	Slope-length exponent	
$M_{(texture)}$	[(Silt% + very fine sand%) (100-clay%)]	
M_{FC}	Soil moisture storage at field capacity	(%v/v)
N	Number of years	
n	Erosive storms (p > 10mm) in N period	
n_g	Grain roughness due to soil particles	
n_m	Micro topographic roughness	
n_{man}	Manning's roughness ($m^{1/6}$)	
n_v	Roughness imparted by vegetation	
OM	Organic matter	(%)
P	Conservation or support practice factor	
$P_{(code)}$	Permeability class	
$P_{(storm)}$	Storm rainfall	(mm)
P_{24}	Daily rainfall	(mm)
P_l	Permanent interception and stem flow	(%)
PLU	Prior land use sub factor	
POR	Porosity	(%v/v)
Q	Runoff depth	(mm)
Q_{in}	Infiltrated amount	(mm^3)
R	Rainfall erosivity	($kJ\ m^{-2}\ mm\ h^{-1}$)
r	Radius of auger hole	(mm)
R_c	Moisture storage capacity	(mm)
RF	Rainfall	(mm)
R_o	Average annual rainfall per rainy day	(mm/day)
S	Slope steepness factor	
$S_{\%}$	Slope	%
$S_{(code)}$	Structure code	
SC	Mulch or Surface ground cover sub factor	
SL	Topographic factor	
SLR	Soil loss ratio	
S^o	Slope angle	
SR	Surface roughness sub factor	
t	Elapse time (seconds)	
ρ_b	Bulk density of soil	(Mg/m^3 or g/cm^3)
ρ_p	Particle density	(Mg/m^3 or g/cm^3)

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Chapter 1 - Introduction

1.1 Introduction

Land degradation and sedimentation of inland water bodies resulting from soil erosion is a widely recognized problem in most parts of the world. Accelerated erosion is an increasing threat to agricultural production. The knowledge of the distribution of erosion within a catchment is important in conservation planning, targeting high-risk areas.

Soil erosion is a diffused process and occurs at widely varying rates over the landscape, over a field, and even along a typical landscape profile within a field. Therefore to understand soil erosion over an area such as a catchment, it is necessary to assess erosion at a large number of places. Assessment of erosion using experimental plots is impractical as the physical measurement of soil erosion is difficult due to the cost and time. The variability of climate requires that at least 10 years of data be used to obtain an accurate measure of average erosion. In arid areas, where large and infrequent storms cause most of erosion, data from many more years is required (Foster, 1988).

With expert and field knowledge of processes occurring in a watershed and survey information on the geomorphologic terrain, soil and cover units in a relational database, it is possible to formulate relational rules for classifying erosion risk (Meijerink, et al., 1994). One of the important assumptions need to be met for this approach to be effective is that some underlying patterns or structures actively exists in the data and that it is non-random. If the knowledge base exhibited considerable randomness then, as with any other form of analysis, the system has little chance of extracting a reliable and effective rule base (Harris, et al., 1990). In general, agricultural lands differ in land and crop management conditions and have high temporal and spatial variation in erosion factors. Therefore, randomness is high in agricultural lands compared to forest or range grasslands.

Erosion modelling is an available option for erosion surveys. However, estimating soil loss with models is particularly difficult, because there are so many variables, some occurring naturally, such as soil and rainfall, and also the many options for management practices. As a result, models, whether empirical or process-based are complex (Hudson, 1995-1). Generally, for complex watersheds, a model base alone will seldom yield a satisfactory erosion risk scenario for entire catchment due to limitations of spatial applicability (Meijerink et al., 1994).

As shown by Meijerink (1989) and Meijerink et al., (1994), hybrid erosion assessment approach; combined approach using model base reinforced with relational rule-based will probably yield more accurate overall assessments. Relational rules can be used to define the physical boundaries of each unit and to classify straightforwardly up to a certain extent as high and low erosion risk units. Erosion models can be applied to high erosion risk areas thereafter for further classification.

A number of models for erosion prediction is available (Charman et al, 1996). However, each of these models performs only a particular task best. For example, Universal Soil Loss Equation (Wischmeier, 1978) estimates long-term average erosion from field size plots with a limitation of slope steepness and slope-length. In event-based methods, average erosion is estimated by summing up erosion due to individual storms and data need is therefore high (Morgan et al, 1998).

For better estimation of soil erosion, the selection of the models to be used is critical. In general, erosion prediction methods are extrapolated beyond the range of the data used to derive them. The ability of a model to perform well, when extrapolated is an important factor in the selection of a prediction method, especially in regions where little baseline data exist (Foster, 1988).

Factors influencing water erosion are highly variable spatially and temporally. During incorporation of these factor variables as model parameters, averaging or aggregating spatially or temporally distributed variables into one lumped parameter is common in erosion modelling. As a result, erosion assessment by models can give unexpected results. Estimation of sensitivity of model input parameters and qualitative performance evaluation of different types of models will help in input parameter processing and in selecting suitable models for erosion assessment under different conditions.

Universal Soil Loss Equation (Wischmeier, 1978) and the Morgan model (Morgan, et al, 1982) are two of the commonly used erosion assessment models. The European Soil Erosion Model (EUROSEM) is a recently developed event based, distributed, catchment model for erosion and runoff estimation (Morgan et al, 1998).

In this research, these three models are evaluated empirically for small catchments to explore their suitability for different conditions and identify model support for erosion risk mapping through merging rational rule-based approach.

1.2 Research Objectives

General objective is to assess the role of erosion modelling in erosion surveys using aerospace data.

1.2.1 Specific Objectives

1. Review of erosion survey using aerospace images and field observations.
2. To study the behaviour of three different models, in estimating, soil erosion
3. To evaluate the model performances qualitatively by comparing with field estimates.
4. Sensitivity analysis of model input parameters to identify critical parameters
5. To merge quantitative approaches with qualitative criteria for assessing and mapping erosion.

1.3 Study Area

Study area is Naivasha basin, which lies in the East African Rift Valley, about 80 km north east of the Nairobi the capital city of Kenya. The basin is located approximately between 0^{o}00’- 1^{o}00’S and 36^{o}00’ – 36^{o}45’E in Nakuru District. It is bounded by Kipipiri Mountains from northeast, by Aberdare Range from east, by Mau Escarpment from west. The basin has a total area of 3387 km^2 of which 132 km^2 belong to the lake Naivasha which is second largest fresh water body in East African Rift Valley.

1.4 Climate

The climate around the lake Naivasha is Semiarid and it is semi-humid to humid in mountainous rain forest areas. Annual values of precipitation for the hilly zones are high, ranging from 1250 mm to 1500 mm (Clarke et al., 1990) while the lower rainfall values average 430 mm at Magadi and 930 mm at Nakuru for the valley floor. The annual rainfall distribution pattern is bi model with highest peak in April and lower peak in October of the year.

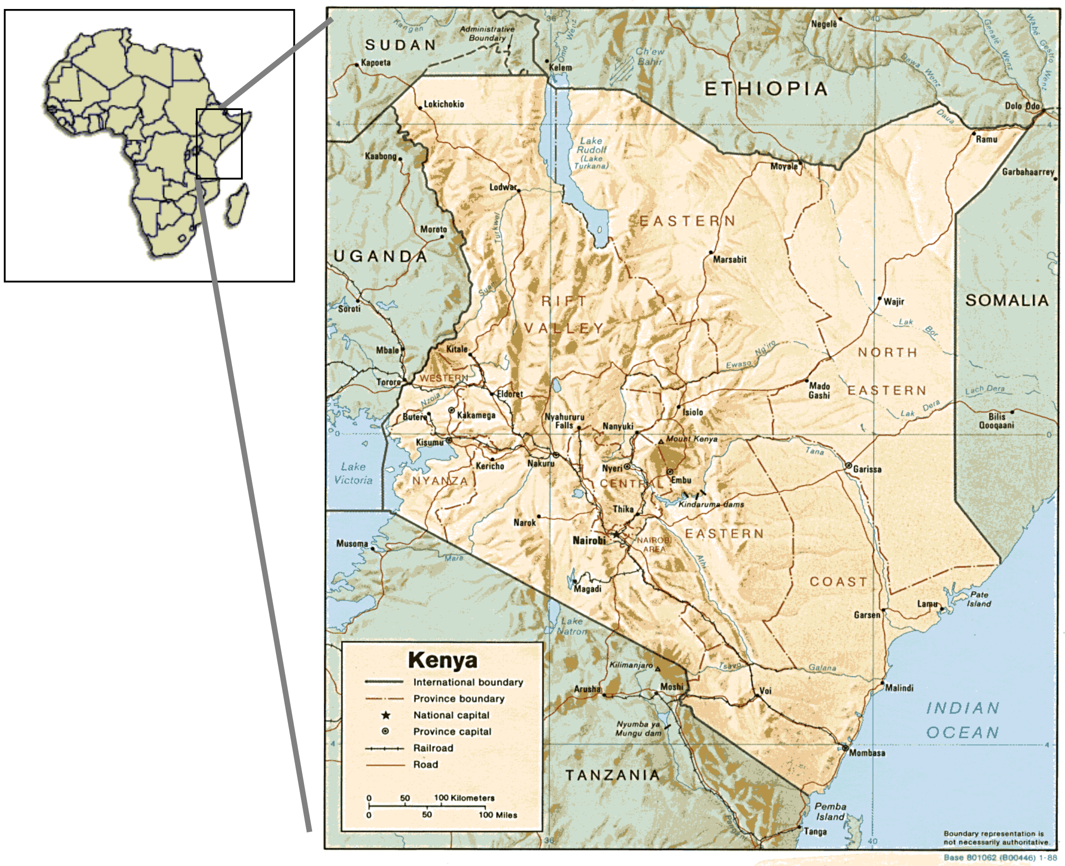


Figure 1-1: Location of Kenya in African Continent

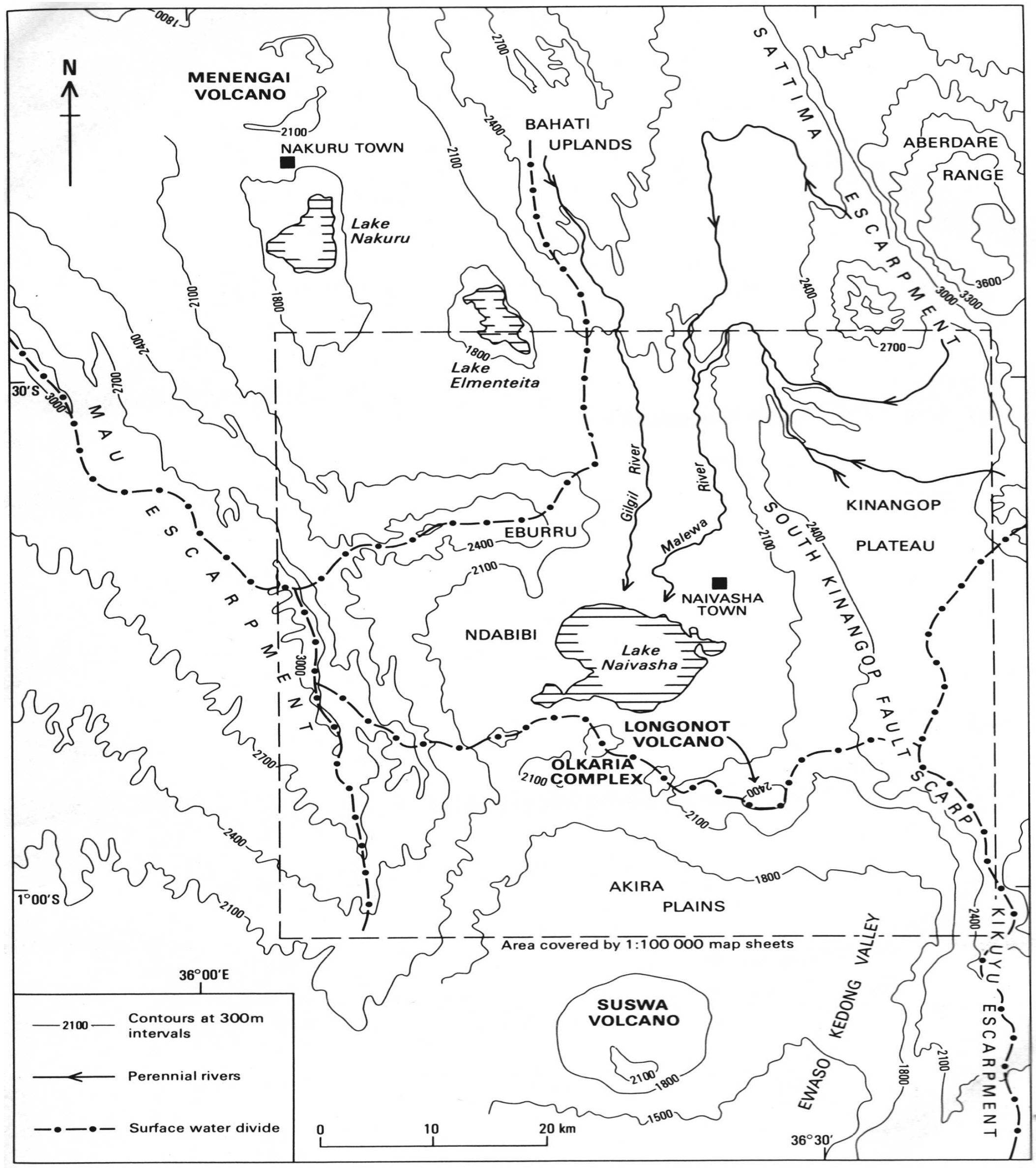


Figure 1-2: Location of Naivasha basin

1.4.1 Rainfall

Observations of rainfall data for past years show high spatial variation of rainfall within the area. The rainfall pattern within the lake Naivasha catchment is influenced by the rain shadow from the surrounding highlands of the Nyandarua range to the east, and the Mau Escarpment to the west. Rainfall data from the Meteorological department of Kenya, as summarised in figure 1-3, shows bi model pattern with highest peak in April and lower peak in November. High spatial variation of monthly rainfall is a prominent feature in the area. According to the figure, monthly rainfall of southern area (*Kinangop*) is nearly twice as that of central (Naivasha) and northwest (*Longonot*) areas.

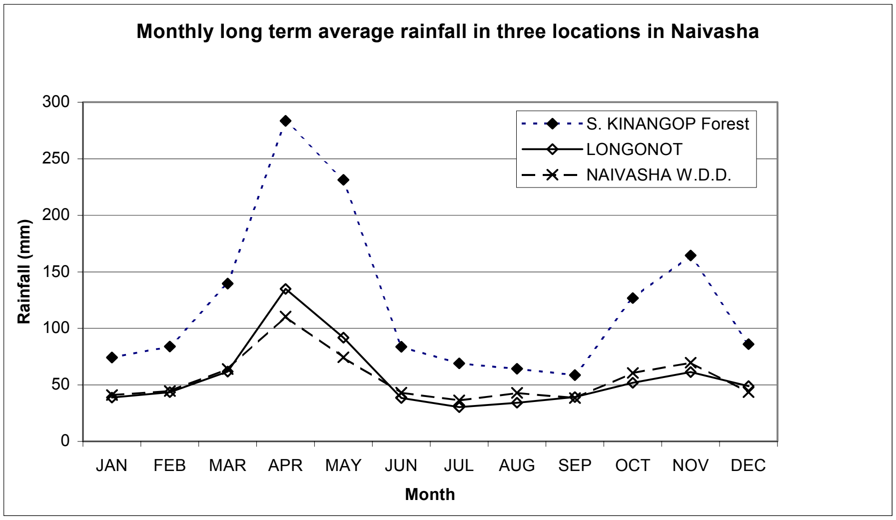


Figure 1-3: Variation of long-term average monthly rainfall

1.4.2 Evapotranspiration

According to the data obtained from Kalders, (1988), the pattern of Potential evapotranspiration (ET_o) variation around Naivasha, is more or less follow the same pattern of rainfall variation. Potential evapotranspiration in the area varies from about 2.5 mm/day to 6 mm/day. Average variation of mean ET_o is plus or minus 1mm/day. Daily ET_o is nearly 2 mm higher in wet areas than that in less wet areas.

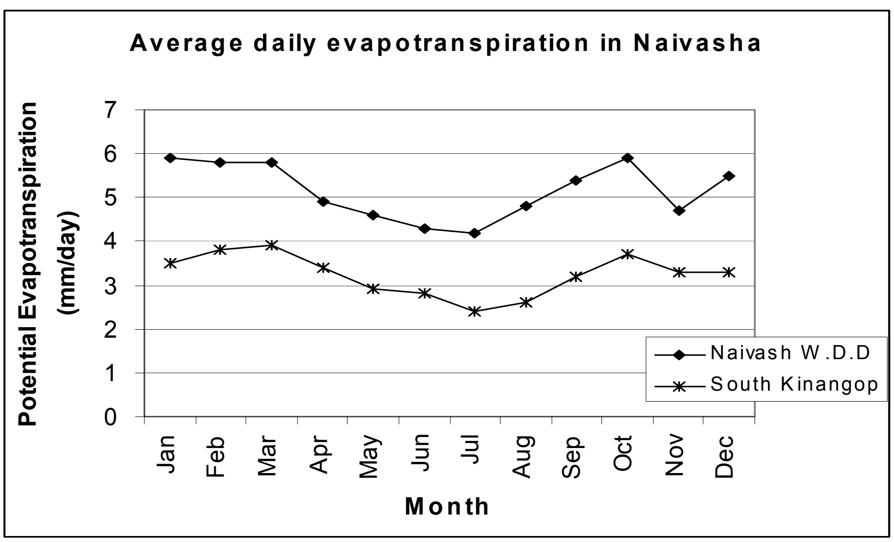


Figure 1-4: Variation of Potential evapotranspiration in Naivasha

1.4.3 Temperature

Average monthly temperature varies from 10 at central areas to 19 ^{o}C at south areas. Lower temperature can be expected in mid July while highest in March and April. Like all parameters temperature follows the bimodal seasonal variation pattern.

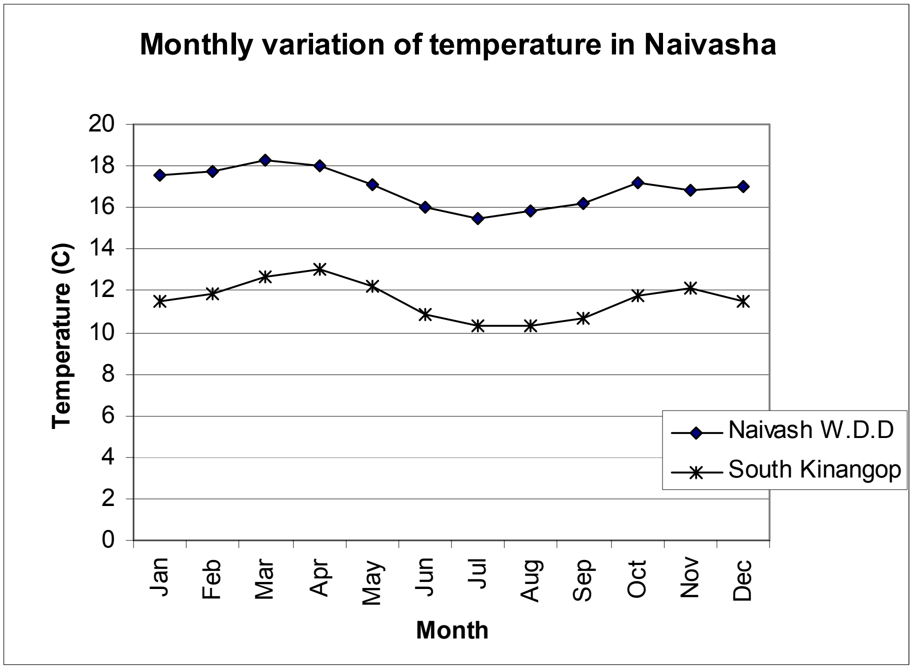


Figure 1-5: Variation of mean monthly temperature in Naivasha

1.4.4 Soils

The soils in the area were derived mainly from weathered volcanic and basement rock system. Soils developed on the Lacustrine plain are moderately well drained, very deep, very dark greyish brown to pale brown, silt-clay to clay-loam. Soils developed on the volcanic plain are well drained, moderately deep to very deep, dark brown to pale brown, with non-calcareous to moderately calcareous topsoil, and moderately to strongly calcareous deep soil (Hammouda, 1999).

1.5 Methodology

The erosion status was reviewed by secondary data on erosion risk maps and erosion potential maps. Thereafter, the thematic maps of elevation contours, land use and rainfall distributions were taken into consideration. The aerial photographs were used in identifying probable erosion areas. Finally, field investigations were carried out to review the erosion status of different units identified above and to evaluate their erosion status.

In order to evaluate the performance of different types of models, small sites, with differing erosion status, were selected. For site selection, features related to erosion conditions were studied during fieldwork. Micro pedestals to splash erosion, flow paths for interill erosion and rill densities for rill erosion were considered to evaluate erosion status of each site and sediment collected in small recovers were estimated. Site selection procedure and the description of each site are discussed in chapter 3.

Evaluation of erosion rates was done using field data collected during the three-week fieldwork. Rill volume was calculated based on the data on cross-area, length and density of rills. In the sites with rills, rill volume was considered as minimum volume of soil eroded during the period between land preparation and data collection. For sites having sediment-collecting reservoirs, sediment volume removed annually, were considered as the erosion rate.

Erosion modelling using Universal Soil Loss Equation (Wischmeier, 1978), the Morgan model (Morgan, et al., 1982) and European Soil Erosion Model (Morgan, et al, 1998) was performed for the period considered for field erosion evaluation. The data used as input to each model were collected from available literature, databases, field data, and laboratory analysis. Since the erosion estimation was done for the period after land preparation (or last disturbance to the topsoil), modelling of erosion was done only for the relevant period. Annual erosion estimations were done for sites which annual sediment removal data is available. Data requirement and data processing for different models used in this study depended on the model type. A description of data processing is given in chapter 4.

Sensitivity of model input parameters for erosion predictions of models was studied through available literature on sensitivity and using simple sensitivity analyses to find out critical parameters.

Erosion model support for assessing and mapping erosion were studied. Study the potential for formulating a methodology to assess and mapping erosion by merging quantitative approaches with qualitative criteria.

The methodological approach is briefed in the figure 1-6.

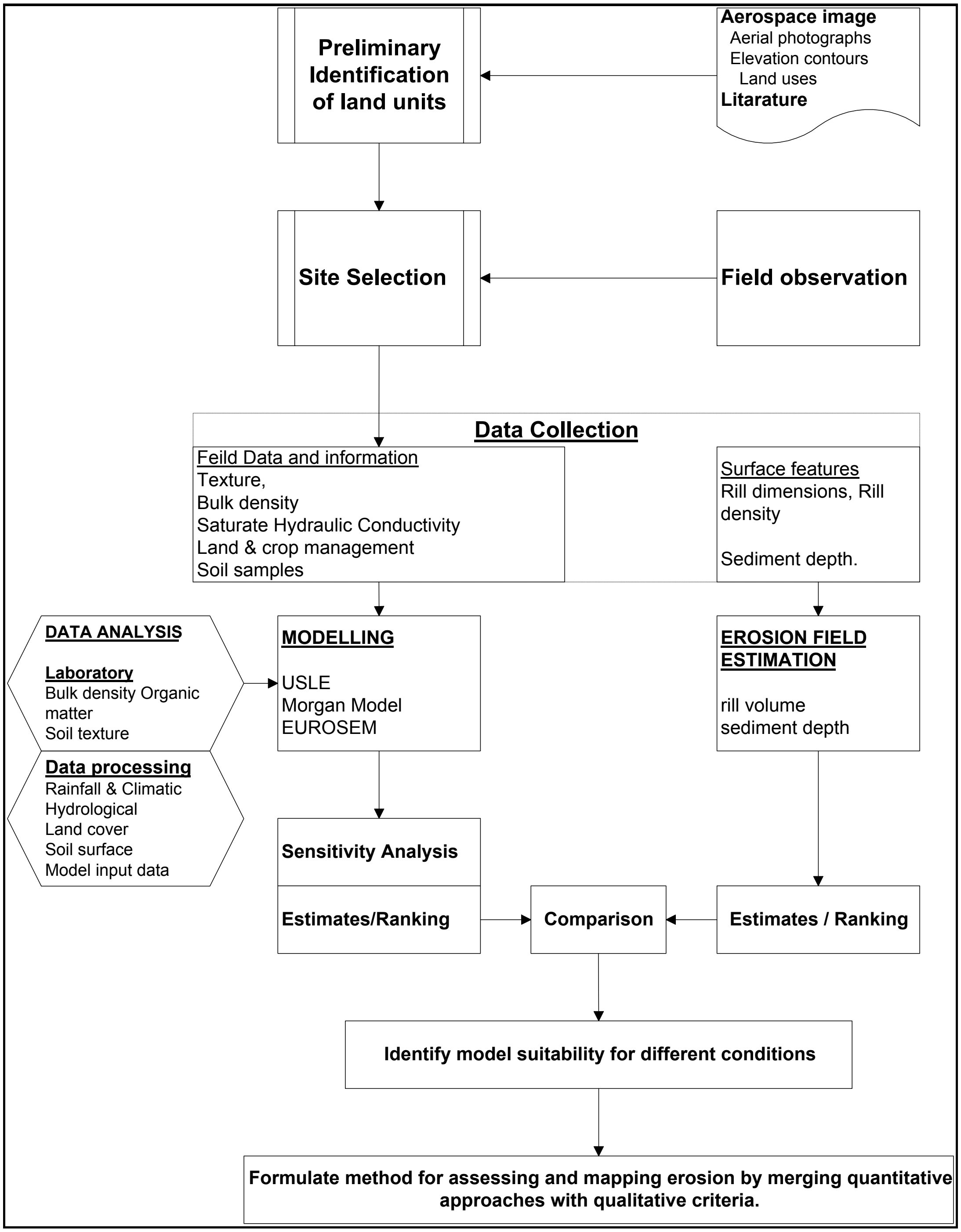


Figure 1-6: Methodological approach of the study

Chapter 2 - Background Information

2.1 Introduction

Erosion is a complex process and shows high variability in time as well as in space domain. There are many types of approaches for assess and mapping erosion. In this chapter, general information on erosion, variables involved in erosion process, development of various erosion assessment approaches, description of models evaluated in this study and input parameter processing methods available for each model, are discussed.

2.2 Water erosion types

The erosion process can be described as detachment of soil particles from the surface due to raindrop impact (splash erosion) and the entrainment by runoff and transport of detached particles by runoff. Major types of soil erosion by water include sheet, rill, concentrated flow, gully, and stream channel erosion. Sheet erosion removes soil in a thin, almost imperceptible layer. Rill erosion, caused by surface runoff, result in numerous, small, eroded channels across a landscape. These two types of erosion, account for the major impact of soil erosion on land productivity (Foster, 1988). The erosion resulting from natural causes is called geologic or natural erosion and it is in equilibrium between soil formation and erosion. Breaking the natural equilibrium, mostly due to agriculture will create accelerated soil erosion, which is more aggressive than geological erosion. (Hudson 1989). This study is only dealing with small catchments or plots and accelerated erosion.

2.3 Factors controlling water erosion

Factors influence the accelerated soil erosion is included climatic, land, topographic, vegetation and management factors. In medium and small-scale agriculture lands, interrill and rill erosion is the most common. Continuous waterways such as drainage channels, irrigation channels will result gullies that are much larger than rills. Erosion is controlled by many factors and they can be categorized into

2.3.1 Rainfall

Rainfall is identified as the main cause of water erosion. Ability of rain to cause erosion is defined as erosivity and it is a function of rainfall (Hudson, 1995-1). The amount and peak intensity are two main important characteristics of a rainstorm that influence its potential ability of causing erosion. Volume and peak rate of runoff are measures of runoff erosivity (Forster, 1988). Rainfall erosivity is defined as summation of product of total Kinetic energy of each storm and maximum intensity in 30min duration in USLE (Wischmeier and Smith, 1978). Infrequent heavy rainfall may cause most of the erosion and event base models may useful to predict erosion from those rainfall events (Morgan et al., 1998).

2.3.2 Soil parameters

Soils vary in their susceptibility to erosion. Soil texture (sand, silt and clay composition), organic matter content, structure and permeability are major factors that effect soil erodibility (Foster 1988).

2.4 Erosion estimation

2.4.1 Erosion evaluation through soil surface features

By recording certain erosion features of the micro-topography on the soil surface it is possible to evaluate the rain erosion hazard. Some features that correlated with dominant processes of surface erosion, such as splash, transport flow and scour can be quantified. As the feature represent the accumulated effect of the erosion in a preceding period, the relative erosion hazard over that period may be classified (Bergsma, 1992). Six categories of micro-topographic features for evaluation of erosion were proposed by Bergsma (1992). They are eroding clods, flow surfaces, rills, pre-rills, depressions and vegetative matters. Eroding clods indicate areas where splash is the dominant process, the flow surfaces indicate dominant inter-rill erosion, the pre-rills and rill areas indicate the rill erosion. The different features indicate different erosive capacity. They are in order of importance: channelled area (rill and pre-rills), flow surfaces, and eroding clods. The relative erosion degree is determined in two ways: by judging the amounts and the relative importance of the flow features, pre-rills and rills, also considering the amount of eroding clods that are still present. The occurrences of clods that are eroding by splash indicate a certain resistance to erosion by the soil surface is used as additional criteria. Studies with various types of lands and management conditions revealed that there is a high correlation of erosion evaluation by soil micro-topographic features, with measured data (Bergsma, 1992).

2.5 Erosion modelling

Developing Erosion prediction or modelling approaches are not new concepts. Works of Horton in 1938 and Ellison in 1947 provided many of the basic ideas of erosion modelling. However, these technologies emerged after mainframe computers became readily available and interest in erosion was stimulated by concern for surface-water quality in 1970s (Foster, 1990). Subsequently, like hand tools, many types of erosion assessment methods emerged: each is best at performing a particular task. Therefore, no single prediction method meets all needs (Foster 1988). Presently available erosion models can be categorized in many ways. Understanding of principles behind the development of erosion models and types of models may be useful to study the models behaviour for different locations with variable parameters. Brief overview of water erosion model types is given in the following section.

2.5.1 Overview of water erosion model types

Many types of water erosion models can be found in literature and can be categorized according to principles used in the development of model, spatial extent (or resolution) the model can apply, temporal resolution of the model, etc. Erosion models can be divided broadly into four categories, based on the development principle, such as stochastic models, Empirical models, Physically based or analytical component models and Rule based expert systems. (Charman et al, 1996, Morgan 1995).

Stochastic models describe erosion according to probabilistic laws, with process developing sequentially in time (Charman et al 1996). They are based on generating synthetic sequences of data from statistical characteristics of existing sample data; useful for generating input sequences to physically based and empirical models where data only available for short period of observations (Morgan 1995).

2.5.1.1 Empirical models

These models describe the erosion based on statistically significant relationships between assumed important variables where a reasonable database exists. Three types of analysis are recognized. Black-box where only main input and outputs are studied, grey-box where some details of how the system works is known and white-box where all details of how the system operates are known. Most of the erosion models used in erosion studies are of the empirical grey-box type (Morgan 1995).

2.5.1.2 Physically based or analytical component models

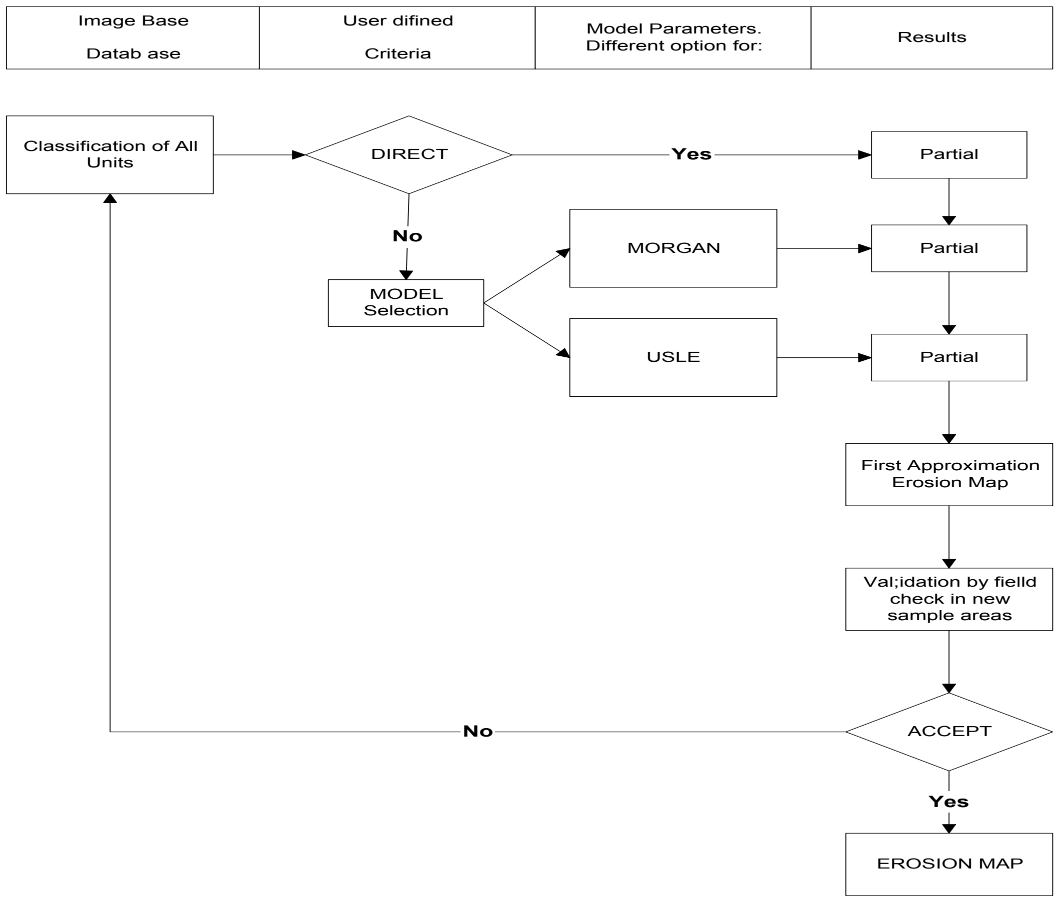
Physically-based models based on mathematical equations that describe the processes involved in the model, taking account of the laws of conservation of mass and energy (Morgan 1995). Use of these models is much expensive because of need of descriptive physical details of the processes involved hence more field data gathering (Charman et al, 1996).

2.5.1.3 Rule based expert systems

Using expert knowledge of processes occurring in a watershed and survey information on the geomorphologic terrain, soil and cover units in a relational database, it is possible to formulate relational rules for classifying erosion risk (Meijerink, et al. 1994). This rule-based erosion assessment approach is based on logical reasoning and construct decision rules from a given knowledge base expressed in IF-THEN form. Expert systems, which seek to uncover logical relationship within a database expressed in the form of rules rather than in the form of mathematical equations, provide alternative approaches to data analysis (Harris, et al., 1990). One of the important assumptions need to be met for this approach effective is that some underlying patterns or structures actively exists in the data and that it is non-random. If the knowledge base exhibited considerable randomness then, as with any other form of analysis, the system has little chance of extracting a reliable and effective rule base (Harris, et al., 1990).

2.5.1.4 Hybrid approach

Hybrid erosion assessment approach is a combined approach using model base reinforced with relational rule-base. Relational rules can be used to define the physical boundaries of each unit and to classify straight forwardly up to some extent as high and low erosion risk units. Erosion models can be applied to high erosion risk areas to further classification. Rule base approach combined with model estimation can be used for erosion estimations after investigating the model applicability for different conditions of each classified land units (Meijerink, 1989). Figure 2-1 shows an example scheme for erosion assessment using hybrid erosion modelling.



(After Meijerink, 1989)

Figure 2-1: Schematic diagram for erosion assessment using hybrid approach.

2.5.1.5 Model types based on spatial and temporal aspects

According to the extent of the land, different model can be applied for erosion assessment. Erosion models can be divided in to Site models and catchment models. Site models can be applied for estimating erosion for a small part of a land. Most of the site models deal with interrill and rill erosion. Catchment models deal with watershed areas ranging from a gully system up to a small stream system. These models need to deal with several component of the water cycle: rainfall, runoff, overland flow and routing (Pullar et al. 2000).

According to the way the model handles data spatially, models can be divided in to Lump models and distributed models. Lump models use spatially averaged parameters and perform computations over the whole catchment region. As the within variations for a catchment increases, the model predictions may become les informative and accurate. Distributed models are based upon the discretisation of landscape into small functional land units. These models are able to better account for local variability in land conditions (Pullar et al. 2000).

According to the time frame over which the model is run, models can be sub divided. Event base single event models assess erosion resulted from a rain storm and run over a short period that covers the rainfall duration and time for runoff to drain from the watershed. Continuous time step models calculate for longer period like a year or over cropping season (Pullar et al. 2000).

2.5.1.6 Erosion Assessment Approach Using Terrain Mapping Units (TMU)

In Terrain Mapping Units (TMU) approach (Meijerink 1988), total area will be stratified according to similarities of landform or geomorphology, internal relief, geology and soil type. Erosion estimations through a suitable method for sample areas of each unit can be extrapolated to the rest of the area, and to convert the TMU map into erosion map. This approach can also be integrated with GIS and remote sensing. Hamududu (1998) applied this method to develop an erosion map for Naivasha basin integrating the TMU with rainfall and vegetation characters (Hamududu, 1998).

2.5.2 Universal soil loss equation (USLE)

Universal Soil Loss Equation (USLE) is the most widely used method for estimating soil erosion by water. USLE is an empirical equation partly based on theory of erosion process and derived from over 10,000 plot-years of data from natural runoff plots and 2,000 plot-years of rainfall simulator data (Wischmeier and Smith 1978). The Universal Soil Loss Equation (USLE) estimates sheet and rill erosion using values for indices that represent the four major factors affecting erosion: R- climatic Erosivity, K- soil erodibility, L and S – topography, and C and P – land use. The USLE was derived from a large database of more than 100000 plot-years of data. These field plots were 'long' (22m for most of the plots), but other plot lengths included 11, 44, 88 and 189m, and covered a range of soils, steepness, crops, management practices and climates over the eastern United States. (Foster 1990). In USLE, a value for soil loss is computed by multiplying six factors (equation 2-1) as given below.

$$A = RKSLCP$$ (Universal Soil Loss Equation) **Equation 2-1**

Where

A = average annual soil loss (ton/ac)

R = rainfall and runoff Erosivity index for a given location

K = soil erodibility factor

L = slope-length factor

S = slope steepness factor

C = cover and management factor

P = conservation or support practice factor

2.5.2.1 Rainfall Erosivity (R)

Several types of methods can be found in literature for Erosivity (R) factor calculations. Originally the equation R factor calculation was done by summing up the product of the maximum intensity recorded during 30 minute (I_{30}) multiplying the kinetic energy of raindrops of individual rainstorm occurred during the considered period (equation 2-2).

$$R = \frac{\sum_{i=1}^{n} (EI_{30})_i}{N} \Big/ 100$$ (Annual Erosivity) **Equation 2-2**

Where

E = Kinetic energy of rain storm

I_{30} = Maximum 30 minute intensity for i^{th} storm

N = Number of years
n = erosive storms (p > 10mm) in N period

Following equations can be used for the calculation of Kinetic energy of each erosive storm (Hudson, 1998)

Table 2-1: Equations for rainstorm kinetic energy (E) calculations (after Hudson, 1998)

Equation	Units		Reference
	Energy	Intensity	
$E = 916 + 331 \log_{10} I$	Foot-tons/acre-inch	in/hr	*Wischmeier et al 1958*
$E = 210 + 89 \log_{10} I$	Tonne-meters/hectare-cm	cm/hr	*Wischmeier and Smith 1978*
$E = 11.9 + 8.7 \log_{10} I$	J/m^2-mm	mm/hr	
$E = 29.22(1-0.894e^{-0.004771})$	J/m^2-mm		*Kinnel 1981*
$E = 30 – 125/I$	J/m^2-mm	mm/hr	*Hudson 1965*
$E = 9.81 + 11.25 \log_{10} I$	J/m^2-mm	mm/hr	*Zanchi and Torri 1981*

For calculation of kinetic energy and the Erosivity using those equations, it is essential to have rainfall data from a recording type rain gauge. Equations have been developed by Mannaerts (2000) in Cape Verde where the Erosivity index (EI_{30}) was related to storm rain amount. The equation below can be used for storms greater than 9mm depth (Mannaerts, 2000).

$$EI_{30} = 0.0723(P_{24})^{1.58}$$ (24 hour Erosivity - Mannaerts 2000) **Equation 2-3**

where
EI_{30} = Erosivity (kJ m^{-2} mm h^{-1})
P_{24} = Daily rainfall (mm) (P24>9mm)

$$EI_{30} = 0.06\left(P_{(storm)}\right)^{1.81} D_p^{-0.36}$$ (Storm Erosivity - Mannaerts 2000) **Equation 2-4**

where
EI_{30} = Erosivity (kJ m^{-2} mm h^{-1})
$P_{(storm)}$ = Storm rainfall (mm)
D_p = Rainfall duration (h)
Note: more than 6 hours dry spell was the criteria used for separation of rain events.

2.5.2.2 Soil Erodibility

Soil erodibility is a measure of the susceptibility of a given soil to erosion by rainfall and runoff. The properties of a soil that influence its erodibility are: soil texture, soil structure, organic matter content, and soil permeability. Calculation of K factor can be done either by using soil-erodibility nomograph or using the equation 2-5 for lands where the silt fraction does not exceed 70 percent.

$$K = \frac{2.1 * M_{(texture)}^{1.14}(12 - OM)\times 10^{-4} + 3.25\left(S_{(code)} - 2\right) + 2.5\left(P_{(code)} - 3\right)}{7.594 \times 100}$$ **Equation 2-5**

Where
K = Soil Erodibility (t.ha.MJ^{-1}.ha.mm^{-1}.h)
$M_{(texture)}$ = (silt% + very fine sand%) (100-clay%)
OM = percent organic matter

$S_{(code)}$ = structure code
$P_{(code)}$ = permeability class

2.5.2.3 Topographic factors

The topographic factor (SL) is included the effect of slope-length and the slope-steepness parameters of the terrain on soil erosion. Steep slopes produce high runoff velocities. Soil loss increases with increasing slope due to the greater volume of runoff accumulating on the longer slope-lengths.

$$SL = \left(\frac{l}{22..13}\right)^m \left(\frac{0.043 * S_{\%}{}^2 + 0.3 * S_{\%} + 0.43}{6.613}\right)$$ (USLE- SL Factor) **Equation 2-6**

where,
SL = Topographic factor
l = slope-length(m)
m = slope-length exponent
$S_{\%}$ = Slope percentage

In the equation 2-6 the '*m'* exponent varies according to the slope steepness; m=0.3 for x<3%, m=0.4 for x=4% and m=0.5 for x>5%(after Moore et al., 1986).

2.5.2.4 Cover and management factor

The cover and management factor, C, is the ratio of soil loss from land use under specified conditions to that from continuously fallow and tilled land. The USLE was developed for use on agricultural fields. It is adapted to use in non-agricultural conditions by appropriate selection of the C factor. This is often done by relating the land use conditions to some agricultural situation. For example, a firing range with a grass cover might be assumed to be similar to a pasture.

2.5.2.5 Limitations of USLE

Since the plots producing the USLE data were of uniform slope, the USLE is restricted in the degree that it applies to non-uniform slopes. However, it can be applied to irregular slopes where erosion is occurring, but not to those portions of slopes, such as toe of concave slopes, where deposition occurs.

A major limitation of USLE is that it does not explicitly represent hydrologic and erosion processes. For example, if an adjustment is made in the USLE to account for an effect of runoff, every USLE factor, except perhaps R, must be modified.

Furthermore, the USLE's equation structure is extremely limiting. The equation does not represent (and cannot be easily modified to present) fully the form observed in experimental data for the effect of cover and steepness on erosion and deposition in furrows. Therefore, no major improvements in erosion prediction technology are likely to come from the USLE or similar empirically based technology. Major improvements are much likely to originate from erosion predictions technology based on fundamental hydrologic and erosion processes (Foster 1990).

2.5.3 Morgan model

Morgan model was developed for predicting annual soil loss from field-sized areas on hill slopes (Morgan et al. 1984). This model is a physically based empirical model and needs less data than most of the other erosion predictive models. In the predicting approach the model is divided in to two phases namely water phase and sediment phase.

2.5.3.1 Water phase

In the water phase, volume of runoff and rainfall energy for splash erosion is determined by annual rainfall. Rainfall energy is calculated by using an empirical relationship between energy and annual rainfall and intensity developed by Wischmeier and Smith (1978). Equations and steps to be adopted are stated below.

$$E = RF(11.9 + 8.7\log_{10} I)$$ (Kinetic energy of rainfall) **Equation 2-7**

Where
E = rainfall energy ($kJ/m^2/yr$)
I = typical value for intensity of erosive rain (mm/h)
RF = rainfall (mm)

The equation for rainfall energy calculation was developed considering the raindrop size distribution for the area. The equation E=29.8-(127.5/I) which was developed for Zimbabwe by Hudson (1965) is also suggested for tropical climates (Morgan 2001).

$$Q = RF.\exp(-R_c/R_o)$$ (Runoff Volume) **Equation 2-8**

Where
Q = runoff volume (mm)
RF = rainfall (mm)
R_c = moisture storage capacity (mm)
R_o = average annual rainfall per rainy day (mm/day)

$$R_c = 1000\mathrm{M}_{FC}\rho_b D_r \left(ET_a/ET_0\right)^{0.5}$$ (Moisture storage capacity) **Equation 2-9**

Where
M_{FC} = soil moisture storage at field capacity (%W/W)
ρ_b = bulk density of soil (Mg/m^3)
D_r = top soil rooting depth (mm)
ET_a = actual evapotranspiration (mm/day)
ET_0 = potential evapotranspiration (mm/day)

2.5.3.2 Sediment phase

The sediment phase is divided into two components; splash detachment and runoff transport. Splash detachment is modelled using power relationship with rainfall energy modified to allow for the rainfall interception effect of the crop. The transport capacity is determined by using Kirkby (1972). Equations and data requirements are stated below.

$$F = K_{\det}\left(Ee^{-aP_l}\right) \times 10^{-3}$$ (Splash detachment rate) **Equation 2-10**

Where
F = rate of splash detachment (kg/m^2)
E = rainfall energy ($kJ/m^2/yr$)
K_{det} = soil detachability (g/J)
a = 0.05
P_l = percentage rainfall contributing to permanent interception and stemflow

$$G = CQ^2 \left(\sin S^o\right) \times 10^{-10}$$ (Sediment Transport capacity) **Equation 2-11**

Where
G = transport capacity of overland flow (kg/m^2)
C = crop cover management factor
S^o = slope angle

Rate of splash detachment (F) and transport capacity of overland flow (G) give two predictions for soil loss. Since soil loss cannot exceed the transport capacity, lowest value from detachment and transport capacity can be taken as soil loss.

2.5.4 European Soil Erosion Model (EUROSEM)

The European Soil Erosion Model (EUROSEM) is an event-based model designed to compute the sediment transport, erosion and deposition over the land surface throughout a storm (Morgan et al, 1998). It can be applied to either an individual field or a small catchments and has the ability to produce hydro graphs and sediment graphs for each event. Compared with other models, EUROSEM simulates rill and interill erosion explicitly from interill areas to rills, thereby allowing for deposition of material. This is considered more realistic than assigning all or a set proportion of the detached material to rills. A more physically based approach to simulating the effect of the vegetation or crop cover is used, taking account of the influence of leaf drainage. Soil conservation measures can be allowed for by choosing appropriate micro topography and plant cover parameters so as to describe the conditions associated with each practices. Unlike other models, however, this model does not describe the eroded sediments in terms of particle size (Morgan, 1995). This model has been developed as a computer program and it deals with a number of components of the hydrological cycle to assess the erosion. For each sub process there is a separate subroutine program in EUROSEM program (see Figure 2-2).

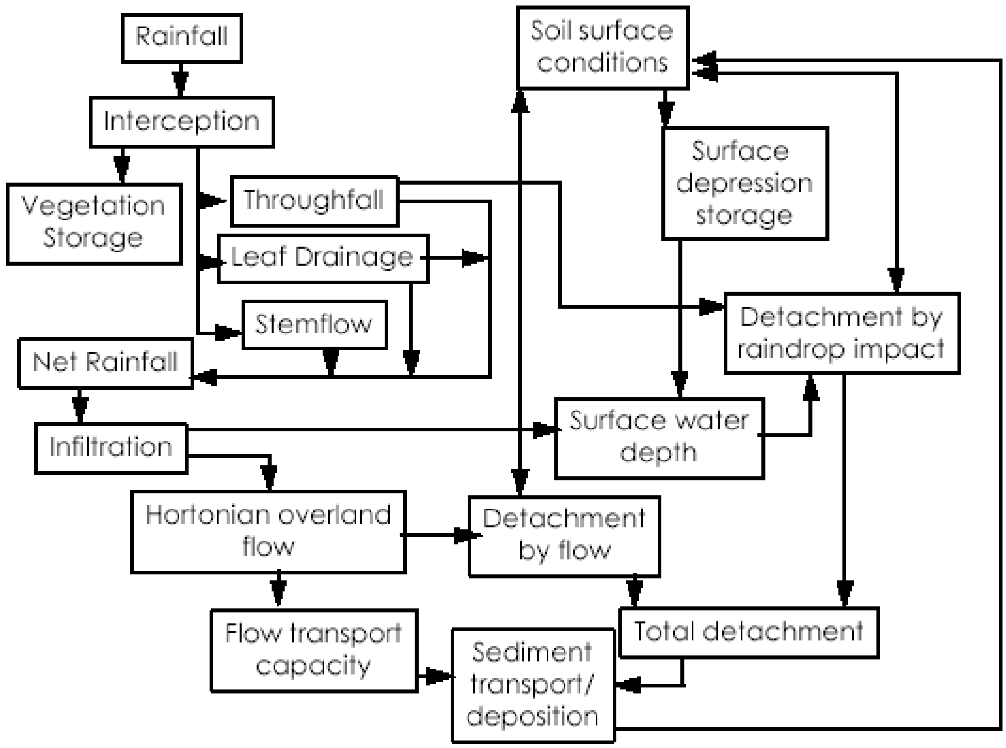


Figure 2-2: Flow chart for the European Soil Erosion Model (after Morgan et al., 1998)

EUROSEM has a modular structure with each module being developed in as much detail as the existing level of knowledge permits. This structure will enable continuous improvements to be made in the light of new research. The model deals with:

- Interception of rainfall by the plant cover;
- Volume and kinetic energy of the rainfall reaching the ground surface as direct through fall and leaf drainage;
- Volume of stem flow;
- Volume of surface depression storage;
- Detachment of soil particles by raindrop impact and by runoff;
- Sediment deposition; and
- Transport capacity of the runoff.

This model can be applied for both homogenous and heterogeneous catchments without lumping data, because this model has options to handle data separately for each element of area dividing the catchment into small units. Parameters of each channels or drainage lines of catchments also cab be described separately by elements. As illustrated in Appendix VIII heterogeneous parts of catchment can be sub divided into different elements. If significant change of parameters of one plan exists, the plan can be subdivided into a sequence of plans, which flow onto one another. Maximum of 60 elements all together plans, channels, drainage lines, etc. can be handled by EUROSEM programme.

2.5.4.1 Elements of the model

Rainfall is assessed by the amount of interception by vegetative cover and the proportions of intercepted rainfall reaching the ground as stem flow or as leaf drip. Soil surface conditions are based on quantifying roughness to assess surface storage. Runoff generation is separated into two components: surface depression and surface flow. The hydrological model simulates runoff as both Hortonian and saturation flow expressed as depth. Soil detachment by rainfall impact is assessed from the kinetic energy of the through fall and separately the energy of leaf drip from the canopy. Soil detachment by runoff is assessed from comparison of the estimation of the estimated velocity of runoff compared with the critical velocity required to detach soil particles, modelled as a function of grain shear velocity. Transport capacity is modelled as a function of stream power defined as the product of flow velocity and slope. Finally a comparison is made of the availability of detached soil for transport and for surface flow, done separately for flow in depressions and for surface flow. In each case there can be net erosion or deposition (Hudson, 1995).

2.5.4.2 Data input for EUROSEM

Input of data facilities of EUROSEM allowed entering data separately for each element into two data files; one for rainfall parameters and the other for catchment characteristics. The format of data files, description of data processing and types of data required were discussed bellow.

2.5.4.2.1 Rainfall data file

There are two main sections for entering rainfall data one section for gauge network data and the other for Rainfall data. Rainfall data should be taken from recording type gauges. If rainfall should be calculated using more than one gauge there is a facility to enter the contribution of each gauge by assigning as weights for different element separately in the gauge network data section. Rainfall data for each gauge with time increments should be entered in the rainfall data section.

2.5.4.2.2 Catchment characteristics data file

Data on Soil parameters, surface conditions of the topsoil, cover characteristic, soil and land management etc. can be incorporated in to the model calculation through the catchment characteristic data input file. The catchment characteristic data file of EUROSEM has four main sections, namely, SYSTEMS, OPTIONS, COMPUTATIONAL ORDER and ELEMENT WISE INFORMATION.

Chapter 3 - Site Selection and Data Analysis

3.1 Introduction

Site selection for the evaluation of different erosion models was done during fieldwork. Input data collection was done at the same time. Before model application, processing and analysis of field data and climatic data were performed for input data extraction. Erosion estimation using field observed data was done for each site. This chapter deals with the selection and description of sites; climatic and field data analysis, the data analysis for erosion modelling using different models and erosion estimation using field observed data for different sites.

3.2 Site selection

Sites with different characteristics related to erosion rates had to be selected for studying the behaviour of different types of models. Before starting the site selection, survey of available literature was performed to find erosion status in site level. It revealed that scale limit of most of the past researches not allowed in finding detailed site information of erosion rates in Naivasha basin. Water erosion risk map of Kenya (Sorter 1997, after Hamududu), shows very high, high and medium water erosion rates in considerable extent in Naivasha Basin. According to Hamududu (1998) water erosion rates modelled through TMU approach proposed by Meijerink (1988), are high in *Longonot* area, moderate in *Kinangop* and *Ndabibi* areas. Ringo (1999) observed generally low erosion hazard in Turasha catchment, which lies in the North Eastern part of the Naivasha basin. Using generalized erosion maps, it was found difficult to identify sites with different erosion rates. Hence aerial photographs, field observations and information from villagers combination with topographic maps, were found useful for the comprehensive understanding of erosion status and in finding suitable sites for this study.

3.2.1 Procedure of site selection

Before field investigation for site selection, aerial photos of scale 1:50000 were examined under stereovision. This helped in identifying probable areas with the likelihood of having varying erosion rates due to slope steepness, relative position of land unit within the landscape, land use/ land cover, internal relief etc. Few sites which, have small ponds that can be used to quantify erosion and sediment yield, were identified by aerial photographs. The aerial photos were taken in year 1984 and they were available only for a part of the Naivasha basin. Therefore in areas where aerial photographs are not available, sites were selected by using information collected from informal interviews, following the pattern of elevation contour distribution and field observation.

3.2.2 Field Observations and Farmer Information

During the field visit, rapid field appraisal was done to select sites, followed by aerial photo interpretation and topographic map references. Field investigation for area selection in those areas was performed giving priority to topographic maps and farmer interviews. During the field investigation for site selection, quick assessment of erosion features of soil surface micro topography as described by Bergsma (1992) was followed.

3.2.3 Identification of sites

Sites were identified from three locations considering, first, the possibility of evaluating erosion status and then the accessibility to the site. Efforts were taken to identify sites, where erosion rates can be quantified using sediment trapping structures, rills created during last season, pedestal occurrence, etc. Severity of occurrence of erosion features on the soil surface was the criteria used for preliminary selection. After comprehensive field investigation following sites were selected from four locations (see table 3-1 and figure 3-1).

Table 3-1: Location of sites selected for the study.

Location	ID	Latitude*	Longitude*	Elevation (m asl)	Land Use
Kijabe	J1	184591	9920450	2192	wheat
Kijabe	J2	184919	9921106	2240	wheat
Kinangop	K1	217529	9942014	2410	grass
Kinangop	K2	217518	9942168	2394	maize
Longonot	L1	224791	9900076	2104	maize
Ndabibi	N1	192912	9920020	1980	maize
Ndabibi	N2	192851	9919828	1972	maize

* UTM zone 37M

3.2.4 Description of different sites

Description of each sites from field observations and farmer descriptions were gathered during fieldwork. Information of cropping patterns, crops cultivated in past, their view on erosion status, rainfall distribution etc. were collected from the farmers. During fieldwork data required on hydraulic conductivity, bulk density, texture of soil by field method and soil samples was collected. Surface features related to erosion were also noted for estimation and evaluation of current erosion status of each site. Information thus collected is given in following paragraphs.

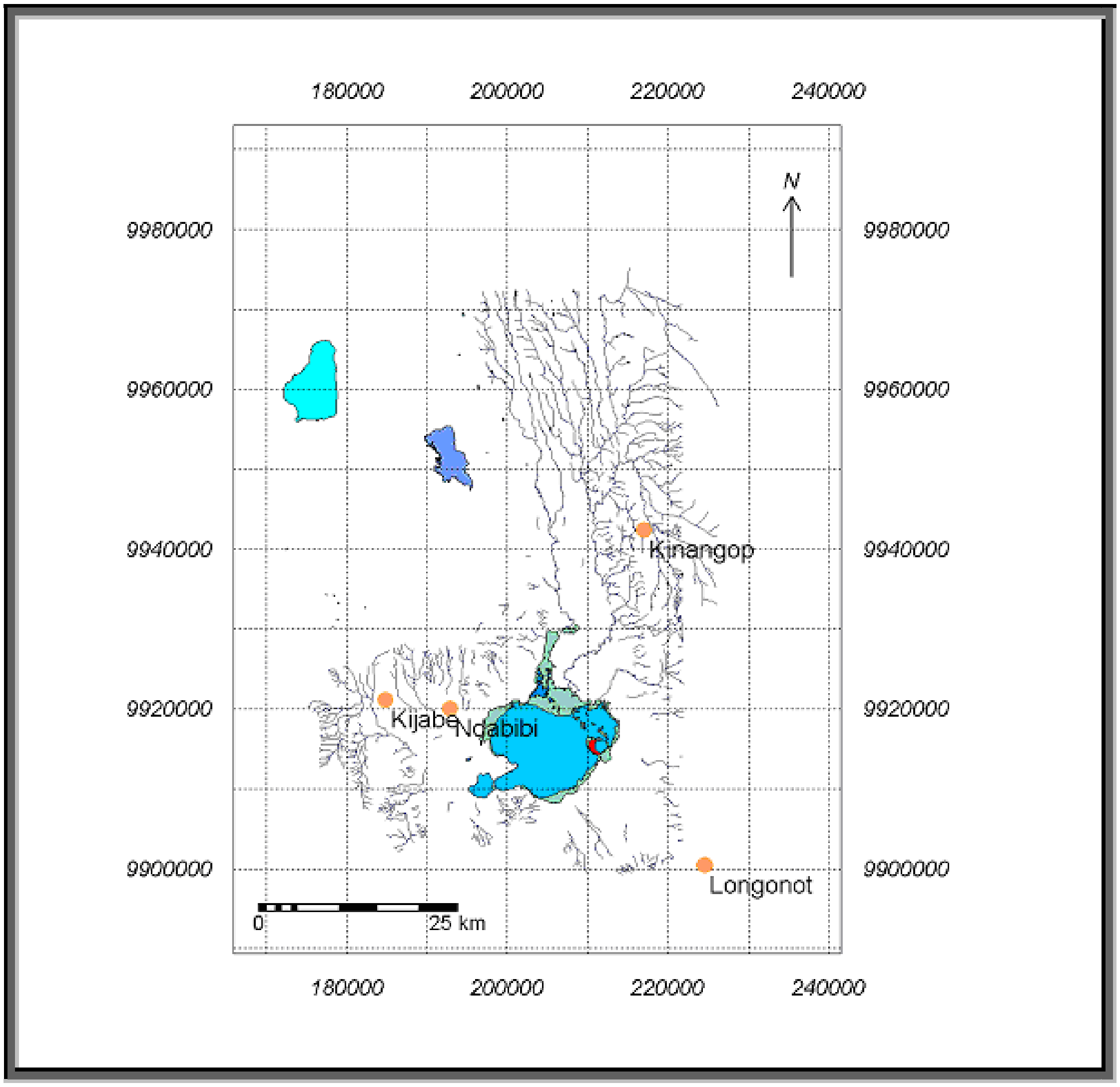
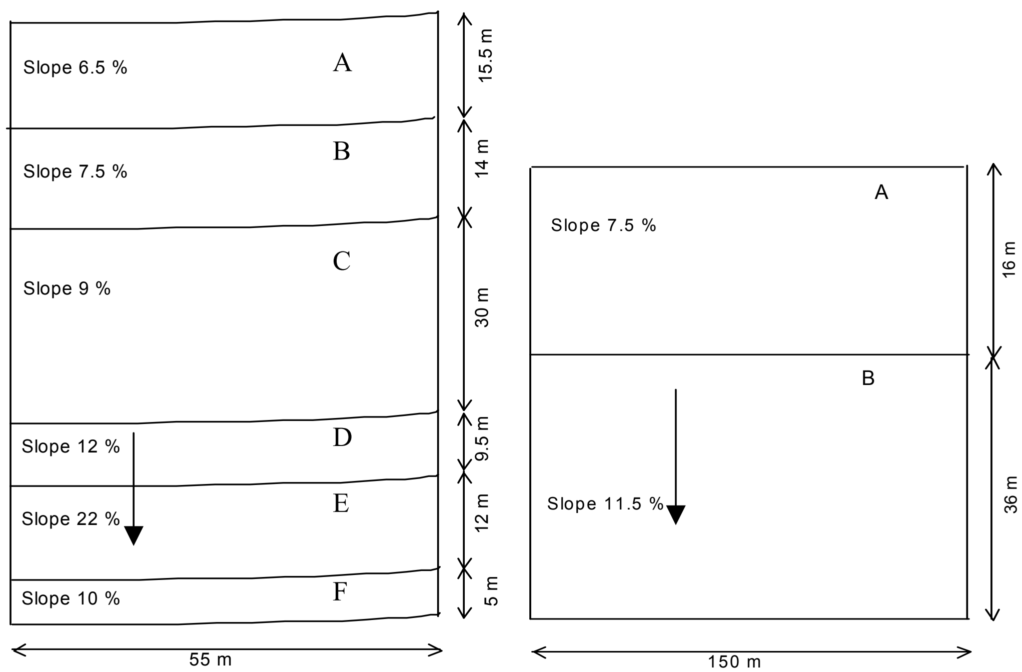


Figure 3-1: Location of selected sites and drainage network of Naivasha area

3.2.4.1 Ndabibi – West of Naivasha basin

Lands selected for the study are used for cultivation of maize as main crop, with beans, pumpkin, and occasionally potatoes. Last few years the main crop was maize in the selected fields. Farmers expect two main cultivation seasons; one starting from February and the other starting from September. But according to farmers most of the time for second season, the lands are abandoned due to lack of rain or due to uncertainty of rain. It was noticed that during periods when it was heavily raining in the surrounding valley and mountains, this area was relatively dry. But according to the farmers, rainfall during the first rain season is normally well distributed spatially. Land preparation for crop cultivation is done using disc harrow



Site 1: Plot of high erosion Site 2: Plot of high erosion

Figure 3-2: Plan diagrams of selected sites from *Ndabibi* area

3.2.4.2 Kijabe – West of Naivasha basin

The sites selected from this area are plots belonging to a large-scale commercial wheat cultivated land. All the cultural practices such as harrowing, seeding, weeding, applying fertilizer etc was done by using combine harvesters. Through out the year wheat crop is cultivated under rain fed condition. According to the manager of the farm, rainfall is more or less well distributed during the year and continuous cultivation of wheat is possible, one cropping cycle after another. The farm was provided with erosion control in the form of dense grass strips 5 years earlier. This strips are about 1.5 – 2m and are quite effective, as is evident from the decrease in slope angle just upstream of the strips, because of deposition. The dense grass filters nearly all the sediment but at a few places runoff flows through the grass to the cultivated strip down slope. Such places have not been selected. Severe erosion during early stage of crop growth was noticed at localized areas. Two sites were selected for further studies. On the surface of the land of both sites, clear rills could be noticed. Those rills must have been emerged due to the cumulative effect of erosion factors occurring after land preparation. The dates of land preparation were 11th and 4th September 2001 for J1 and J2 sites respectively. Plan diagrams of sites are given in figure3-3.

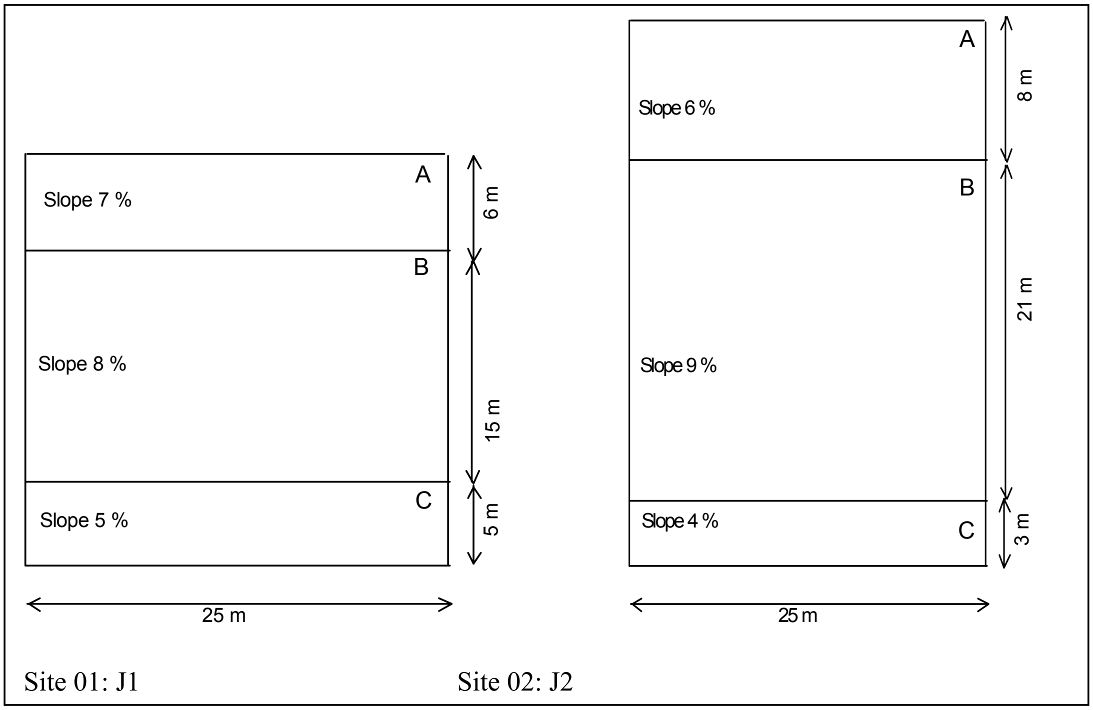


Figure 3-3: Plan diagrams of selected sites from *Kijabe* wheat farm

3.2.4.3 Kinangop – North East of Naivasha basin

In this area rainfall is well distributed through out the year and soil is much permeable and most of the season the land is covered by vegetation. Therefore the erosion rates were found to be low. One catchment was selected from the area. The catchment can be divided into two main elements; one cultivated with seasonal crops and the other is grassland maintained for about 4 years continuously for grazing. Cropland is used for crops such as maize, potatoes, pea, pumpkin, etc. under rain fed condition and well-distributed rainfall pattern for this area allow for efficient cultivation during both seasons. At the down slope end of the catchment, there is a pond constructed for runoff water collection and as a sediment trap. Width of the pond is about 24m and length is about 70m and the shape of the pond is semi elliptical (figure 3-4). The area of the pond was calculated as 1268 m^2. During dry season, farmers remove the sediment collected in the pond. Annual removal of the sediment collected at the bottom of pond is on average 15 cm annually, according to the information of farmers. It is likely that the depth is a maximum value, as not the entire may be de-silted. The area of the cropland is 39600 m^2 and area covered by the grassland is 38300 m^2. Average slope is 10% and 7.5%, respectively on the cropland and grassland.

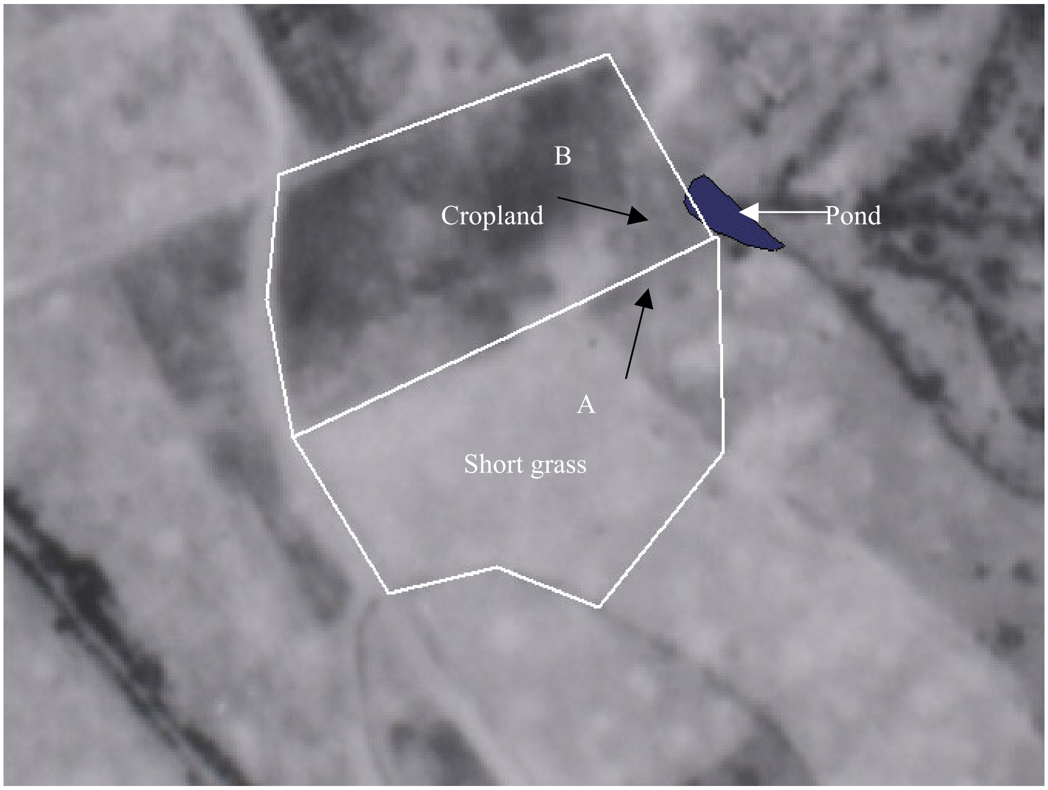


Figure 3-4: Catchment from *Kinangop* overlaid on aerial photo

3.2.4.4 Longonot- South East of Naivasha basin

According to the farmers of the area, most of the time crops fail due to uncertainty of rainfall and during the last 2 years crop cultivation was not good enough to meet their expectations. They revealed that even a little rain in dry season creates concentrated flows of runoff and sedimentation. Investigations on soil surface showed that the surface sealing is a prominent feature in the area and rill density and depth of rill was high despite soil conservation measures practiced by the farmer. Contour planting and contour drain cutting for runoff and sediment tapping could be seen as conservation measures practiced in this farm. Maize has been cultivated under rain fed conditions for the last few years. Crops this year have failed due to water shortage during flower initiation stage of the crop.

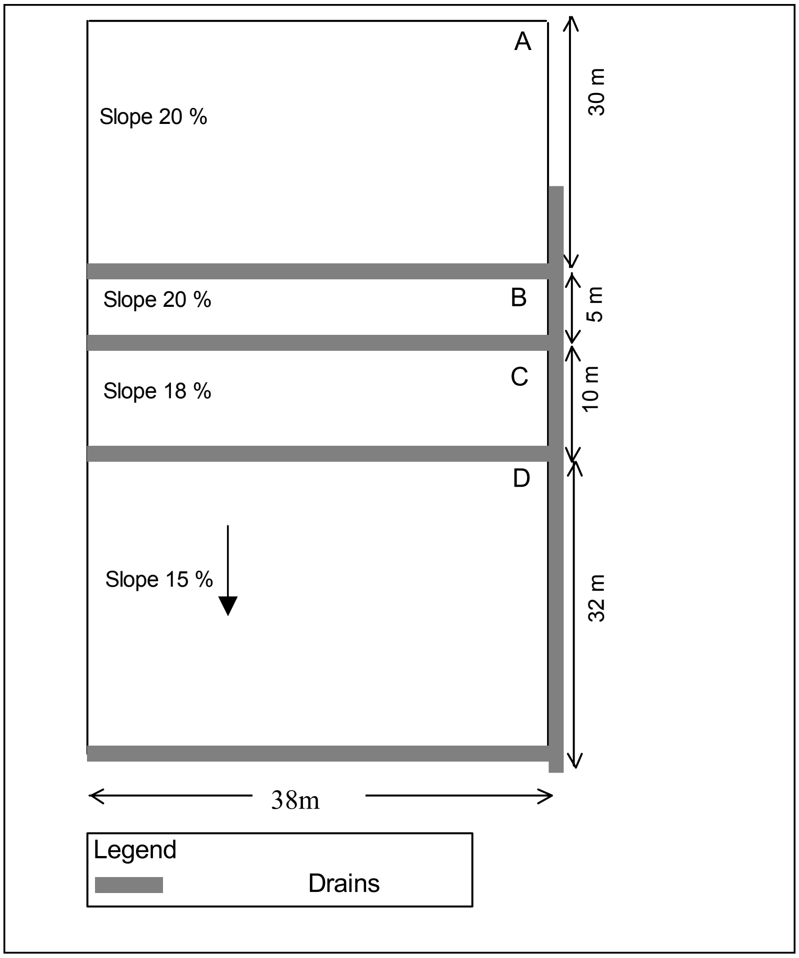


Figure 3-5: Plan diagrams of selected site from *Longonot*

3.3 Data Collection

Data required for EUROSEM, USLE, the Morgan model and field erosion estimation were collected for all sites. Data on different soil parameters, crop management in relation with vegetative cover, land management etc. and climatic data such as rainfall etc were collected during fieldwork.

3.3.1 Rainfall

A recording (tipping bucket type) rain gauge was installed for two weeks at the site of *Kijabe* site 02, to understand the rainfall intensity patterns and to compare the variability of rainfall with other nearby rain station records. Apart from that rain gauge, daily rainfall data for *Kijabe* and *Ndabibi* for the year 2001 up to the end of September and past rain records from WREM database of ITC were collected for the study.

3.3.2 Soil, vegetative and hydrological parameters

Soil texture for each site was primarily determined by using the texture chart in the field and by performing soil textural analysis for each element of every site by using composite samples. Element wise information on micro topographic feature; number of rills, extent of eroded surface, occurrence of pedestals, signs of splash erosion, etc were also collected. Saturated hydraulic conductivity (K_s) was measured using auger hole method. Bulk density was determined by using an augur and thin flexible bags. The method was to remove all the soils of augur hole carefully and to measure the volume of the hole by adding a known volume of water into a polythene bag in the augur hole. The soil removed from the hole, was weighted after oven drying and calculated the bulk density for each site. Data on cropping patterns, crop types cultivated during past seasons, etc were collected to derive the temporal variation of land cover for each site. Most of the data on agricultural practices were collected by informal farmer interviews and from literature.

3.4 Analysis of Field Data and Climatic Data

Field evaluation of erosion for each site would give the resulting erosion from cumulative effect of erosion factors occurred after land preparation. Therefore the modelling of erosion was limited to the period and data analysis was done for each site for the period from date of land preparation to the date of field data collection. The duration considered for each site is given in Table 3-2.

Table 3-2: Some of the collected information from each site.

Location	ID	Land preparation date	Data collection date	Field Determined Soil Texture (Texture Chart)	Method of land preparation*
Kijabe	J1	04 / 08 / 2001	17 / 09 / 2001	Silt Clay	DH/ CH
Kijabe	J2	25 / 08 / 2001	20 / 09 / 2001	Silt Clay	DH/ CH
Kinangop	K1	February 2001	14 / 09 / 2001	Silt Clay	DH
Kinangop	K2	4 years old	14 / 09 / 2001	Silt Clay	--
Longonot	L1	February 2001	26 / 09 / 2001	Sandy Clay Loam	M
Ndabibi	N1	February 2001	21 / 09 / 2001	Sandy Clay	DH
Ndabibi	N2	February 2001	21 / 09 / 2001	Sandy Clay	DH

• *Land Preparation Method; H – Disc Harrow, CH – Combine Harvester, M- Manual*

Table 3-3: Description of features of each site selected for the study

Location	ID	Crop/ Vegetation	Slope range %	Slope Shape	Deposition area	Prominent Features
Kijabe	J1	wheat	5-8	Weak Concave	10%	Rills
Kijabe	J2	wheat	4-9	Weak Concave	15%	Rills
Kinangop	K1	maize	10-11	Straight concave	Not prominent	No rills
Kinangop	K2	grass	7-8	Straight concave	Not prominent	No rills
Longonot	L1	maize	15-20	Convex	<5%	Rills
Ndabibi	N1	maize	12-22	Convex/concave	< 5%	Rills
Ndabibi	N2	maize	7-12	Concave	< 10	No rills

3.4.1 Soil properties

Soil properties for erosion are included Data on soil properties for erosion modeling were collected in the field.

3.4.1.1 Organic carbon content of the topsoil

Organic matter content of the soil was determined following the Walkley-Black procedure (Reeuwijk, 1995) in the soil laboratory of the ITC.

Table 3-4: Organic Carbon content and Organic matter content

Site ID	Organic Carbon %	Organic matter %
J1	4.7	8.2
J2	5.1	8.7
K1	5.3	9.1
K2	3.2	5.4
L	2.3	4.0
N1	2.4	4.1
N2	2.8	4.8

3.4.1.2 Soil Texture

Processing of input parameters for models need the texture of soil. The primary soil texture classes were determined by using texture chart field method (Appendix II) during fieldwork. Texture classes determined according to the texture chart are presented in the table 3-2. According to the results most of the soils in selected fields are clay soils. Laboratory analysis for particle size distribution using pipette method (Reeuwijk, 1995) was carried out for samples taken from each site.

Table 3-5: Particle size distribution of topsoil

ID	Clay% (<0.002 mm)	Site % (0.002-0.05mm)	Very fine sand % (0.05-0.125mm)	Sand% (0.125-20mm)	Texture According to Particle size
J1	26.7	30.2	20.3	14.5	Clay loam
J2	26.7	30.2	20.3	14.5	Clay loam
K1	32.0	32.0	13.4	15.4	Clay loam
K2	36.5	28.2	13.8	16.0	Clay loam
L1	14.0	28.6	21.7	31.7	Sandy Loam
N1	18.5	29.0	27.0	21.3	Sandy Loam
N2	15.0	31.8	20.9	27.6	Loam

According to the nomenclature United States Department of Agriculture (USDA) and the texture triangle (figure 3-6), texture classes were determined for each site. The texture classes determined were given in Table 3-5. The texture determined by field method gives only a rough estimate because it can be varied person to person; the decision taken by person according to the feel of grittiness of small amount of wet soil.

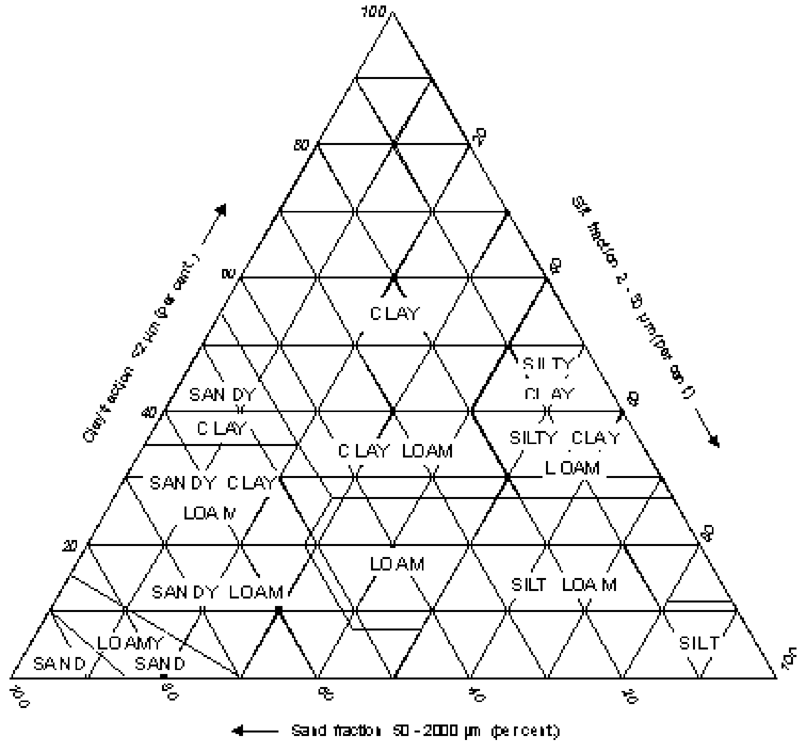


Figure 3-6: Soil texture triangle according to USDA nomenclature

3.4.1.3 Bulk density

As shown in table 3-6, the bulk density of the topsoil is very low. This is due to the parent material, which consists of volcanic stuff containing pumice. Furthermore, the organic matter content (see table 3-4) is high. The low bulk density of some sites cane be related with loose topsoil when harrowing for land preparation, especially in wheat fields (J1 and J2).

Table 3-6: Bulk density for different sites.

ID	Land Use	Bulk Density g/cm^3	Standard Deviation
J1	wheat	0.99	0.30
J2	wheat	0.84	0.11
K1	maize	0.71	0.22
K2	grass	1.05	0.12
L1	maize	1.02	0.11
N1	maize	0.93	0.03
N2	maize	0.93	0.16

3.4.1.4 Hydraulic conductivity

When it rains, the rate of rainwater absorbance by surface soil (infiltration) is important to determine the runoff component of the water balance. The infiltration rate depends on the surface condition, properties of soil matrix, instantaneous soil moisture content, rainfall intensity, etc.. During rain, wetting front of topsoil will expand and make moisture saturation zone and mean time infiltration rate decreases towards saturated hydraulic conductivity (Chow et al., 1988). In erosion models the permeability of soil is included as saturated hydraulic conductivity (K_s). The USLE use the K_s, to determine the permeability class of soil for calculation of erodibility (Wischmeier and Smith, 1978), Infiltration is a complex process that varies for every event and it is difficult to achieve proper estimates that cover the whole study are in time and space (Wit, 2001). The elements are separated according to the similarity of some characteristic such as slope, number of rills, deposition, etc.. Heterogeneity of topsoil in elements is less. In each element of selected sites, the K_s was measured at many locations.

The saturated hydraulic conductivity of the soil was estimated by the inverse augur hole method (Oosterbaan, 1994). The procedure as follows; first a hole with radius r and depth D is augured. The hole is pre-wetted by maintaining the head of the water level at the top of the hole. After about 30 minutes the wall and the soils around hole are assumed as saturated with water. Based on the Darcy's law, using equation 3-1 and 3-2 the K_s was calculated for each element.

$$Q_{in} = -\pi r^2 * dh/dt = K_s A_s = 2K_s \pi r(h + r/2)$$ (Darcy's [K_s]) **Equation 3-1**

where,

Q_{in} = quantity of infiltrated water (mm^3)
r = radius of auger hole (mm)
t = elapse time at the moment (s)
h = water level in hole (mm)
K_s = Saturated Hydraulic Conductivity
A_s = surface over which the water infiltrates into the soil at time considered (mm^2)

Rearranging the equation 3-1 the K_s can be separated.

$$K_s = r/2\left[\frac{\ln\left(h_{(t_1)} + r/2\right) - \ln\left(h_{(t_2)} + r/2\right)}{(t_2 - t_1)}\right]$$ **Equation 3-2**

Linear section of the curve between (h+r/2) and elapse is related to saturation or constant infiltration rate (figure 3-7). Under saturated condition, the relation between log (h(t)+r/2) and elapse time is linear (figure 3-8). Using linear regression tool, slope of the curve and the K_s was calculated for each site.

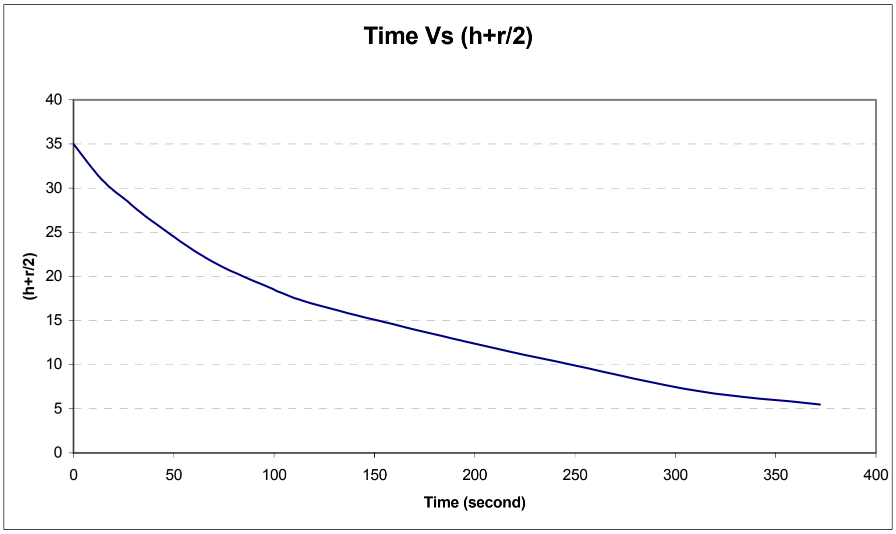


Figure 3-7: Relationship between (h+r/2) and elapse time for Ks calculations in *Longonot* Site

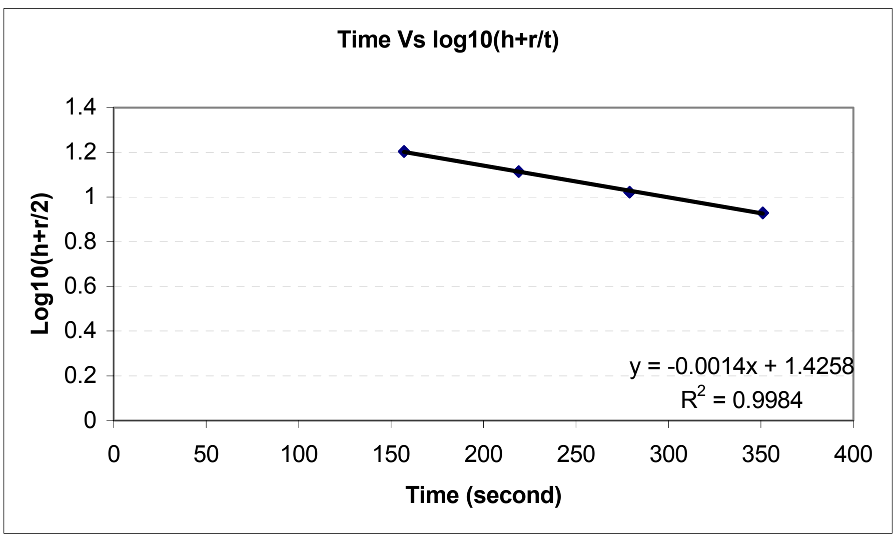


Figure 3-8: Curve and regression line between log (h+r/2) and elapse time in *Longonot* area.

The field condition was dry during most of the period of the data collection. Hence to get a constant absorption rate, in most cases one dry run and 2 or 3 wet runs were used, after the soil gets well saturated. As shown in table 3-7, Ks values obtained are much higher than those reported in the literature, according to their texture (Saxton, 1986). Wit (2001), in a study in Guadalentin basin, southeast Spain, observed similar range of K_s Values for loamy soils. His experiment resulted in a minimum of 1.84 and maximum 34.6 cm/hr; K_s values those determined by using inverse auger hole method. This means that, K_s value derived according to soil texture classes is not valid for every region and for the K_s variations; soil texture is not the only variable for all soils.

Table 3-7: Hydraulic conductivity measured with Auger hole method

Location	ID	Element	Hydraulic Conductivity (K_s) (cm/hr)		Texture Class (Texture Chart)
			Dry run	Wet run	
Kijabe	**J1**	**A**	3.7	1.8	Clay loam
		B	9.3	1.3	Clay loam
		C	1.6	1.4	Clay loam
Kijabe	**J2**	**A**	4.9	4.9	Clay loam
		B	3.3	1.6	Clay loam
		C	6.6	4.9	Clay loam
Kinangop	**K1**		1.14	0.45	Clay loam
	K2		0.49	0.33	Clay loam
Longonot	**L1**		36	24	Sandy Loam
Ndabibi	**N1**	A	13	10	Sandy Loam
		B	13	10	Sandy Loam
		C	13	10	Sandy Loam
		D	16	13	Sandy Loam
		E	23	21	Sandy Loam
		F	23	21	Sandy Loam
Ndabibi	**N2**	**A**	16	13	Loam
		B	16	13	Loam

3.4.2 Estimation of soil loss using rill data and sediment yield

Eroding clods indicate areas where splash is the dominant process. The flow surfaces indicate dominant inter rill erosion, the pre-rill and rill area indicate the rill erosion. The different features indicate different erosive conditions. Qualitative evaluation of erosion hazard can also be done studying these surface features and the area fraction related to each type of erosion (Bergsma, 1992). The rills are formed due to the removal of topsoil resulting from the cumulative effect of factors, after the land preparation. The rill volume can be estimated using cross-area of the rill taken at regular length sections by multiplying the cross-area and the section length. The estimation of rill volume gives a part of soil that was eroded concentrated rill flow during the period considered. Hence the rill volume can be considered as the minimum erosion during the period. Therefore, sites, which have rills, the minimum soil loss were estimated by using rill volume. In the site selected from *Kinangop* area, the North of Naivasha, sediment yield removed annually from a pond that collect all the runoff and sediment generated from catchment was used for the erosion estimation. For calculation of weight basis soil loss, using rill volume multiplied by the average bulk density of the site. Topsoil of all the fields selected for the study was well ploughed and very loose. Therefore, bulk density values are comparatively lower than the values given in literature for relevant texture classes (Table 3-7 and Appendix I).

Table 3-8: Erosion estimates using rill volume and sediment data

Location	ID	Eroded soil volume (m^3)	Area of site (m^2)	Estimated soil loss during period (kg/ha)
Kijabe	J1	45	625	>706
Kijabe	J2	26	725	>298
Kinangop	K1	12680	38300	<1432
Kinangop	K2		39600	
Longonot	L1	360	2930	>1255
Ndabibi	N1	96	4730	>189
Ndabibi	N2	N.A.	7800	N.A

3.4.3 Rainfall Data

3.4.3.1 Spatial and temporal variability of Daily rainfall

Daily rainfall data from three close stations were analysed to check for the spatial and temporal variability within the area. Duration considered for correlation analysis is 1st of January and 30th of September 2001. The upper *Ndabibi* site, only 2 weeks rainfall was collected during fieldwork. The correlation of amount of daily rainfall of different stations was examined. The location map of stations is shown in figure 3-9.

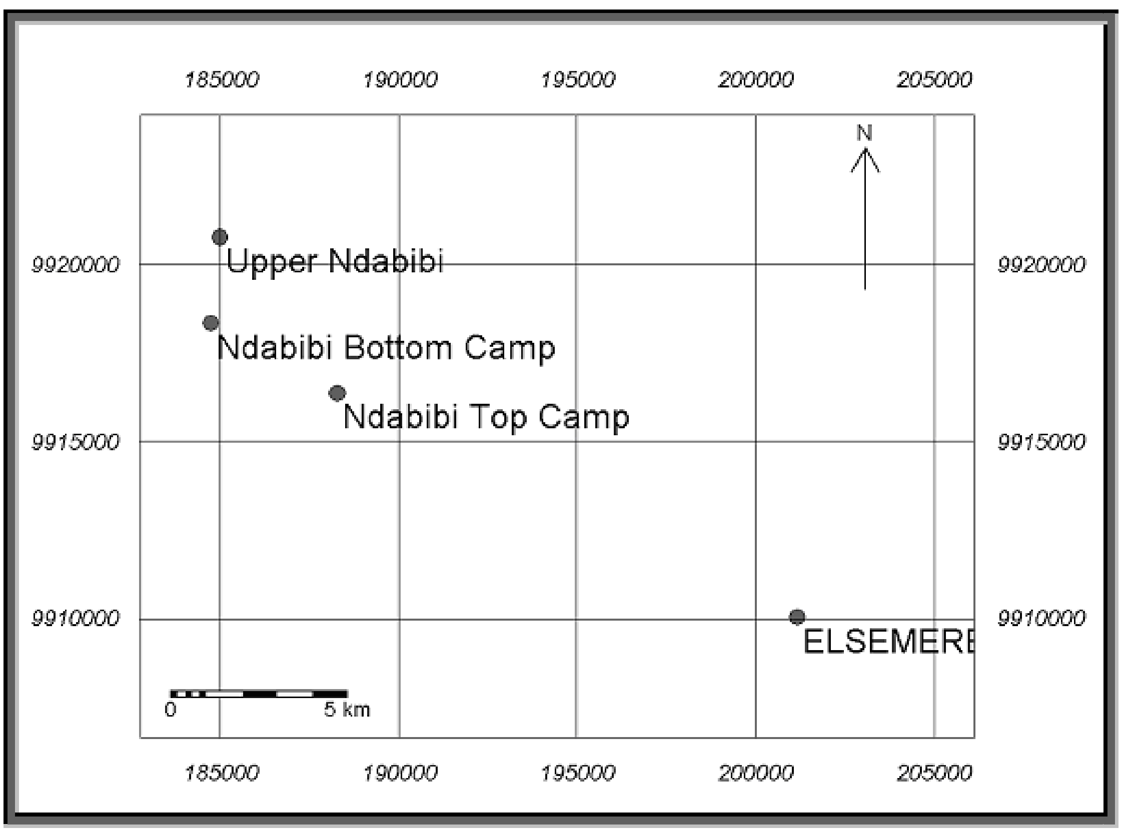


Figure 3-9: Location map of rainfall stations around *Ndabibi* and *Kijabe*

Table 3-9: Covariance and Correlation Between Daily rainfall data

Parameter	(A,B)	(A,C)	(B,C)
Distance (m)	14360	18400	4045
Elevation differ. (m)	129	253	124
Covariance	8.59	6.18	16.72
Correlation	0.27	0.22	0.54

A- ELSAMERE, B-Ndabibi top camp, C- Ndabibi bottom camp

The analysis shows weak correlation among the daily rainfall of three stations. But the rainfall of stations close together showed higher correlations than the stations for apart.

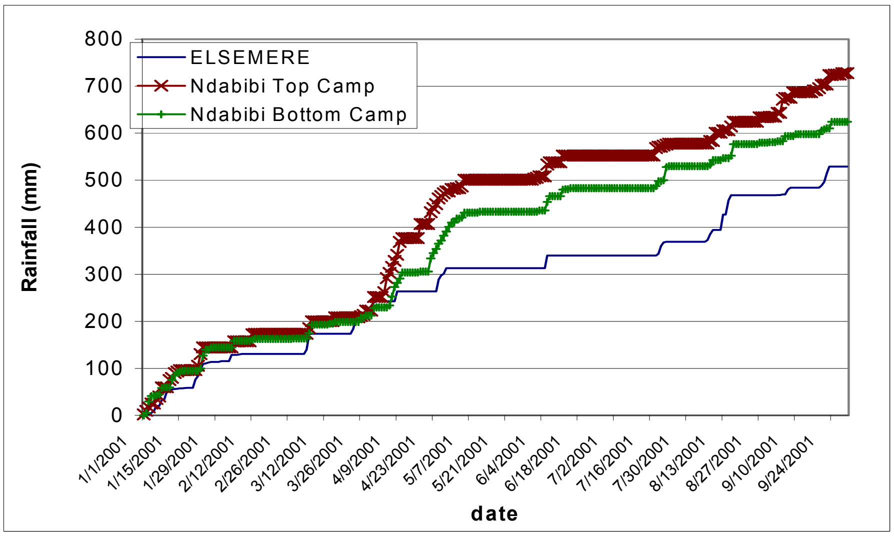


Figure 3-10: Comparison of cumulative rainfall from three stations

According to the cumulative rainfall recorded at three stations as shown in figure 3-10, the duration of rain is more or less matched during January to April except the station data at ELSAMERE. But the amount rained during the period is not distributed similarly. In the month of April 2001, considerable variation of cumulative rainfall can be observed. According to the figure 3-10, even for stations close to each other, intense rain which can induce runoff and erosion, can be different, hence the erosion rate.

3.4.3.2 Occurrence of erosive rain storms

Many researches proved that, most erosion takes place in two or three storms each year on hillside plots and in small watersheds in Europe (Morgan, et al., 1998). Frequency of occurrence of high amount daily rainstorm was examined for daily rain from three station of study area (see figure 3-11). More than 30% of rainy days, amount of precipitation was less than 7 mm. The rainstorms exceeding 25mm per day occurred in less than 10% of rainy days. That means the infrequent high daily rainstorms can be expected this region, causing most of the erosion.

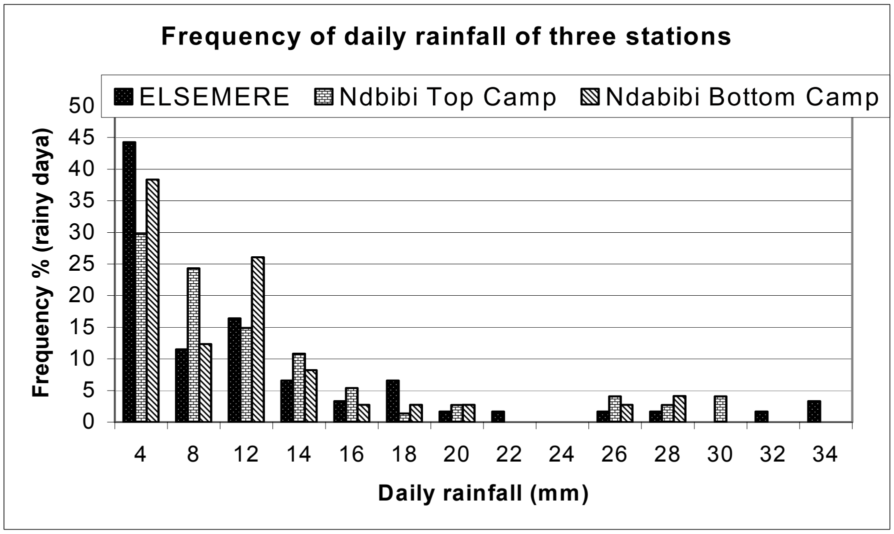


Figure 3-11: Comparison of frequency of rainstorm recorded at three different stations during January to October 2001

3.4.3.3 Daily rainstorm duration

Storm rain amount it self is not enough for the evaluation of rainfall characteristics that influence erosion. The duration and the intensity are essential parameters here. Mannaerts (2000) showed that knowledge of storm rain amount and the duration can be used to estimate erosivity. The storm duration and amount rain were plotted in figure 3-12 using recording rain gauge data for 1999 recorded at *Kinangop* station. It shows that the average storm duration of this area is 4 hours for rainstorm between 3 and 12 mm. Average storm duration of medium storms (13-17mm) are around one hour. The intensity calculation considering the total duration and the storm amount will not give enough intensity values that exceeds infiltration rates of the area (see table 3-7 for K_s).

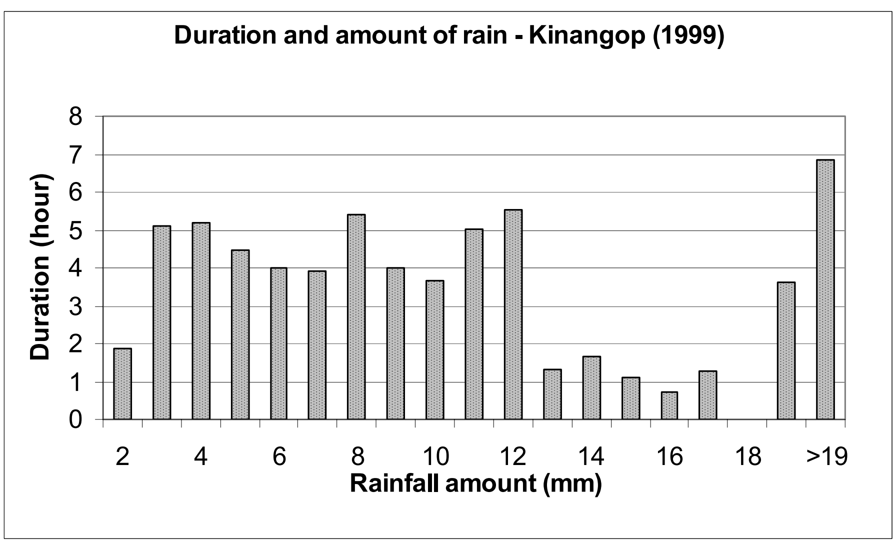


Figure 3-12: Duration and the amount rained

3.4.3.4 High intense rain for shorter duration

If the intensity of rainfall is calculated for smaller intervals, the high intense rainfall prevailed for shorter durations can be traced. The figure 3-13 and 3-14 shows the intensity of rainfall calculated using different time intervals. Higher the time interval considered, lower the interpreted intensity. It is better to determine rainstorm intensity variation with shorter time intervals but lack of required data types make it inconvenient. USLE and the Morgan model do not consider the high peaks of intensity for calculation of erosion. Event based models (EUROSEM) deals with these types of recording data.

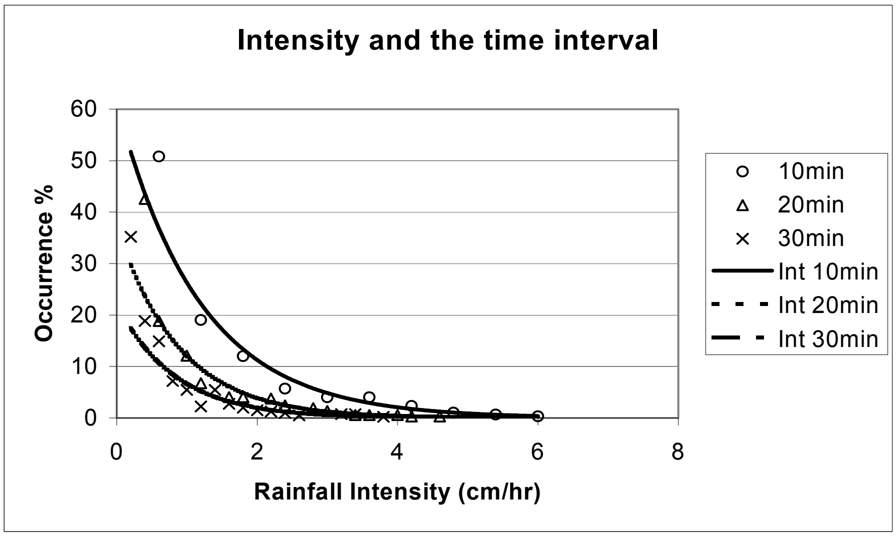


Figure 3-13: Intensity calculated for different time intervals

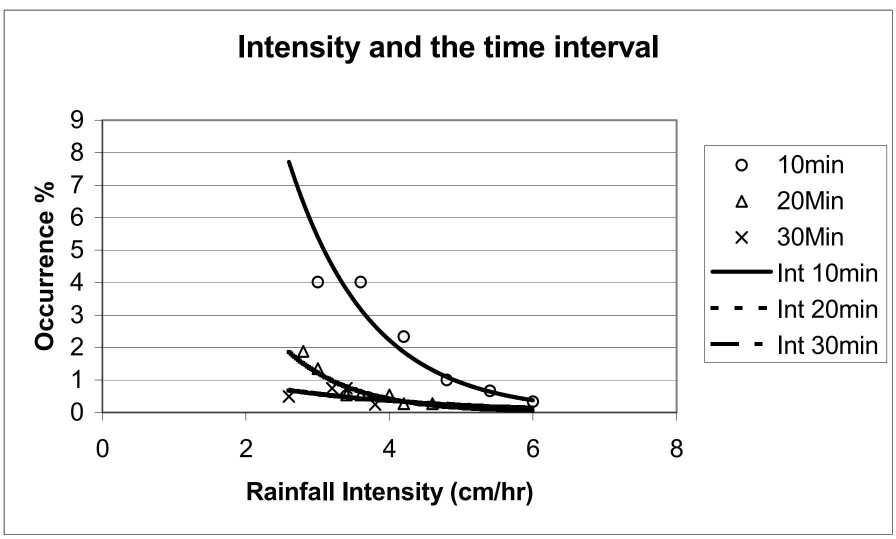


Figure 3-14: Intensity calculated for different time intervals (2-6 cm/hour)

3.4.3.5 Storm amount and intensity distribution during a rainstorm

Intensity distribution pattern within a storm differs event to event. As shown in figure 3-15, small rainstorms can produce very high intensity for a short period. If the topsoil is saturated, exceeding the infiltration rates, this type of storms can initiate runoff and erosion.

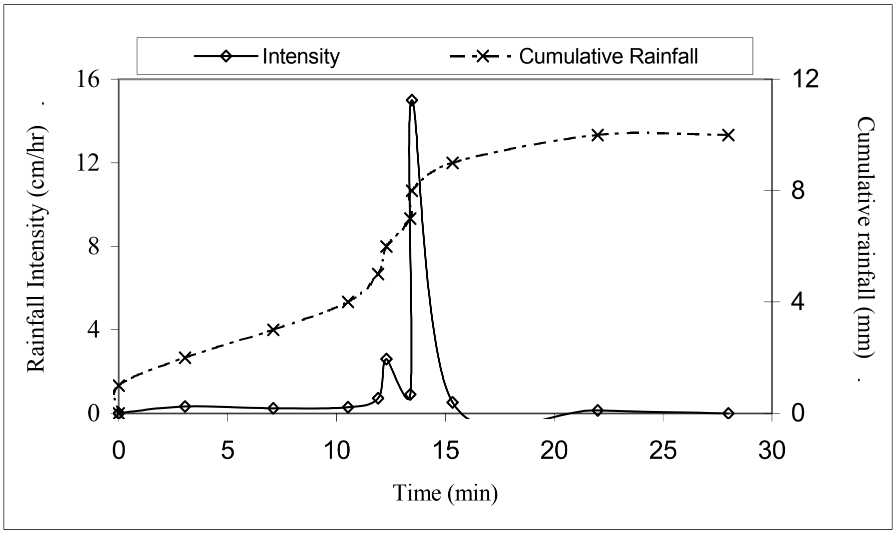


Figure 3-15: Variation of storm intensity and cumulative rainfall for low amount rainstorms in *Kinangop* during October

In some occasions, fairly large rainstorms do not give high intensity rainfall even for shorter durations (see figure 3-16).

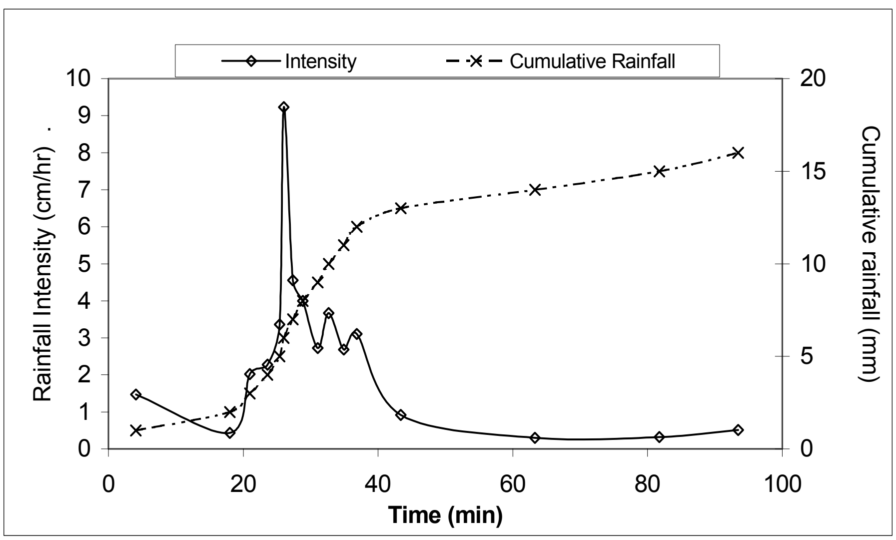


Figure 3-16: Variation of storm intensity and cumulative rainfall for medium amount rainstorms in *Kinangop* during October

Two peaks of rain depths even within 30 minutes will results low intensive rainstorms, despite high amount of rainfall with one hour (see figure 3-17).

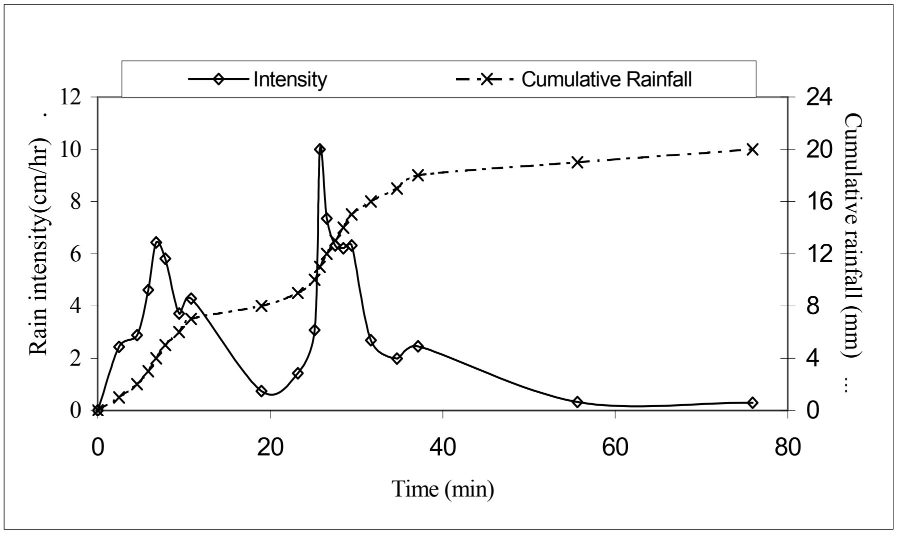


Figure 3-17: Variation of storm intensity and storm depth of two peak rainstorms in *Kinangop* during August

3.4.3.6 Rainfall, infiltration, surface sealing on erosion

Infiltration rate reduces with time when it rains. If rain rate exceeded the infiltration rate, the excess water remains on the surface will contributes to runoff and erosion. A rainstorm after a dry spell may not create runoff due to high initial infiltration rate. As illustrated at point ① in the Figure 3-18, some rainstorms are not strong enough to create runoff. But if rain continues, runoff occurs as infiltration decreases further.

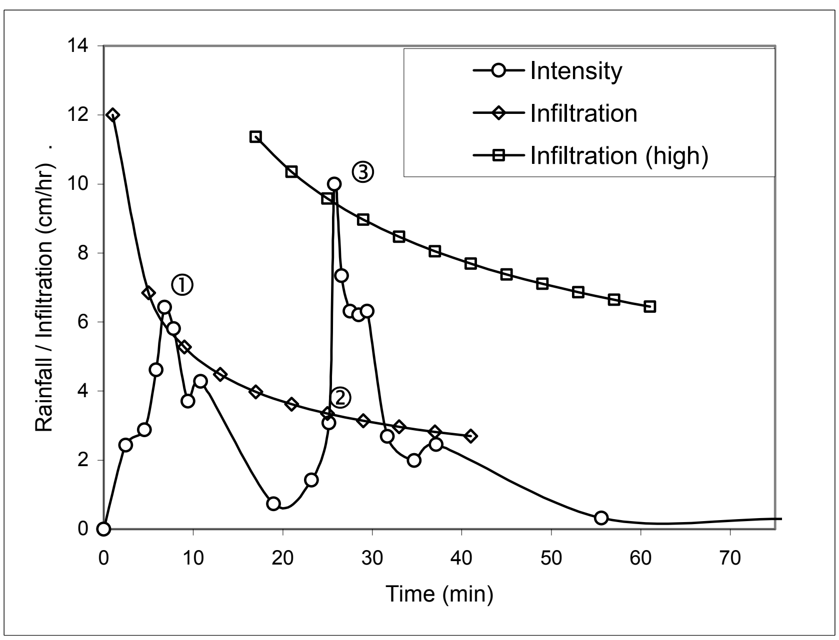


Figure 3-18: Effect of surface sealing during a storm & potential for runoff generation

In the study area infiltration rates were found to be very high if soils were not crusted. Hence, runoff could be little, even with high intensity rainfall, see point ③ in the figure.

This is not the case in most of agricultural lands. Impact of raindrops on the soil surface develops surface sealing, thus reducing enormously the infiltration rate. Therefore runoff and erosion can be intensified due to the development of surface sealing or due to soil compaction resulting from either large storms or from previous rains. Surface sealing was observed in the field at various locations. As mentioned, infiltration rates of the soil below the surface are high, and thus one could expect little or no erosion. The fact that moderate erosion was observed from the surface features, i.e. rills and pedestals, points to the importance of surface sealing or crusting. As no artificial rainfall instrument was available, no experimentation could be done to learn, for example how fast sealing can develop under varying rainfall rates.

Chapter 4 - Erosion Modeling

4.1 Introduction

Model application for erosion assessment is common for erosion risk mapping. Ringo (1999), Hamududu (1998), and many others, have applied USLE and the Morgan model under GIS environment for erosion assessment in Naivasha and found that erosion rates were very low within the area and compared differenced between model results. Assessed erosion rates may vary according to model type applied and also according to the characteristics of land units. Field observations revealed highly eroded localized areas within the catchment. For selected sites erosion models have applied and compared to evaluate the ability of each models to separately identifying lands according to its erosion status.

4.2 Universal Soil Loss Equation (USLE)

As described in chapter two, data preparation for USLE sub factors and erosion assessment for each site are discussed below.

4.2.1 Erosivity

Erosivity reflects the power of rainfall to cause soil erosion. Although it is given as a function of rainfall intensity in many equations, kinetic energy per in unit rain amount depends on the drop size distribution of storms. Drop size distribution varies regionally. Therefore, it is advantages to derive erosivity indices using rainfall characteristics. But the erosivity indices for many areas are not yet developed. Regression relationships developed for erosivity calculations from rain amount are common, especially for data scares areas. Bols (1979) developed a relation between daily rainfall (P_{24}) and EI_{30} as EI_{30}=a P_{24}^{b}. He used 2850 pairs of EI_{30} and P_{24} of 15 stations in Java, Indonesia to determine 'a' and 'b' by regression. The result is $EI_{30} = 2.34*(P_{24})^{1.98}$ with r=0.96. Bols found for some stations differences in 'b' from one year to another, but not for other stations. As discussed earlier, Mannaerts (1992) derived several relationships between erosivity and daily rainfall, storm rainfall and rain duration for Cape Verde (see chapter 2).

As in the case of many data scarce areas, no erosivity indices can be found for Naivasha region. Hamududu (1998) derived an equation by regression analysis for monthly erosivity using monthly rainfall amount for erosion assessment in Naivasha area as $EI_{30}=2.1745*P_{month}-5.7867$ where P_{month} is monthly rainfall in mm. The relationship was developed using rainfall data of one year and the R^2 for this relationship is 0.75.

Availability of rainfall data for the region during the study year is rather limited. In the areas where the study focussed, available data on rainfall is on daily basis except for 2 weeks when a tipping bucket type gauge was installed near *Kijabe* wheat farm site. Using available past rainfall data from tipping bucket type rain gauge, relationships were developed between EI_{30} erosivity index and daily rainfall amount by using regression analysis. The kinetic energy was calculated using the method described by Wischmeier and Smith (1978). The relationships were shown in the figure 4-1.

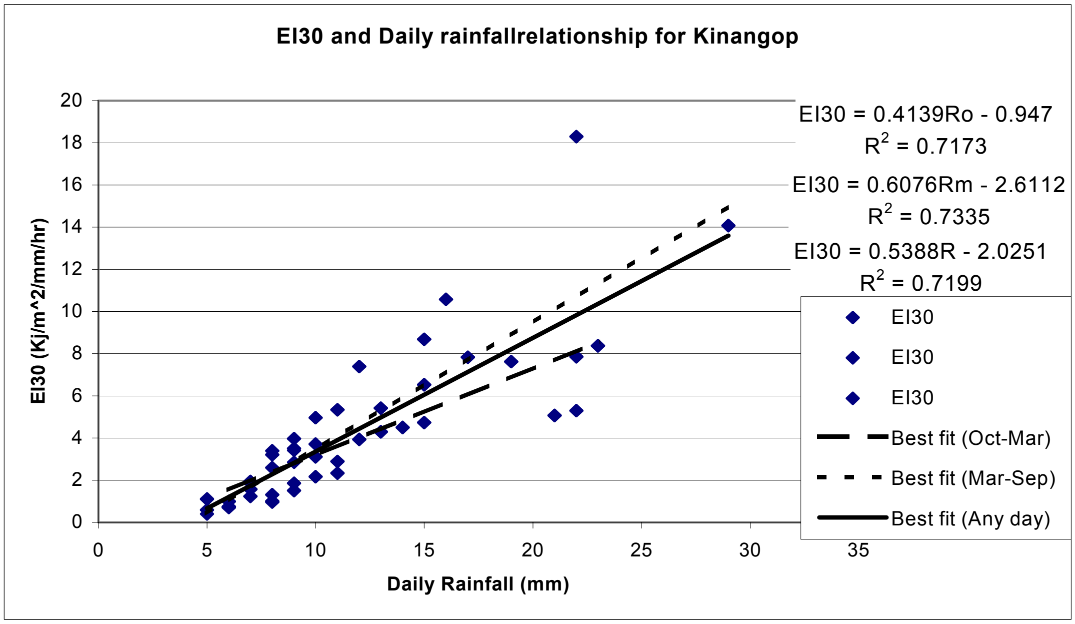


Figure 4-1: Relationship between EI30 index and daily rainfall in *Kinangop* Station

Equations derived for Erosivity calculations:

$$EI_{30} = 0.4139P_{24} - 0.947$$ (Erosivity for October – March) **Equation 4-1**

$$EI_{30} = 0.6076P_{24} - 2.6112$$ (Erosivity for March – September) **Equation 4-2**

$$EI_{30} = 0.5388P_{24} - 2.0251$$ (Erosivity for Any date) **Equation 4-3**

Where the P_{24} is daily rainfall in mm and the EI_{30} is in kJ $m^{-2}mm.hr^{-1}$. These relations were used for the calculation of erosivity in this study using daily rainfall data. The erosivity was calculated for the period considered for field evaluation erosion rates.

Table 4-1: Erosivity calculated for each site

Location	ID	EI $_{30}$ ($kJ.m^{-2}.m.hr^{-1}$)
Kijabe	J1	39.9934
Kijabe	J2	26.561
Kinangop	K1	179.3209
Kinangop	K2	179.3209
Longonot	L1	158.8216
Ndabibi	N1	159.5928
Ndabibi	N2	159.5928

4.2.2 Soil Erodibility

Erodibility of a soil gives its susceptibility or vulnerability to erode by both rainfall detachment and runoff. As mentioned by Hudson (1995-1), there are few groups of parameters, which affect erodibility. They include soil chemical and physical composition, topographic features and management condition of lands. In the USLE, the erodibility is included as a factor, which gives soil erosion per unit erosivity in a bare, continues fallowed land. Wischmeier and Smith (1978) developed a nomogram and regression equation to calculate erodibility of soils using permeability, structure, textural composition and organic matter content of soil. The erodibility was estimated accordingly using equation 2-5 in chapter 2.

Permeability code was assigned according to the saturated hydraulic conductivity determined by augur hole method during the fieldwork. Permeability of soils was high because of the well-ploughed topsoil in some sites. Sites under cultivation Structure code was assigned according to the structure determined.

Table 4-2: Permeability code assigned for hydraulic conductivity class

Saturate hydraulic conductivity (cm/hr)	Permeability Code
>6.0	1
1.0-6.0	2
0.5-1.0	3
0.2-0.5	4
0.1-0.2	5
<0.1	6

Table 4-3: Structure of soil and structural code

Structure	Structural Code
Vary fine granular	1
Fine granular	2
Medium sub angular	3
Massive Blocky	4

Table 4-4: Permeability and Structural code assigned for each site

Soil ID	Ks (cm/hr)	Permeability code	Structure	Structural code
J1	1.3	2	Medium granular	3
J2	1.6	2	Medium granular	3
K1	0.45	4	Massive/Blocky	4
K2	0.33	4	Medium granular	3
L	33	1	Massive	4
N1	10.	1	Massive	4
N2	13	1	Blocky	4

Table 4-5: Size limits of soil separates in the USDA soil textural classification system

Name of soil separate	Diameter limits (mm)
Very coarse sand	2.00 - 1.00
Coarse sand	1.00 - 0.50
Medium sand	0.50 - 0.25
Fine sand	0.25 - 0.10
Very fine sand	0.10 - 0.05
Silt	0.05 - 0.002
Clay	< 0.002

Table 4-6 : Organic matter and particle size distribution of topsoil

Soil ID	Organic matter %	Clay % < 0.002 mm	Silt % 0.002-0.05mm	Very fine sand % 0.05-0.125 mm	Coarse Sand % 0.125-2.0 mm
J1	8.2	26.0	30.0	20.5	15.0
J2	8.2	26.7	30.2	20.3	14.5
K1	9.0	32.0	32.0	13.0	14.0
K2	5.4	36.5	28.2	13.8	16.0
L	4.0	14.0	28.6	21.7	31.7
N1	4.1	18.5	29.0	27.0	21.3
N2	4.7	15.0	31.8	20.9	27.6

Table 4-7 : Sub factors and the calculated Erodibility for each site

Site ID	Organic matter %	Clay %	Silt + Very fine sand %	Structural Code	Permeability	Erodibility (kg.m^{-2} per kJ.m^{-2}.mmh^{-1})
J1	8.2	26.0	50.5	3	2	0.014
J2	8.2	26.7	50.5	3	2	0.013
K1	9.0	32.0	45.0	4	4	0.020
K2	5.4	36.5	42.0	3	4	0.022
L	4.0	14.0	50.3	4	1	0.033
N1	4.1	18.5	56.0	4	1	0.034
N2	4.7	15.0	52.7	4	1	0.031

4.2.3 Calculation of Topographic factor

Topographic factor (SL) of the USLE is reflects the effect of slope-length, slope steepness and the surface condition contributing to the erosion from a land. It gives the slope-length effect by L factor and Slope steep ness by S factor. SL factor is a combination of two different factors, which derived from two separate and different relationships (Hudson, 1995-2). Combined equation of L and S factor as shown in equation 2-6 mentioned in the chapter 2 was used for calculation of SL factor. Slope % for all the sites exceeds 5%. Therefore the 'm' exponent used here is 0.5. The elements of the *Longonot* site is divided by contour drains, hence the overland flow not contribute to the lower element of the site. Therefore, SL factor and the erosion rates were calculated separately.

Table 4-8: Topographic Factor

Site ID		Slope-length (m)	Slope %	SL Factor
J1		26	7	0.78
J2		32	8	0.94
K1		279	10	4.65
K2		370	7.5	4.11
L	A	30	20	0.55
	B	5	20	0.11
	C	10	18	0.15
	D	32	15	0.37
N1		86	11	2.19
N2		52	10	1.73

4.2.4 Cover management factor

To identify the vegetation and soil management conditions is important in estimating soil erosion. Because influence of erosion by these factors can vary from zero in well-covered soils to 1.5 for finely tilled, ridged surface compared to soil loss in reference conditions in USLE plots (Renard et al, 1994). Comparing grass covered plots with bare plots Hudson (1995-2) showed that the soil loss from bare soil is more than hundred times from the other. Therefore, attention should be paid to calculate the cover factor.

In USLE and the Morgan model, the effect of cover management conditions is included as C factor. This factor is defined as ratio of soil loss or soil loss ratio. The soil loss ration (SLR) is based on the concept of deviation from the standard. In this case the standard is an area under clean-tilled continuous fallow conditions. SLR is then used to estimate soil loss under actual site conditions compared to losses experienced under the standard conditions (continuous fallow). The C value for the standard condition is one (Wischmeier and Smith, 1978, Renard et al., 1991).

The C factor represents the effect of plants, soil cover, soil biomass and soil disturbing activities on erosion (Renard, 1993). The sub factor method is proposed for the computation of SLR as a function of four sub factors to include the effect of parameters represent. The sub factor relationship for SLR is given by the equation 4-4.

$$SLR = PLU * CC * SC * SR$$ (USLE C Factor) **Equation 4-4**

Where;
SLR = Soil Loss Ratio
PLU = Prior land use sub factor
CC = Crop Canopy sub factor
SC = Mulch or Surface ground cover sub factor
SR = Surface roughness sub factor

CC sub factor will incorporate the raindrop interception by the canopy cover. This depends on the effective fall height and the percentage covered by the canopy. This sub factor hence, depend on the crop types and the growth stage. Crop types normally have 4 growth stages; namely initial, development, mid and late stage (Appendix III). Assuming plant is fully-grown after mid stage, third and fourth stages considered and one stage. Therefore CC was calculated for three stages of crop growth assuming effective plant height 10%, 50% 70% from the maximum height of crops. Canopy cover is assumed as varies according to growth stage.

$CC = 1\text{-}CC_e * e^{-0.348He}$ (USLE- CC Sub Factor) **Equation 4-5**

Where,
CC_e= Canopy cover fraction
He = Effective plant height (m)

Table 4-9: Calculated Canopy Cover sub factors for each site

Location	ID	Maximum plant height (m)	**Effective plant height**			**Canopy cover %**			**CC for Season**			**CC sub factor**
			G1*	G2*	G3*	G1	G2	G3	G1	G2	G3	
Kijabe	J1	0.5	0.05	0.25	0.35	10			0.88			0.88
Kijabe	J2	0.5	0.05	0.25	0.35	15			0.84			0.84
Kinangop	K1	1	0.1	0.5	0.7	10	65	85	0.87	0.34	0.14	0.45
Kinangop	K2	0.2	0.1	0.2	0.2	95	95	95	0.05	0.05	0.05	0.05
Longonot	L1	1	0.1	0.5	0.7	10	60	80	0.87	0.39	0.19	0.48
Ndabibi	N1	1	0.1	0.5	0.7	10	50	80	0.87	0.48	0.19	0.52
Ndabibi	N2	1	0.1	0.5	0.7	10	65	85	0.87	0.34	0.14	0.45
CC=(1-(Canopy cover/100))*EXP(-0.34*effective plant height)												

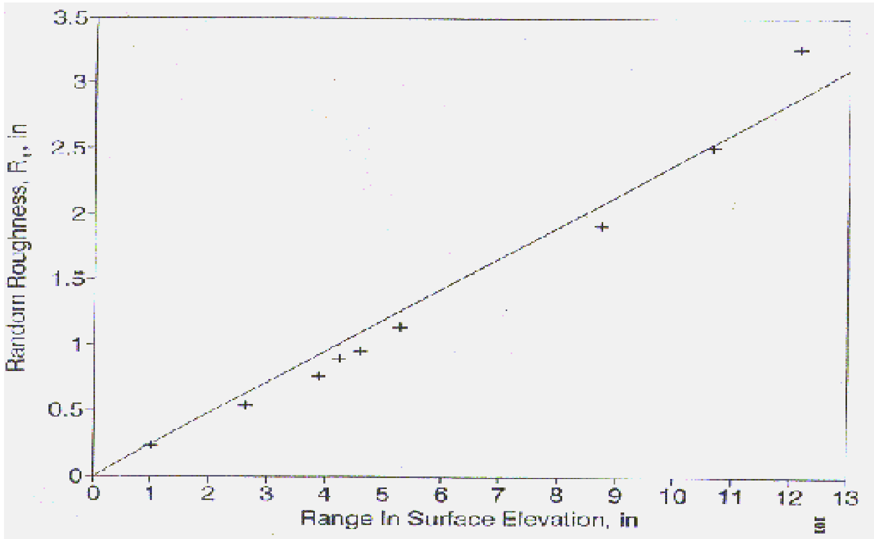
**Note: G1, G2 and G3 = Growth stages of each crop cultivated in the land*

PLU and SC sub factor values describe the within soil effect of accumulated root biomass and the canopy or residue touching the ground surface. SC can be calculated using equation below

*SC=EXP (-b * ground cover %)* (USLE-SC sub factor) **Equation 4-6**

The b coefficient is assigned a value between 0 and 1. The value for b is increased as the tendency for rill erosion to dominate interill erosion. In RUSLE the value "b" 0.035 is considered as typical standard value. For bare surfaces with interrill erosion the value is 0.025, for the surfaces with prominent rill erosion the value is assigned as 0.05, for rangelands it should be 0.045 (Renard et al., 1991 and Renard, 1993). The 'b' value assigned for grassland is 0.045 considering the similarity to rangeland. The proportion of bare soil at the sites of *Kijabe* is high and dominated rills, therefore 'b' value of 0.05 were selected. For the other sites with croplands the typical value of 0.035 was used.

Surface Roughness (SR) sub factor deals with the micro topographic relief of the soil surface and that is closely associated with the method of land preparation and is the intensity of rainfall (Renard et al., 2000). SR can be estimate according to the range in surface elevation by using the figure 4-2. Using visual interpretation of field surface conditions using photographs of each site SR factor was assigned. Estimated SR values are in table 4-10.



(Source Renard, 1993)

Figure 4-2: Relationship between random roughness and surface elevation

PLU sub factor expresses the influence on soil erosion of subsurface residual effects from previous crops and the effects of previous tillage practices on soil consolidation. It ranges from zero to one. Many types of parameters required for estimation of PLU such as, mass density of live and dead roots and residue density of upper 1 inch layer of soil, impact of soil consolidation on the effectiveness of incorporated residue, etc. (Renard et al., 2000). Considering data availability and the time limitation, the effect of PLU was skipped in this research.

Table 4-10: Estimated Sub factors and Cover factor

Location	ID	Ground cover %	"b" value	SC Sub Factor	SR Sub Factor	CC Sub Factor	C Factor
Kijabe	J1	10	0.05	0.61	0.60	0.88	0.322
Kijabe	J2	10	0.05	0.64	0.60	0.84	0.304
Kinangop	K1	10	0.035	0.70	0.35	0.45	0.111
Kinangop	K2	60	0.045	0.07	0.25	0.05	0.001
Longonot	L1	15	0.035	0.59	0.50	0.48	0.143
Ndabibi	N1	10	0.035	0.70	0.50	0.52	0.182
Ndabibi	N2	10	0.035	0.70	0.35	0.45	0.111

The estimated C factors are higher in *Kijabe* wheat sites than the rest. Wheat plants of these two sites were very young and larger part of the surface area was bare during the period considered for the study. The lowest value estimated for the grass site at *Kinangop* (K2). Most of the area is covered by thick grass.

4.2.5 Erosion estimates of USLE

Erosion estimations of the USLE calculated using the equation 2-1 and sub factors calculated above is given in the table 4-11. According to the results, USLE gives highest estimated erosion for *Ndabibi* N1 site for duration of 34 weeks. The site N1 at *Ndabibi* is characterized by high SL factor and cover factor. This combination makes the USLE erosion estimate high in that site. The *Longonot* site is consist of elements with steep slopes and shorter lengths. USLE estimates for that site gives lower values than the other sites due to shorter slope-lengths. The erosion rate of the *Kinangop* site was estimated by using field data on reservoir sedimentation and the value should be less than estimated value of 1430 kg/ha, because the depth mentioned by farmers probably not applicable to whole bottom area. But the USLE estimates for this site gives nearly three times higher value than the field estimated value. This high estimation of erosion is probably associated with the high SL factor of this site. The calculation of SL factor gives high value because of the longer slope-length of the site not because of slope. The bottom of the slope is concave with dense grass, which causes deposition. The USLE does not account for deposition. The slope of this site is not so steep when compared with the other sites. The slope range is 7% - 11% in the *Kinangop* sites. USLE estimates are further discussed in the chapter 6, compared with other model results.

Table 4-11: Estimated Erosion using USLE compared with field estimates.

Location	ID	Duration (Weeks)	Erosivity (kJ.m^{-2}.mm.hr^{-1})	Erodibility (kg.m^{-2} per kJ.m^{-2} .mm.h^{-1})	SL Factor	Cover Factor	USLE (kg/ha)		Field estimates (kg/ha)
							Element	Site	
Kijabe	J1	6	40.0	0.014	0.78	0.322	1362	1362	>706
Kijabe	J2	4	26.6	0.013	0.94	0.304	1026	1026	>298
Kinangop	K1	52	179.3	0.020	4.65	0.111	18247		
Kinangop	K2	52	179.3	0.022	4.11	0.001	128	18375	<1432
Longonot	A	34	158.8	0.033	0.55	0.143	4085		
	B	34	158.8	0.033	0.11	0.143	836		
	C	34	158.8	0.033	0.15	0.143	1150		
	D	34	158.8	0.033	0.37	0.143	2757	8827	>1255
Ndabibi	N1	33	159.6	0.034	2.19	0.182	21766	21766	>189
Ndabibi	N2	33	159.6	0.031	1.73	0.111	9599	9599	N.A

4.3 Morgan model

As mentioned earlier in chapter 3, the Morgan model will find the detachment rate of topsoil and the transport capacity of runoff water. Lesser value out of these two findings is considered as the soil erosion rate (Morgan et al., 1982). Data sources and methods followed for estimation of model input parameters are summarized in table 4-12.

Table 4-12: Calculation method of input parameters for the Morgan model.

Input parameter		**Data source/ Calculation method**
RF	Rainfall (mm)	Daily rain record & tipping bucket rain gauge data
KE	Kinetic energy (J/m^2)	From daily rain records, using regression equation developed from past intensity data
MS	Moisture storage at field capacity (v/v%)	From literature according to texture class of the top soil
ρ_b	Bulk density (Mg/m^3)	Determined experimentally
D_r	Top soil rooting Depth (mm)	Literature according to crop type
ET_a/ET_o	ET ratio	From literature
K	Soil detachability (g/J)	From Literature according to texture class
C	Crop cover factor	C factor calculated for USLE

Input parameter		Data source/ Calculation method
S^o	Slope angle	Field measurements
M_{FC}	Soil moisture storage at field capacity (mm)	Calculated using equation 2-9

4.3.1 Estimation of rainfall Kinetic energy

Cumulative kinetic energy of rainfall (E) for duration considered for each site was determined with total rainfall (R mm) and average intensity of rainfall. Rainfall data was taken from the nearest rain gauge according to thiessen polygon of rainfall gauge stations. According to Wischmeier et al, 1978, Kinetic energy of rainfall is directly related to rain intensity.

Availability of rainfall data in many stations for the considered period are as daily accumulations. Therefore, a relationship was developed for kinetic energy and daily rainfall using equation 2-7 for past rainfall data collected using tipping bucket rain gauge. Results of regression analysis for the relationship between daily rainfall and kinetic energy calculated using equation 2-7, shows fairly good correlation (R^2 =0.75) as shown in the figure 4-2. This relationship was used to calculate kinetic energy of rainfall for sites where only daily rainfall is available. The relationship between daily rainfall and the kinetic energy is given in the equation 4-7. Kinetic energy calculations were done using this relationship for the duration considered of each site.

$$E = 17.001 P_{24} - 9.315$$ (Rainfall Kinetic Energy) **Equation 4-7**

Where;
E = Kinetic energy (kJ/m2)
P_{24} = Daily rainfall (mm)

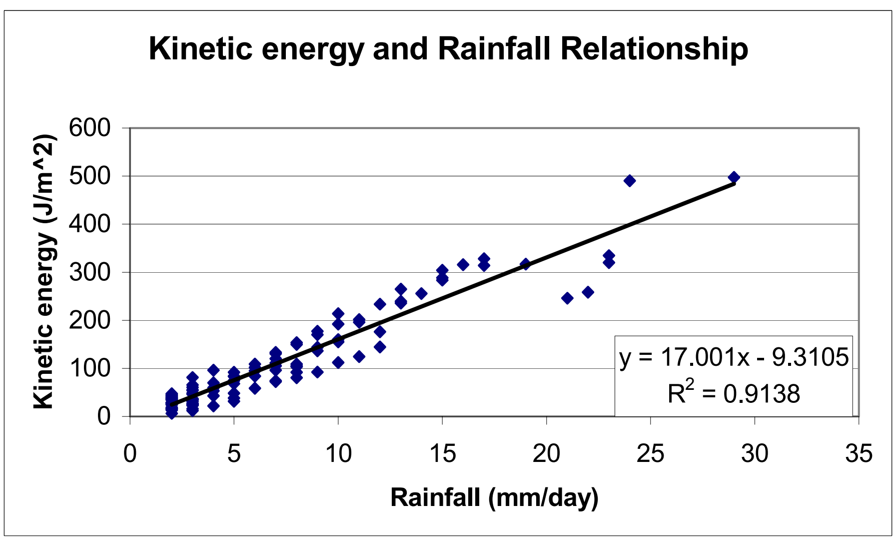


Figure 4-3: Relationship between daily rainfall amount and kinetic energy

4.3.2 Estimation of runoff

The model performs calculation of runoff, assuming that, runoff generation occurs when the daily rainfall exceeds the soil moisture storage capacity and daily rainfall amount approximate and exponential frequency distribution (Morgan, 2001). Parameters for model input were derived discussed here.

Moisture content at field capacity (MS) was estimated according to texture of the soil from typical values for soil parameters used (Morgan, 1995). Rooting depth (in m), defined as the depth of soil from surface to an impermeable or stony layer, to the base of the A horizon, to the dominant root base or 1-0 m, whichever the shallowest. Reasonable values are 0.05 for grass and cereal crops and 0.1 for trees and tree crops (Morgan 1995). The ET_a/ET_o ratio, for maize varies between 0.67 – 0.70, for wheat the ratio is 0.60 and for grass 0.80-95 (Morgan, 1995). Average value of ET_a/ET_o ratio for each site were used except wheat fields in J1 and J2 sites where the most of the area is not covered by wheat crop and hence the ratio of 0.1 is considered for those sites. Runoff volume of each element was calculated using the equation 2-8 mentioned in chapter 2.

Table 4-13: Typical values for soil parameters used in the Morgan model (after Morgan, 1995 & 2001)

Soil	Moisture at field capacity	Bulk Density	Soil Detachability (g/J)
Clay	0.45	1.1	0.02
Clay Loam	0.40	1.3	0.4
Silt Clay	0.30	-	-
Sandy Loam	0.28	1.2	0.3
Silt Loam	0.25	1.3	-
Loam	0.20	1.3	1.0
Find Sand	0.15	1.4	0.2
Sand	0.08	1.5	0.7

4.3.3 Estimation of soil detachment rate

Soil detachment depends on the amount of kinetic energy received from rainfall and the susceptibility of topsoil for the detachment. For the calculation of detachment rate, soil detachment index; mass of detachment per unit energy, was estimated according to the texture class of the soil using guide values taken from the table 4-13. Percentage rainfall contributing to permanent interception and stem flow (A) was taken from the typical 'A' values and for maize considered here is 25%, for grass it is 35% and for wheat 43% for fully grown crop. For wheat fields with 10% crop cover the 'A' value is assumed as 1% considering the bare soil percentage of the sites at *Kijabe* (J1 and J2), because no interception losses occur on bare soil. Detachment rate of the topsoil due to rainfall impact is calculated using the equation 2-10.

4.3.4 Estimation of the transport capacity of overland flow

Transport capacity of overland flow depends on amount of runoff water, the slope and the cover characteristics of soil surface. Field measured slope percentage was converted in to slope degrees. The Cover factor calculated for USLE was used.

4.3.5 Detachment rate and transport capacity

Erosion from each site equals to the lower value of detachment rate and the transport capacity of over land flow. Both detachment rate of topsoil and transport capacity of over land flow were estimated for each element of all the sites separately. Parameters and the estimated soil erosion rates from the Morgan model is give in Appendices V-VII.

The splash detachment is fairly high in the *Kijabe* sites despite the shorter duration considered due to the cover percentage lesser of younger wheat plants. The splash detachment is high in *Kinangop* because cumulative rainfall is high and the considered period is higher than the other sites (Appendix VI). Transport capacities of the sites at *Kinangop* are comparatively very low because low in estimated cover factor. The Appendix VII gives element wise transport capacity and the erosion rates estimated by the Morgan model. The Morgan model takes the lower value from the estimated detachment rate and the transport capacity. Some sites with high detachment rates According to results, some site with higher in detachment capacity shows low erosion rates due to low transport capacity. Unlike USLE, this model does not give higher estimates for sites with longer slope-lengths, because the model switch between detachment rate and transport capacity to give the lower value as erosion rate.

4.3.6 Erosion estimates of the Morgan model

The erosion rates, soil detachment rate, and transport capacity estimated by the Morgan model for each site are given in the table 4-14. According to the result, transport capacity does not exceed the detachment rate for all the sites. Erosion estimates for the sites at *Kinangop* and *Longonot* gives comparatively very low values. The Morgan model determines the transport capacity for the average daily basis runoff volume. In *Kinangop*, low average daily rainfall combined with high soil moisture storage, as the soil is sandy loam and gentle slope, make little amount of runoff. (see Appendix V). Therefore the sediment transport capacity and the erosion are low despite high detachment rate. In K1 site the estimated erosion is negligible and that it realistic because the canopy cover is consist with dense grass most of the area.

Table 4-14: Estimated soil erosion by the Morgan model compared with field estimates

Site ID	Detachment rate (kg/ha)	Transport Capacity (kg/ha)	Soil Loss (kg/ha)	Field estimated Erosion
J1	22682	4605	4605	>706
J2	14190	1748	1748	>298
K1	11419	33	33	<1432
K2	6926	1	1	
L	22846	962	962	>1255
N1	39228	21837	21837	>189
N2	13076	7886	7886	N.A

Soil of *Longonot* is highly permeable (see table 3-7). If no surface crusting or sealing in *Longonot*, runoff generation by meeting rain intensity and infiltration rate is seldom. But rill erosion in that area was a prominent feature. the Morgan model estimates low erosion rates for the *Longonot* site because low runoff due to comparatively high bulk density and less amount of average daily rainfall. In *Kijabe* where crop cover was less the Morgan model estimates higher erosion rates. Slope is fairly high in the N1 site at *Ndabibi*. According to the farmers, erosion at N1 site is much higher than N2 site. The

Morgan model reflects that condition giving higher erosion rate for N1 than N2 site at6 *Ndabibi*. The Morgan model estimates are further discussed in the chapter 6, compared with other model results.

4.4 Eurosem

In EUROSEM data input has to be prepared for the sub routines describing each sub process of erosion. There are two input files; a rainfall data file and a file with catchment characteristic file. The rainfall data file deals with the weight of each rainfall station for each element, the time and depth of rainfall recorded from each gauging station. In catchment characteristics file, all the data required for modeling should be given in a systematic DOS text formatted file in a way keeping the element wise information separately according to the order of the element the catchment. Procedures described in EUROSEM documentation and user's guide was followed for data preparation and data entering to each input file. Definitions of input variables and parameters as mentioned in the EUROSEM documentation, are given in Appendix IX.

4.4.1 Rainfall data

Rainfall input to the model should be in the form of a depth for each time step during a storm. From this input, intensity and volume are calculated. Cumulative depth and time step data collected from tipping bucket type rain gauges were used whenever the data available for the considered season. For sites where daily rainfall data available, it is assumed that the distribution pattern of the rainfall during the storm similar to distribution pattern of past rain storms in the area.

4.4.2 Manning's 'n' calculation

Since the Manning's n cannot be measured directly, values for Manning's n for each element was estimated by interpretation of field observations and using the guide values proposed in the EUROSEM user guide. The Manning's roughness coefficient gives the resistance to overland flow. To determine the Manning's 'n' the value can be split into three main components. They are grain roughness component, surface irregularity component and vegetal drag component as describe in the equation 4-8.

$$n_{man} = n_g + n_v + n_m$$ (Manning's 'n') **Equation 4-8**

Where

n_{man} = Manning's roughness

n_g = grain roughness due to soil particles

n_v = roughness imparted by vegetation

n_m = micro topographic roughness of the surface, associated with tillage practices and stoniness

Grain roughness was estimated by using the median particle size (D50) with the Strickler formula proposed by Morgan et al., (1998). D50 values were calculated using, experimentally analysed particle size distribution for each site. The D_{50} values calculated from grain size distribution and grain roughness are given in the table 4-15.

$$n_g = 0.014 * D50^{0.167}$$ (Strickler Formula) **Equation 4-9**

Roughness due to vegetation and micro topography was estimated using the EUROSEM guide values for vegetation conditions, tillage practices and surface conditions of each site. Sites of the *Kijabe* area

(J1 and J2) were wheat-cultivated lands but the crop is very young and the cover is less. Therefore n_v values for those sites considering the dominant bare soil surface. For the other sites which cultivated maize a middle value of 0.04 for n_v component of the roughness were selected. The grasslands at *Kinangop* were well covered with dense short grasses. Therefore a higher value of 0.06 was selected from guide values (Appendix X).

The micro-topographic roughness, which associated with tillage practices, was also estimated using the guide values from appendix X. Except grassland, in all the other sites, land preparation (twice a year) is done using disc harrow. The n_m value for lands where use Disc harrow is range from 0.1 to 0.53 according to the incorporated residue rate. A middle value of 0.16 was used for n_m component for sites use disc harrowing as land preparation method. For the grassland a middle value of 0.3 was assigned as n_m value, considering no tillage conditions. The components estimated and the calculated Manning's n values for each site are given in the table 4-15.

Table 4-15: Estimated Manning's roughness coefficient for different sites

Site ID	D_{50} (Microns)	n_g	n_v	n_m	Manning's 'n' ($m^{1/6}$)
J1	389	0.024	0.01	0.16	0.194
J2	389	0.024	0.02	0.16	0.204
K1	290	0.023	0.04	0.16	0.223
K2	249	0.022	0.06	0.30	0.382
L1	624	0.026	0.04	0.16	0.226
N1	541	0.025	0.04	0.16	0.225
N2	549	0.025	0.04	0.16	0.225

4.4.3 Hydrological properties

Input data are required on those soil properties, which influence the generation of runoff. The soil properties describe the infiltration capacity are required for the model calculation of runoff generation ability of soil. Information required by the model is moisture content at saturation (THMX), initial moisture content of topsoil (THI), soil porosity (POR), effective net capillary drive (G), and effective saturated hydraulic conductivity of soil (FMIN). Steps followed during input data processing are described in this sub chapter.

For EUROSEM the saturated hydraulic conductivity (mm/h) should be the values of soils itself and should not be adjusted for plant cover or stoniness. Saturated hydraulic conductivity values measured during fieldwork, using inverse augur hole method were used as input data.

Porosity for each site was calculated using the bulk density determined experimentally in the field, and the relationship described in the equation 4-10.

$$POR = 1 - \rho_b/\rho_p \quad \text{(Porosity)} \qquad \textbf{Equation 4-10}$$

Where
POR= porosity (v/v)
ρ_b = Bulk density (g/cm^3)
ρ_p = Particle density (g/cm^3)

Particle density of soil is assumed as standard (2.65 g/cm^3).

Effective capillarity drive, soil moisture content at saturation were determined using texture classes of each site and the guide values for soils of different texture classes given in the EUROSEM user's guide.

Infiltration recession factor (RECS) defined as average maximum local difference in micro relief was estimated according to the land preparation method of each site and using the guide values provided in the user's guide. For sites in the *Kijabe* area the value of 15mm and for other sites 25mm were selected considering the method of land preparation. For grasslands a lower value (5mm) was selected.

4.4.4 Vegetation properties

Maximum interception storage (DINTR) of plant cover was estimated according to the crop type cultivated and the guide values using the appendix XIII. Wheat crop cultivated in the *Kijabe* site was not fully grown. Therefore a value of 0.1 and 0.2 was taken considering the canopy cover observed during the field data collection. Plant cover was estimated considering the period from planting date to the date of rainstorm considered for each event. The shape of the leaves for maize was assigned as broad leaves and needle leaves for wheat and grass, referring to the guide parameters. Stem angle for different crop types were estimated using the guide parameters in Appendix XIV. Percentage of basal area (PBASE) was estimated using parameters in appendix XV according to the land cover and the condition of the crop cover.

4.4.5 Surface characteristics

Data on surface characteristics in combine with other data is required to assess the surface storage and the surface runoff by the model. Rill density as average number of rills across the width of the slope plane (DEPNO), average width (RILLW) and depth (RILLD), slope of rills and other required dimensions related to rills were estimated by averaging rill measurements took during fieldwork. The scaling factor (RS) that determines the variation of the upslope rill dimensions alone field as 1 for sites with smaller rill dimensions towards upslope and 0 for the other sites. The model required interill and rill slope in m/m, for which field data were used.

4.4.6 Soil erodibility

Values for the detachability of the soil particles due to raindrop impact (EROD) are assigned according to the texture of the surface soil (see appendix XVI). Cohesion (COH) of the soil effected by the root system of the vegetation and the compaction of the soil. Values for COH were estimated using the data in Appendix XVII. Typical value for the specific gravity (RHOS) of soil was taken as 2.65 g/cm^3 as mentioned in EUROSEM user's guide.

4.4.7 Preparation of input data files

Files for input data in EUROSEM should be prepared in DOS ASCII text format. Preliminary data analysis and preparation for model input was done using Microsoft Excel spreadsheets. Then processed input data were transferred in to the ASCII text format 'NOTEPAD' 'DOS' text editing computer package. The input data files for rainfall characteristics and catchment characteristics are annexed in the appendices XVI and XVII.

4.4.8 Erosion estimation of EUROSEM model

EUROSEM Version 3.6, which runs under DOS environment, was used here for all the simulations. For the erosion simulation with this model, rainfall data (rain depth, time pairs) from recording type rain gauges should be available. The rainfall data should be in the form of amount or storm depth against time. Hence, the EUROSEM model was used only for the sites where such rainstorm data were available. Erosion assessment using EUROSEM was performed for all the rainstorms higher than 5 mm depth during the year 1999 at *Kinangop* gauge station. According to the model results, runoff generation can be observed only in 65% of the rainstorms higher than 5.2mm/day. Erosion occurs only 11 days during the year, according to the model results. About 53% of the total estimated erosion is due to the 22mm storm occurred on October 15th. Another rainstorm of 27mm on 04th August responsible for 22% of the annual erosion. Contribution of the other rainstorms for total erosion was remarkably low (see table 4-16).

Table 4-16: Summarized results of EUROSEM erosion simulation for *Kinangop* K1 (maize) site

Month	Date	Rainfall (mm)	Storm duration (min)	Peak Rainfall (mm/h)	Peak flow rate (litre/sec)	Peak sediment discharge (g/sec)	Erosion	
							(kg/ha)	(%)
January	7	12.3	200	54	12100	9.83	428	2.6
January	9	5.2	101	3.7	0	0.00	0	0.0
January	13	13.2	100	43	319	0.00	0	0.0
March	13	22.2	589	75	5390	6.18	120	0.7
March	15	18	599	26	0	0.00	0	0.0
March	16	8.2	20	33.2	26	0.00	0	0.0
March	17	10.3	95	66.6	8030	5.02	145	0.9
April	25	7.2	280	3.4	0	0.00	0	0.0
April	27	20.2	83	37.5	13420	26.04	1258	7.7
May	17	9.2	192	24.3	0	0.00	0	0.0
May	21	7.2	33	41.6	0	0.00	0	0.0
May	25	14.2	44	99.1	20900	14.71	1107	6.8
July	18	19.2	1200	40	0	0.00	0	0.0
August	4	27.2	37	100	45100	22.22	3607	22.0
August	13	8.28	155	17.6	0	0.00	0	0.0
August	31	10.2	314	56.3	2	0.00	0	0.0
September	16	11.3	55	39	1452	2.87	15	0.1
September	19	13.2	74	51.1	4279	5.78	89	0.5
October	15	22.2	60	100	105600	22.81	8673	52.9
October	17	15.2	50	99.1	13200	19.89	945	5.8
October	14	6.2	510	4.3	0	0.00	0	0.0
November	7	12.3	200	54	12100	9.83	428	2.6
Total	**21**						16387	**100**

The higher intense rainfall for shorter time creates runoff and erosion. High amount, low intense rainstorms lasting for long time produces low or no runoff. Storm produced large proportion of erosion and the runoff rate simulated by EUROSEM is given in figures 4-4 and 4-5. It can be noticed that, a higher rainstorm with two peaks gives low runoff and erosion while lower rainstorm with high intensity produced higher erosion.

Erosion rates calculate by field sediment data is about 1400 kg/ha. The catchment at *Kinangop* has two elements. No prominent erosion signs could be noticed from the grassland (K2) element. The area of the K1 and K2 is 38000 and 39600 m^2 respectively. Since most of the sediment comes from the K1 (maize) element, the magnitude of the field erosion estimate should be doubled because the contributing area is nearly half. If the depositional area at the bottom slope of the site considered as a separate element, the EUROSEM may give reasonable estimation.

The EUROSEM simulation for the site K2 (grassland) at *Kinangop* resulted little amount of runoff for few events no runoff for the other events. The contribution the catchment total erosion of the grassland component is minute. The rainstorm occurred on 15th October, which gave highest erosion in the adjoining maize field, was the only erosive rain for grassland. But the amount eroded was less than 1kg for the whole grassland, according to the EUROSEM simulation.

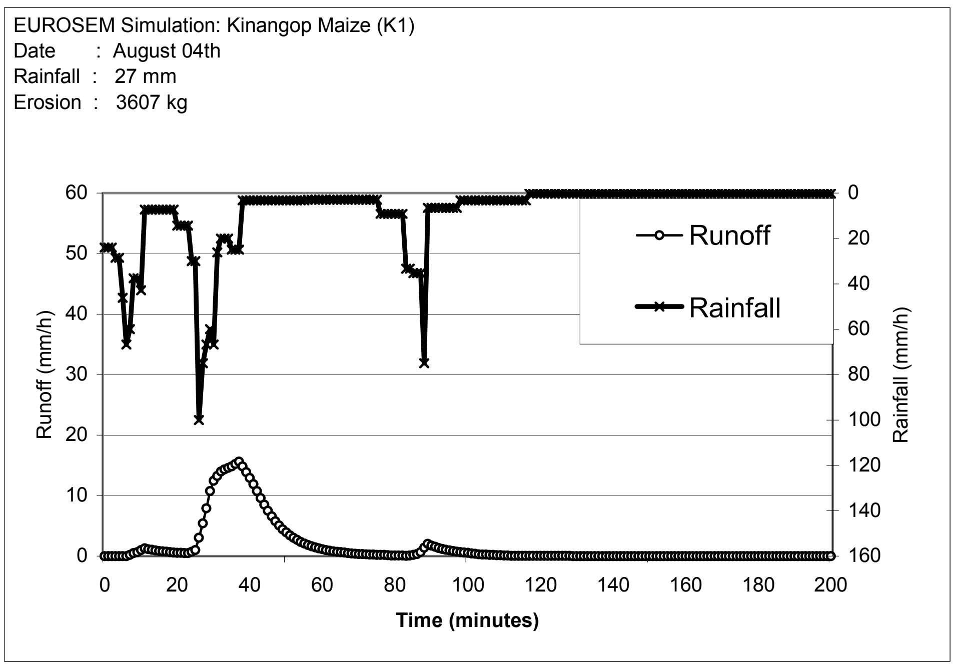


Figure 4-4: Rainfall and runoff simulated by EUROSEM for 27mm rain storm on 4th August

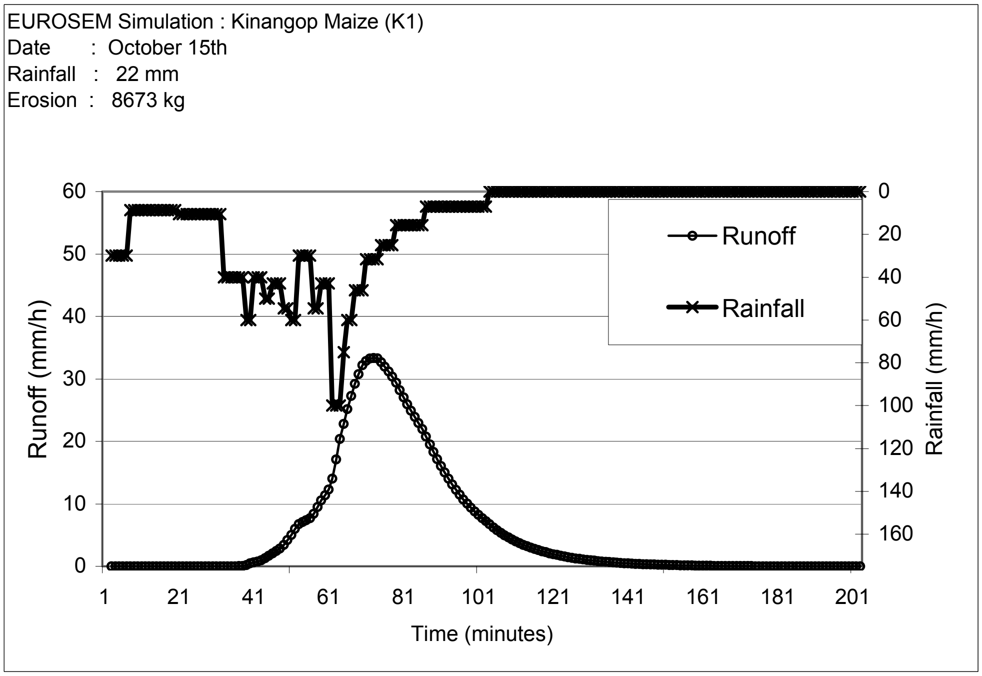


Figure 4-5: Rainfall and runoff simulated by EUROSEM for 22mm rain storm on 15th October

Chapter 5 - Sensitivity of model input

5.1 Introduction

The response of model estimations for variation of input parameters provide information about the model behaviour for different settings of site characteristics and gives an idea of errors that can be occur during parameter processing for model input. Here the parameter sensitivity analysis was done using simple analyses where individual input variables and parameters were changed one by one and the model results examined.

5.2 Factor sensitivity for USLE estimates

The erosivity calculated according to the rainfall characteristics is the base of model output in USLE. For bare standard plots where all the other factors remain as 1, the estimated erosion equals to erosivity. Erosion estimates for sites differ from standard conditions, deviate according to the degree various parameters and conditions extracted through data collection and data process.

5.2.1 Parameter sensitivity for calculated erodibility

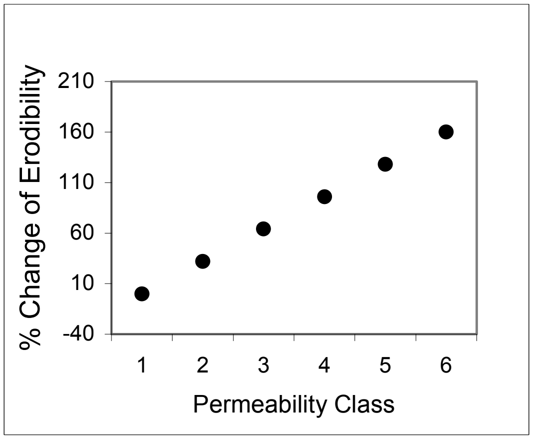
Erodibility (K) of USLE can be estimated by using the soil texture, permeability, structure and organic matter content of soil with nomogram equation (equation 2-4). Parameter sensitivity for calculated erodibility was examined, by changing values of sub parameters, which extracted from field data collection and laboratory analysis and considering the change percentage of the erodibility. The base values and parameters used for the analysis were taken from the data of *Kijabe* site J1 (see table 5-1).

Table 5-1: Base parameters used for sensitivity analysis of erodibility

Texture by feel	Silt Clay
Texture class lab analysis	Clay Loam
Organic Matter%	8.2
Clay %	26
Silt %	30
Very fine sand %	20.5
Coarse sand %	15
Structural code	3
Permeability class	2
Erodibility [kg/m^2 per $kJ.m^{-2}.mm.h^{-1}$]	0.0136

5.2.2 Sensitivity of erodibility for soil structure and permeability

Soil structure consider for erodibility calculations is the aggregate stability, which refers to the size distribution and resistance of soil aggregate for degradation. Four structural codes were considered for K calculations They are very fine granular, Fine granular, medium sub angular and massive or blocky and code values are increased respectively from 1 to 4. From the equation 2-5 it can be easily noted that soil erodibility varies linearly with structure code and permeability (see figure 5-1). A shift of structural code from upper to lower value or vice-versa will result in nearly 80% change of calculated erodibility value for the site selected.



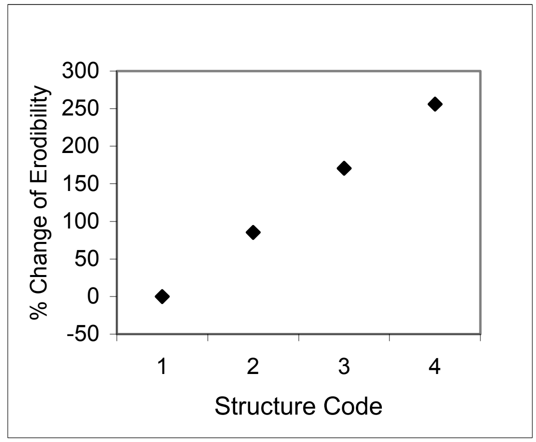


Figure 5-1: Sensitivity of Erodibility for soil structure and permeability

Permeability of the soil is incorporated in the erodibility calculations in the nomogram equation as permeability code assigned for each class of saturated hydraulic conductivity. The value of the permeability code is higher for lands with low permeability. Land with higher permeability will result lower runoff due to higher infiltration leave lesser water on the surface for runoff and hence the erosion. According to the analysis, the influence of permeability for K estimation shows a linear relationship. A shift in permeability code will result in nearly 30% change in erodibility. The permeability codes used here were derived according to the hydraulic conductivity measured in the field. Hence the effect of surface sealing is not included in this estimation of permeability. According to the table 4-2, permeability code for lands with K_s value of 6 cm/hr or higher remains as 1. This will prevent further decrease in erodibility for land with higher K_s. Structure is very important in the erodibility calculation, because a shift in the structural code will result nearly 100% change in the erodibility.

5.2.3 Sensitivity of Erodibility for texture and organic matter content of top soil

Soil texture can affect on soil erosion through many aspects and dimensions. In lands with coarse textured soil, the higher infiltration reduces the runoff and erosion on one hand. On the other hand lower aggregate stability of coarser soils will increase the detachment and also high energy is needed for transport will create resistant for erosion. The erosion in the lands with fine textured soil can be expected to be low due to high cohesiveness. The least resistant particles are silt and very fine sand. The figure 5-2 shows the relationship of estimated erodibility for change in silt and very fine sand (VFS) content. Relationship between erodibility and texture components of the soil is nearly linear because the exponent of the M of equation 2-5 is 1.14. According to the figure a 50% increase in silt or VFS will result nearly 50% increase in estimated erodibility. The effect of an increase in the clay content, exhibit decrease in erodibility.

Increase in organic matter content of the soil will increase the water holding capacity of the soil, increase the micro biological activity of top soil, improve the soil structure of the top soil, and will create soil resistance for erosion. The results show that (see figure 5-2), the calculated erodibility is very sensitive to the organic matter content of the soil. It shows 25% decrease in organic matter content will result nearly 50% increase in soil erodibility. Therefore it important to pay attention to the estimation of organic matter content of top soil for erodibility estimation using the equation of USLE for the factor K (or nomogram).

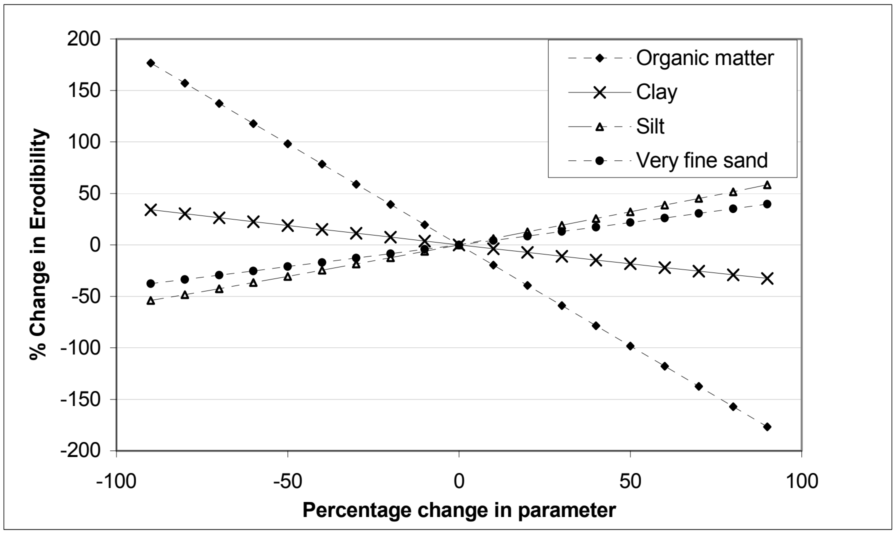
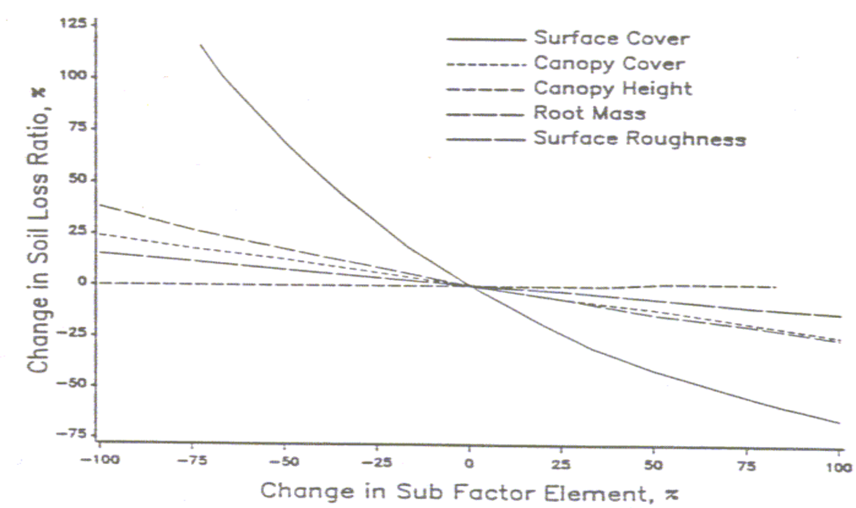


Figure 5-2 : Sensitivity of Erodibility for texture and Organic matter

5.2.4 Sensitivity of cover factor for input parameters

The Cover Factor (C) of the soil loss equation termed as soil loss ratio (SLR) is calculated using sub factors. The effect of change in sub factors on the C factor is positive for all factors (see equation 4-4). Sub factors for change of each input parameter behave in a different manner because of the non linear equations (see figure 5-3). According to the figure, SLR is most sensitive to the surface cover.



(source: Renard 1994)

Figure 5-3: Sensitivity of Soil Loss Ratio to Sub Factor Elements

A 25% change in surface cover will result 25% change in SLR and 75% change will result more than 100% change in SLR because the relationship is non-linear. This can be explained by the fact that surface cover reduces, even eliminates, the raindrop impact, and prevent sealing of the soil surface. Furthermore, surface cover could increase microbiological activities and organic matter content, both increasing infiltration capacity of the soil. The effect of change in plant height on the SLR is negligible. The effect of the other elements on SLR is less when compared with the ground cover. When estimating the cover factor (C) for the USLE much attention should take in estimating surface cover or mulch cover percentage.

5.2.5 Sensitivity of SL factor for slope and length

Influence of change in slope and the slope-length on SL factor of USLE was examined by changing the slope and the length in the equation 2-6 for different slope and lengths. The relationship is non linear. Effect of the percentage change in length on percentage SL factor remains same for all slope classes. A 50% change in slope-length will result nearly 20% change of SL factor (see figure 5-4). It showed that the SL factor is less sensitive for length change.

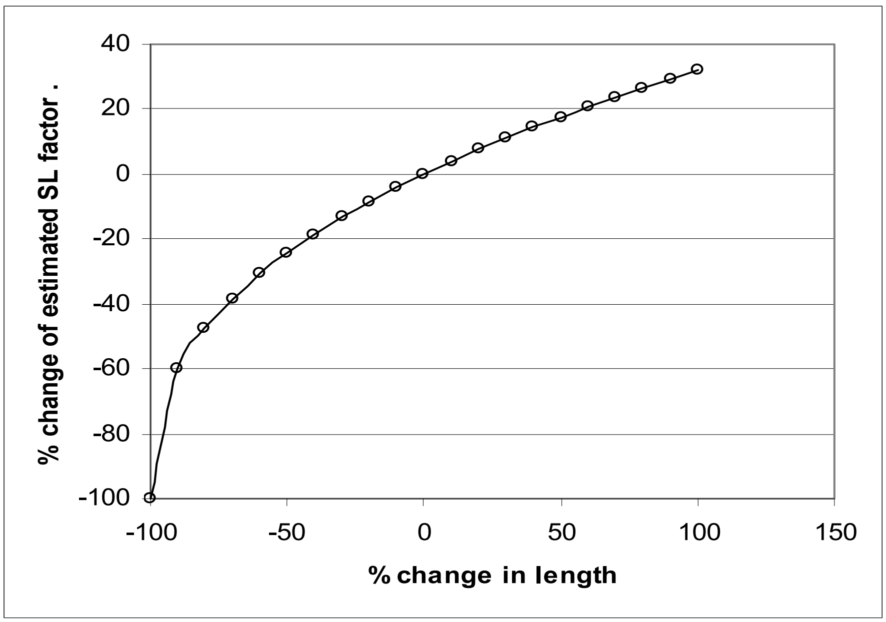


Figure 5-4: Effect of change in length on Slope-length (SL) factor

Using the equation 2-6, change of SL factor for change in slope was examined for different slope classes and different slope-lengths. Changing pattern of SL factor for the change in slope was same for every length classes. Percentage change of SL factor for percentage change in slope, for different slope classes is given in the figure 5-5. Effect of percentage in slope, on SL factor differs according to the slope class. For lower slope classes the effect is less and it is higher for steep slopes. About 10% change in slope will result nearly 10% change in estimated SL factor. Therefore the sensitivity of USLE estimated erosion for slope and length changes is less compared to the other parameters used for the other USLE factor estimations.

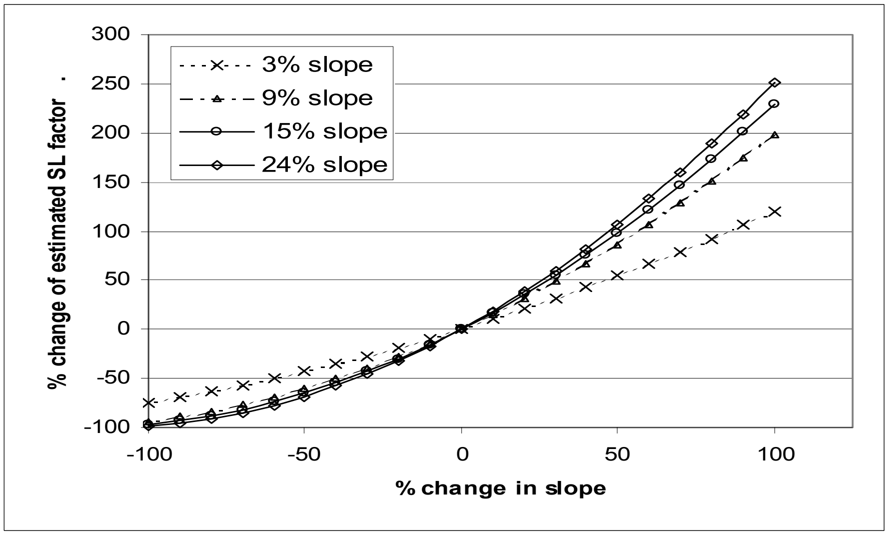


Figure 5-5: Effect of change in slope on Slope-length (SL) factor

5.3 Morgan Model

Sensitivity analysis of estimated erosion for input parameters was performed using set of parameters processed for few sites (table 5-2). The analysis was done changing one parameter and keeping all the other parameters constant. The change of estimated erosion for change in input parameters was studied for different parameters separately.

Table 5-2: Parameters used for the sensitivity analysis of the Morgan model

Parameters	***Kijabe***	***Kinangop***	***Ndabibi***
Total RF (mm)	126	688	480
Kinetic Energy (J/m^2)	1987.09	9963.76	7606.71
Moisture at FC (V/V)	0.40	0.40	0.20
Bulk Density (Mg/m^2)	0.99	1.05	0.93
Rooting Depth (m)	0.05	0.05	0.05
ET_a/ET_o Ratio	0.10	0.70	0.70
Soil Moisture Storage (mm)	6.26	17.57	7.78
Number of rain days	8	144	56
Rain per (mm)	15.75	4.78	8.57
Run off volume (mm)	84.67	17.40	193.64
Soil Detachability (g/J)	0.40	0.40	0.30
Rainfall Interception Factor %	1	25	25
Splash Detachment (kg/m^2)	0.76	1.14	0.65
Cover Factor	0.32	0.06	0.11
Slope (Degree)	4.00	5.71	4.29
Transport Capacity (kg/m^2)	0.16	0.002	0.31
Area (m^2)	150.00	39616.00	2400.00
Detachment rate (kg/ha)	7560.70	11418.66	6538.08
Transport capacity (kg/ha)	1611.90	18.98	3119.95
Estimated soil loss (kg/ha)	1611.90	18.98	3119.95

In the Morgan model, first the soil detachment capacity of the soil due to kinetic energy of rainfall and the soil detachability is determined and then the sediment transport capacity of generated runoff according to the rainfall amount. The erosion rate takes the lower value from the detachment rate and the transport capacity. Estimation of rainfall amount, kinetic energy of rainfall and soil detachability index can be done using the spatial distribution of rainfall and soil types.

Effect of vegetative conditions and parameters considered for moisture storage and runoff generation on estimated erosion were examined here.

5.3.1 Effect of slope change on erosion estimated by the Morgan model

According to the equation 2-11, the slope change effects on the sediment transport capacity of the runoff water. The effect of slope changes on the estimated erosion for to slope classes, is given in the figure 5-6. Although the equation takes the sinus value of slope, the change of estimated erosion for slope change shows a linear relation. Increase of slope for some critical slope classes (e.g. 10^o), do not reflect in the erosion estimation because it limited by the detachment rate as shown in figure 5-6. About 10% change in slope will result 10% change in the estimated erosion by using the Morgan model, but the change will have effect only up to the transport limited point.

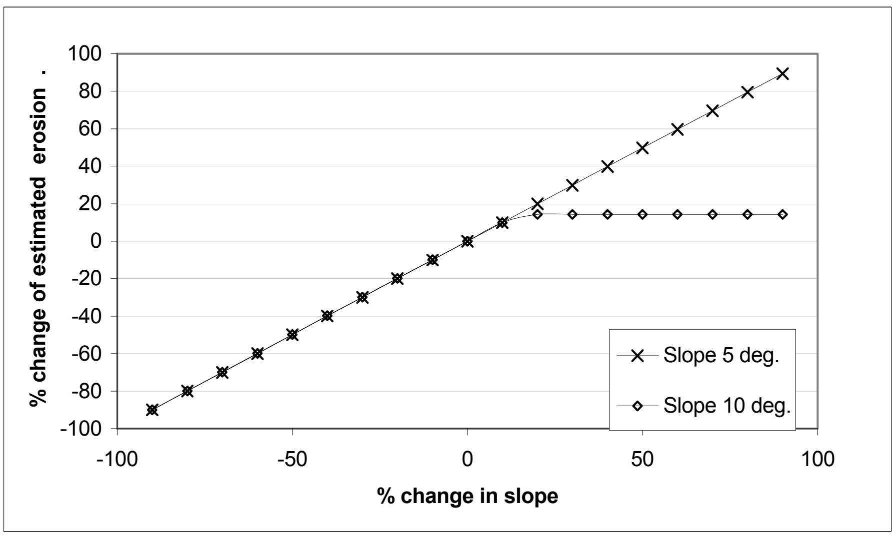


Figure 5-6: Change in estimated erosion by the Morgan model for change in slope

5.3.2 Effect of soil moisture and evapotranspiration on estimated erosion

The sediment transport capacity is a function of the runoff, sinus of slope and cover factor, as shown in the equation 2-11. Many components of the water budget are used for the calculation of the runoff amount over the considered period. Moisture content at field capacity (M_{FC}) differs according to the soil characteristics. Actual evapotranspiration (ET_a) of vegetation gives the moisture removal rate from the system. ET_a varies according to the type of crop, cover percentage, growth stage, etc.. Both parameters determine the amount of rain excess for overland flow. The relation between those parameters and Morgan estimated erosion is shown in the figure 5-7. According to the figure if the M_{FC} or ET_a/ET_o ratio is decreased the estimated erosion is increased due to high potential for overland flow. The relationships show exponential pattern extended from transport limited point to zero runoff point. If the erosion estimate is below the detachment limit, attention in calculating these factors seems to be important.

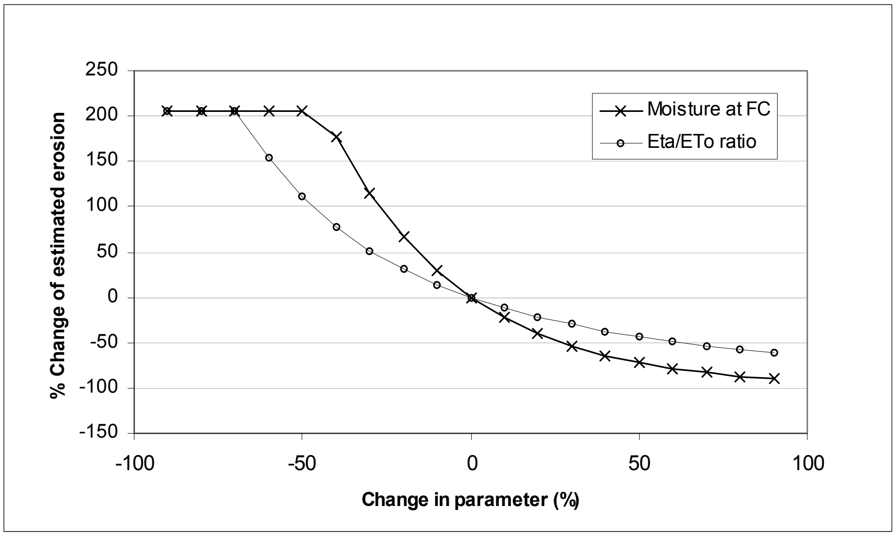


Figure 5-7: Change in erosion estimated by the Morgan model for change in moisture at field capacity and change of ET_a/ET_o ratio

5.3.3 Effect of cover factor estimation on the Morgan model erosion estimation

The cover factor used in the Morgan model is calculated following the same estimation procedure of USLE C factor. The effect of cover factor change on estimated erosion for two slopes (5^o and 10^o) is given in the figure 5-8. According to the figure an increase in the C factor results increase in estimated soil erosion. Effect of cover factor change on estimated erosion, is higher for steeper slopes. Therefore, cover factor estimation is more critical for steeper slope when using the Morgan model.

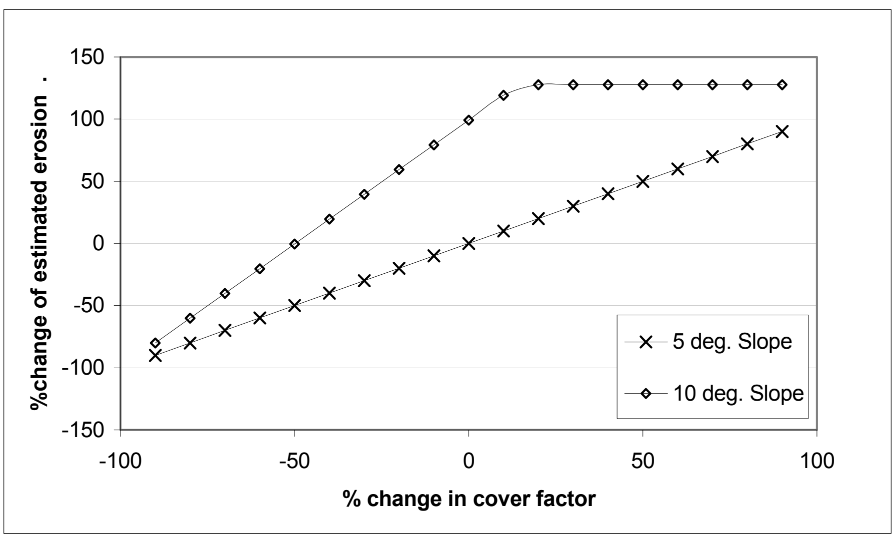


Figure 5-8: Change of erosion estimated by the Morgan model for change in cover factor

5.4 Use of model parameters for qualifying lands in to erosion classes

Generally, experimental data collection for model parameter processing is difficult. Parameter estimation is common in erosion modeling. Different dimensions and sensitivity of parameters, can effect on final classified map. The effect of parameter change on classified map is given in figure 5-9

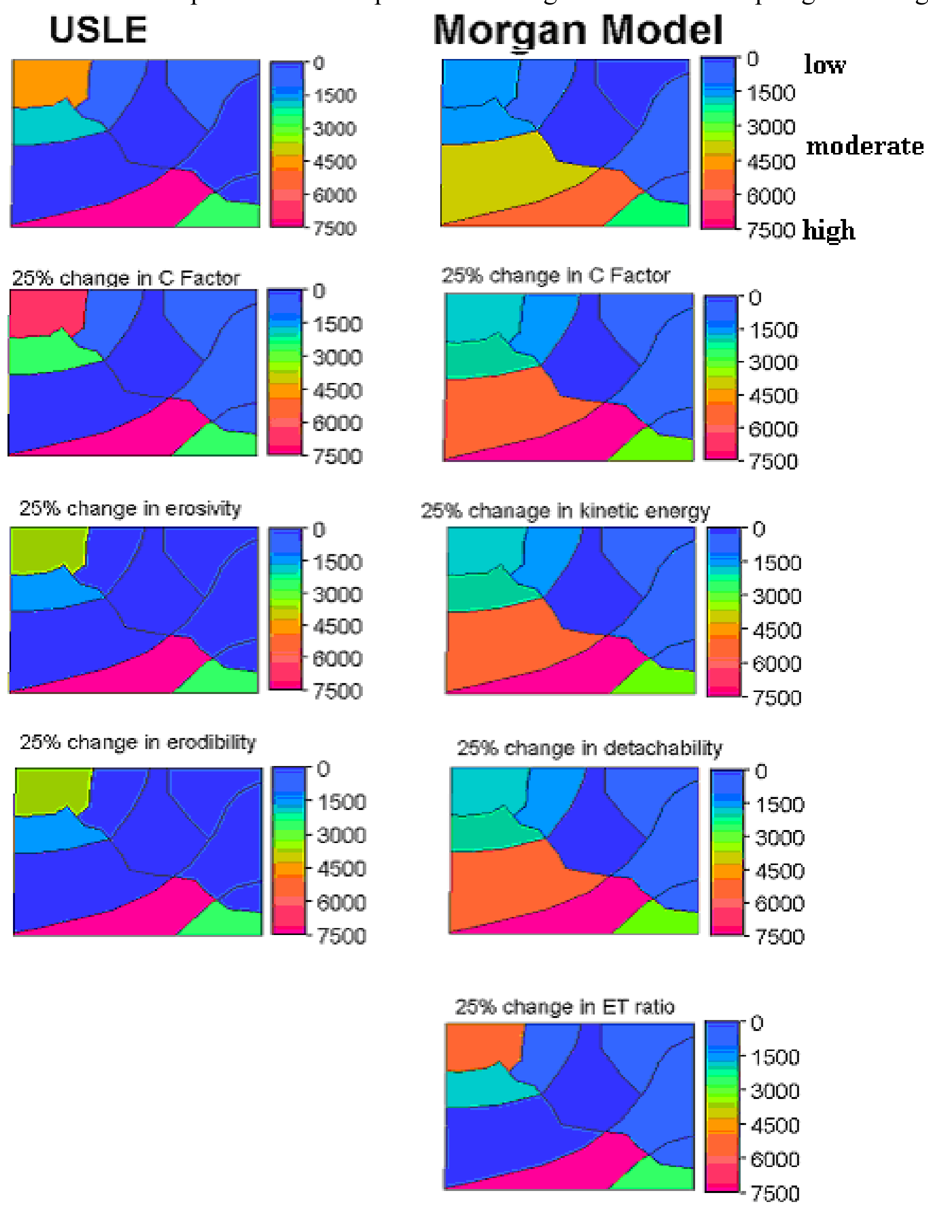


Figure 5-9: Effect of systematic change in model parameters for classified map

The maps shown in figure 5-9 are hypothetical maps to illustrate parameter behaviour. Percentage change of a parameter will not reflect any change if the sensitivity for final estimation is linear. Effect of C Factor change for the Morgan model results only visible when it is within the transport limit. Parameter change will not effect the classification of lowest and highest class for those land units considered in this assessment. Changing the C factor in both model can do a quick qualification of land units for a different class.

Chapter 6 - Erosion Model Evaluation

6.1 Introduction

Ability of different model types to classify lands according to erosion may differ according to the set of parameters considered, spatial and temporal scale, topographic, land cover conditions, management condition and according to behavioral characteristics of the prediction model. Model performances in erosion assessment for different type of lands are discussed in this chapter.

6.2 Erosion assessment by different models

Erosion rates estimated by using different models and field estimation are compared in the table 6-1. According to the results, for two sites, erosion estimates of the USLE and the Morgan model was similar and agreed with the observed erosion rates. Most of the other sites do not show agreements for erosion rates estimated by each model.

Erosion estimates of the USLE and the Morgan model for both sites of *Ndabibi* maize field give similar results. Field observations and farmer information confirmed that the erosion at N1 is much higher than N2 site although both sites are close to each other. Slope steepness is high in N1 site. The slope ranges between 7-12% in N1 and 7-22% in N2. The slope-length is higher in N1 than the other site. Increased slope-length will not effect on the estimation of the Morgan model because length is not considered in the modeling process.

6.2.1 Erosion modeling and slope-length

Although USLE is less sensitive for length changes (see figure 5-4), for land units with longer slope-lengths, an overestimate of erosion rates obtained for K1 site in *Kinangop* (table 6-1), because the slope-length is major function of USLE. The erosion rate for K1 estimated by USLE is much higher than the Morgan model estimate. The EUROSEM estimation gives a higher rate than the Morgan model and the value is 4130 kg/ha, which is three times greater than field estimate for whole the catchment at *Kinangop*. Actual erosion rates should be lower than 1432 kg/ha as shown in table 6-1. Land units with long slope-lengths as at *Kinangop,* models overestimate erosion rates, except for the Morgan model.

Estimated erosion rates by three models, for the grassland site (K2) at *Kinangop* are very low when compared with estimated values for all the other sites. Field observations confirmed that there was very low or no erosion in the K2 site and no erosion or runoff paths could be observed in the site. This shows any of the considered models can be used to identify grass-covered lands as units of low erosion rates.

6.2.2 Canopy cover and estimated erosion

Erosion estimations of the USLE and the Morgan model, for sites of *Kijabe* (J1 and J2) were matched with the observed minimum rates from rill volumes. The Morgan model estimated erosion rate is nearly 4 times higher than the estimate of the USLE for J1 site. The sites at *Kijabe* have a high percentage of bare soil. But the evidence is not enough to say which model gives more reasonable estimates for sites with less vegetative cover.

Table 6-1: Erosion estimated using different method

SITE	ID	Area (m^2)	Rainfall (mm)	Estimated Erosion rates (kg/ha)			
				Field	USLE	Morgan Model	EUROSEM Model
Kijabe	J1	625	126	>706	1362	4605	
Kijabe	J2	725	80	>298	1026	1748	
Kinangop	K1	38300	688	<1432	18247	33	4138
Kinangop	K2	39600	688		128	1	0.0
Longonot	L1	2930	310	>1255	8827	962	
Ndabibi	N1	4730	480	>189	21766	21837	
Ndabibi	N2	7800	480	N.A	9599	7886	

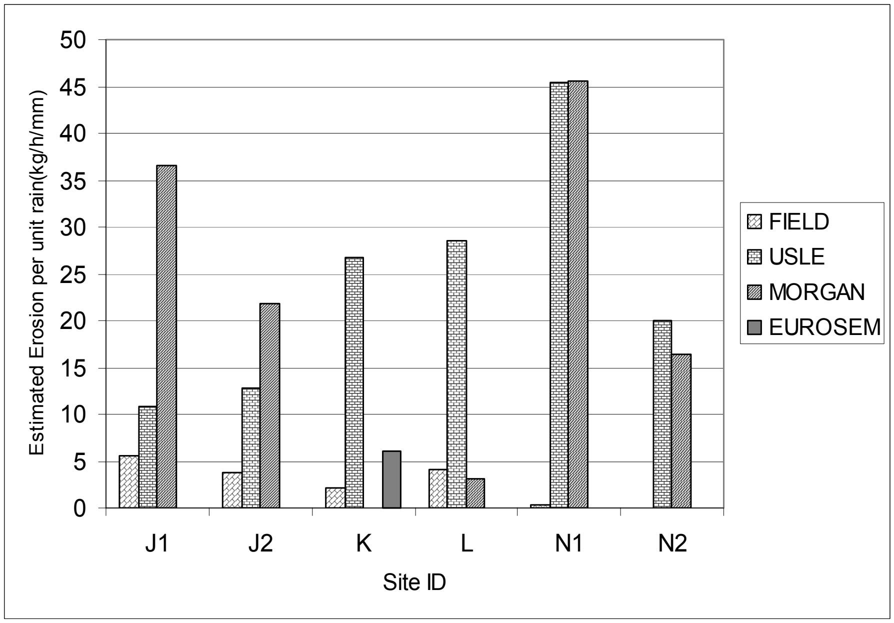
6.2.3 Model application for high permeable lands

For moderately permeable land units with steeper slopes and medium slope-lengths, the USLE and the Morgan model gives closer estimates (site N1). Field observations and farmer information provide strong evidence for highest erosion risk in the N1 site than for the other considered sites. General visual observation showed that erosion rate of N2 site was much lower than site 'L' and site N1. If these three sites are ranked according to the erosion risk, order should be N1>L>N2. The estimates of the Morgan model do not show this ranking. Estimates of USLE agreed with this ranking. Estimated value by the Morgan model for *Longonot* site is much lower than that for N2 site. According to that, USLE estimates for those three sites are more realistic than the Morgan model estimates.

Saturated hydraulic conductivity (table 3-7) values show that these three sites are highly permeable, compared to the other sites. Slope-length ranges between 5-86 m and the slope steepness ranges is 10 –20% for those three sites (see table 4-8). According to results, erosion assessment for these type of lands, use of USLE seems more reliable than the Morgan model.

6.2.4 Estimated erosion and rainfall

The duration of simulation and observation considered for each site is different. Therefore to facilitate the comparison of the erosion estimates of different models, among sites, erosion rate per unit rain is considered (see figure 6-1). Erosion estimated by the Morgan model are high for the *Kijabe* sites where the surface area is dominated by rills and a high percentage of bare soil. The estimates of USLE are closer to the field estimates. But the field estimates is a minimum value for actual erosion rate, because it only included the rill erosion occurred after last land preparation.



note : Field estimates are minimum value except for site(K)where is the maximum value, EUROSEM only for site K

Figure 6-1: Comparison of estimated erosion rates per unit rainfall

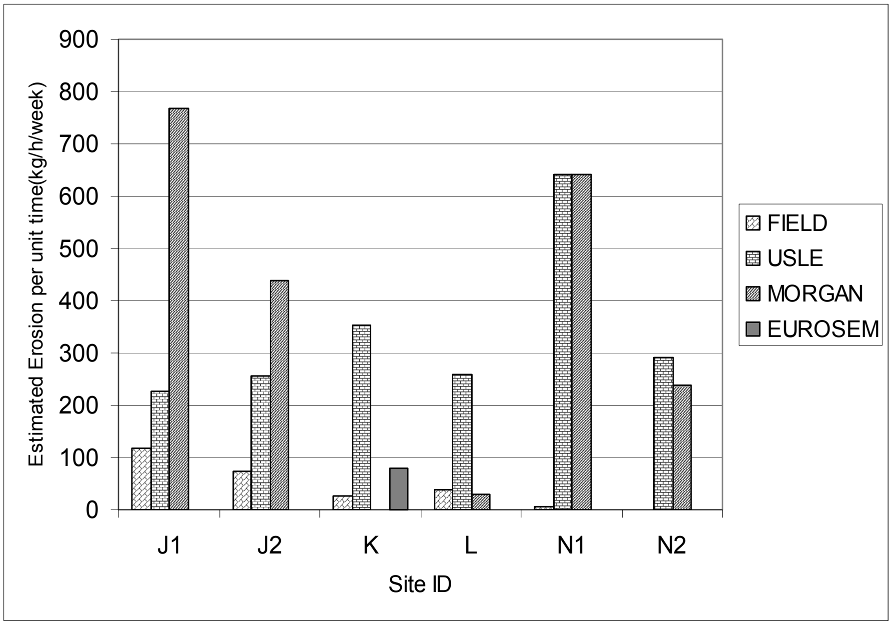
6.2.5 Estimated erosion and duration

The erosion estimation may differ among sites and models because of the duration considered were different. Estimated erosion for a unit time was calculated by dividing the erosion rates from the duration considered. It should be noticed that the field estimates stated in the figure are minimum values except for *Kinangop* site. For *Kinangop* site the field estimated value gives the maximum value because it was estimated using yearly de-siltation rate of the reservoir and the bank erosion should be deducted from the erosion estimated. J1 site gives the highest estimation by the Morgan model and the site is consisted with bare soil for higher proportion. USLE estimates considerable low values for J1 and J2, which were low in vegetative cover. The Morgan model and the USLE estimated similar high values for N1 site, where slope-lengths are moderate.

6.2.6 Model results and field estimates

Erosion estimation by using field information gives the minimum erosion rate for each site, except for the catchment at *Kinangop* where the erosion estimation used a rough estimate of de-siltation of a reservoir. Rill dimensions were used to evaluate erosion for other sites. They give only a estimation of erosion due to rill erosion and erosion rates should be higher than that value because sheet and splash erosion should be added.

Results shows that the Morgan model gives lower estimation for *Longonot* than the minimum field soil loss. For sites with high infiltration capacity or permeability the USLE seems more suitable than the Morgan model, because high permeability gives under estimation for the Morgan model. However, the effect of surface sealing is not taken in to account by the two models, all the lands with K_s higher than 6 cm/hr, the USLE takes permeability code as 1. Therefore the USLE restricts further decrease of erosion estimates. If the K_s is much more than 6 cm/hr, no lower erosion rates can be calculated even.



note : Field estimates are minimum value except for site(K)where it is the maximum value, EUROSEM only for site K

Figure 6-2: Comparison of estimated erosion per unit time

For *Kinangop* site soil erosion estimates should be lower than field estimated rates. But the USLE gives much higher estimated erosion for *Kinangop* than maximum field estimation. It is 7 times higher than maximum estimation. The Morgan model estimates was lower than the maximum erosion rate. EUROSEM gives high value for the same site (see table 6-1). None of the models take the effect of deposition at the bottom of the slope into account.

Erosion estimates for *Ndabibi* N1 site are the same for both USLE and the Morgan models and higher than the minimum rate estimated using field data. Slope-length of N1 site is close to 100m. This length can be proposed as a break point for slope-length switching between models for use in a erosion approach.

Chapter 7 - Model support for erosion assessment

7.1 Introduction

Although many methods available for erosion assessment, no method is perfect. Erosion assessment by interpretation of surface features related to erosion status, is difficult because high human interference of some lands and destruction of surface features. Rule based method have limitation of applicability for further classification erosion risk as discussed in chapter 2, due to increase complexity in rule formulating for land units with high variability (such as agriculture lands). As shown in previous chapter, different models result in completely different erosion rates for the same site. Therefore, prediction of erosion risk areas using one method is probably not yield reasonable results. On the other hand, models can be applied selectively for land units according to the suitability of each model and only for land units needed further classification after applying rule-based method. Model suitability for different site characteristics and model support for erosion assessment are evaluated in this chapter.

7.2 Use of aerospace maps and field observation for erosion assessment

Qualitative criteria can be used to classify aerospace maps according to erosion potential by feature interpretation. Using aerial photographs (AP) under stereovision, image classification can be done, identifying land categories according to erosional status. Some of the image features can be used to classify land units that related to low erosion potentials.

7.2.1 Land units with dense canopy cover

Erosion and land use change are very strongly related. Rates of soil loss accelerated quickly to unaccepted levels whenever land is misused (Morgan, 1995). Land units with dense canopy cover, have low erosion potential. It is possible to identify land units with dense canopy cover using AP interpolation and categorized them as low. Some areas of the Northeast part of the Naivasha basin is best example for these types of land units. Forest lands with dense canopy cover and grasslands with trees and bushes can clearly be identified using aerial photographs. Field observations on these land units confirmed that very low or no erosion signed visible those land units with undisturbed canopy cover.

7.2.2 Gentle slopping and flat lands

Land units with flat surface or gentle slope have low erosion potential. This type of units can be identified in AP interpretation or using a slope class map with suitable scale in a GIS environment. Considerable extent of lands in Naivasha can be categorized as low erosion according to this criterion. Field observations verify that, erosion signs are rare in those agricultural land with the slope steepness is less than 7%.

7.2.3 Surface drainage

Absence or low density of surface drainage indicates the permeability of surface soils or the depositional areas. In Naivasha especially in northwest part, the drainage lines started in up slope completely disappear at the foot slope of the land unit. This type of lands indicates high permeable lithology and the erosion potential is negligible.

7.2.4 Agriculture lands

Agriculture lands can clearly be identified using AP interpretation. Within the Naivasha basin, scale of agriculture lands range between 1ha household lands to few square km large-scale commercial farms. According to the erosion signs observed during the field inspection, highly erosive areas could be identified in slopping cultivated lands of both large and small-scale farms. Classification of these slopping cultivated land according to erosion rates is not easy with AP interpretation and field observation.

7.3 Model support for erosion assessment in agriculture lands

Proper assessment of models can be done, with statistically selected statistically designed experimental plots. In this study model evaluations were done using available erosion estimates and limited data that could be collected during limited fieldwork time. Few hints for model support can be extracted from this study.

7.3.1 Model suitability for different site characteristics

According to results USLE overestimates gives higher estimated erosion for *Kinangop*. The USLE estimates the erosion rate as 18375 kg/ha but the actual erosion rate should be less than 1430 kg/ha. Length of the site is considerably high (see table 4-8). EUROSEM gives over estimation for the same site. But the estimation of the Morgan model can be interpreted as reasonable because the value is matched with the field estimation. Therefore it can be proposed that the Morgan model is most suitable for land units with high lengths. USLE and the Morgan model estimate similar values for N1 site that is about 90m in length. According to that the length limit for USLE can be set as 90m. The site at *Longonot* is low in slope-length. The Morgan model under estimates the erosion rate and estimation of USLE is matched with the actual rates. Therefore, it can be agreed for that the Morgan model is more suitable for sites with 90m in length or higher.

The Morgan model gives lower estimation for *Longonot* than the minimum soil loss. For sites with high infiltration capacity or permeability, the USLE is good rather the Morgan model, because high permeability gives under estimation for the Morgan model. Since effect of surface sealing is not taken in to account by both models.

Combine effect of longer length and higher permeability for model estimates cannot be evaluated because no such a site has been selected for this study.

Sites at *Kijabe* comprised with young wheat seedlings and exposure of bare soil is high. The Morgan model estimates comparatively higher values for both sites (K1 and K2) than USLE estimates. But estimations of both models are agreed with field estimates because both estimates are higher than the minimum observed erosion rates. Although the Morgan model gives much higher values than USLE, it cannot be said whether that value is correct or not.

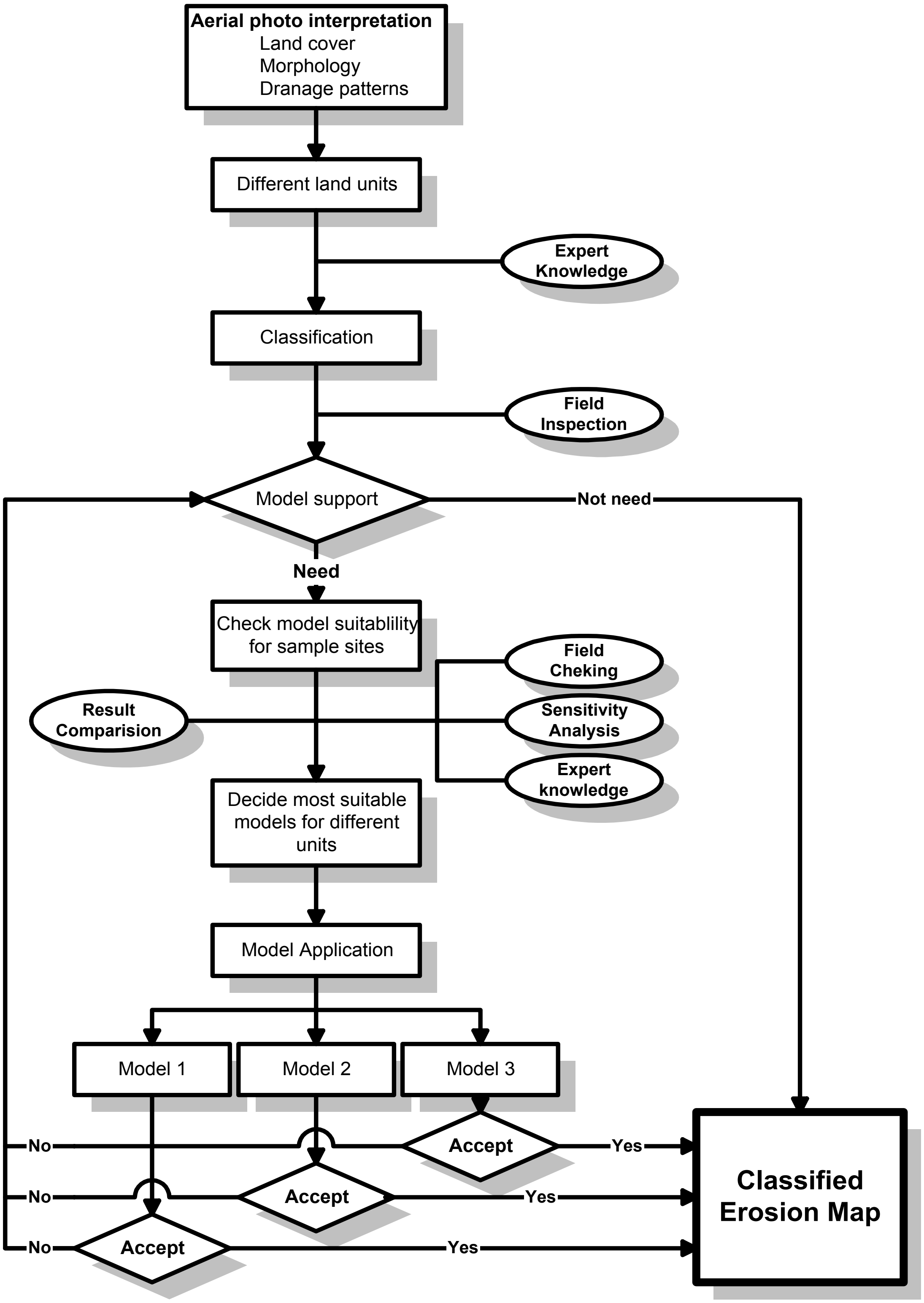


Figure 7-1: Merging quantitative approaches with qualitative criteria for erosion mapping

According to the results, no criteria could be formulated about the estimated erosion of different models for slope shape differences. However, the overestimation by models for the *Kinangop* site could be due to ignoring the bottom concavity.

7.3.2 Merging quantitative approaches with qualitative criteria for mapping erosion

As shown in the figure 7-1, first the qualitative criteria could be used to classify land units according to the erosion potential. For some land units, classification could be done easily without using erosion models. The other land units such as slopping cultivated lands, for which qualitative criteria cannot be applied confidently, could be classified by using different models. Appropriate model for different types of land units could be selected after model evaluation. Expert knowledge is required for this purpose. Studying the behavior of models in an erosion assessment approach, it can be noticed that model result and final classified map can give varying results. Even though, automated classification can be done using computers in a GIS environment, since no defined rules for extraction of most of the parameters exist, careful attention is needed when erosion model applying. Different models estimate different erosion rates for the same site, therefore supervised model application is better specially when using a model for untested areas. Before using models for erosion assessment, checking of model suitability for different types of land units by applying them to selected sample site may yield better erosion assessment.

7.3.3 Aerial Photographs for Erosion Classification

Aerial photographs can be used to identify separate land units according to the land cover conditions. As shown in the figure 7-2, the aerial photo that covers *Kinangop,* the units with good cover and steep valley units have been excluded when erosion assessment using models. For each parcels shown, model parameters have to be determined. Total area considered was 6000ha. For 50% of the area, erosion models could be meaningfully applied. Model application for areas with dense cover is not needed because no erosion takes place. For the other parts with steep valleys erosion model use is not meaningful.

In figure 7-3 land units where models can give unexpected estimates. In the slopping, dissected land units, model support may help in classification. The drainage lines disappeared at the bottom of the foot slopes and indicate that the beginning of highly permeable land units with deposition or low erosion rates. For those land units, erosion model may yield wrong results. Field investigation is required for some land units to see whether the models may useful or not for erosion assessment.

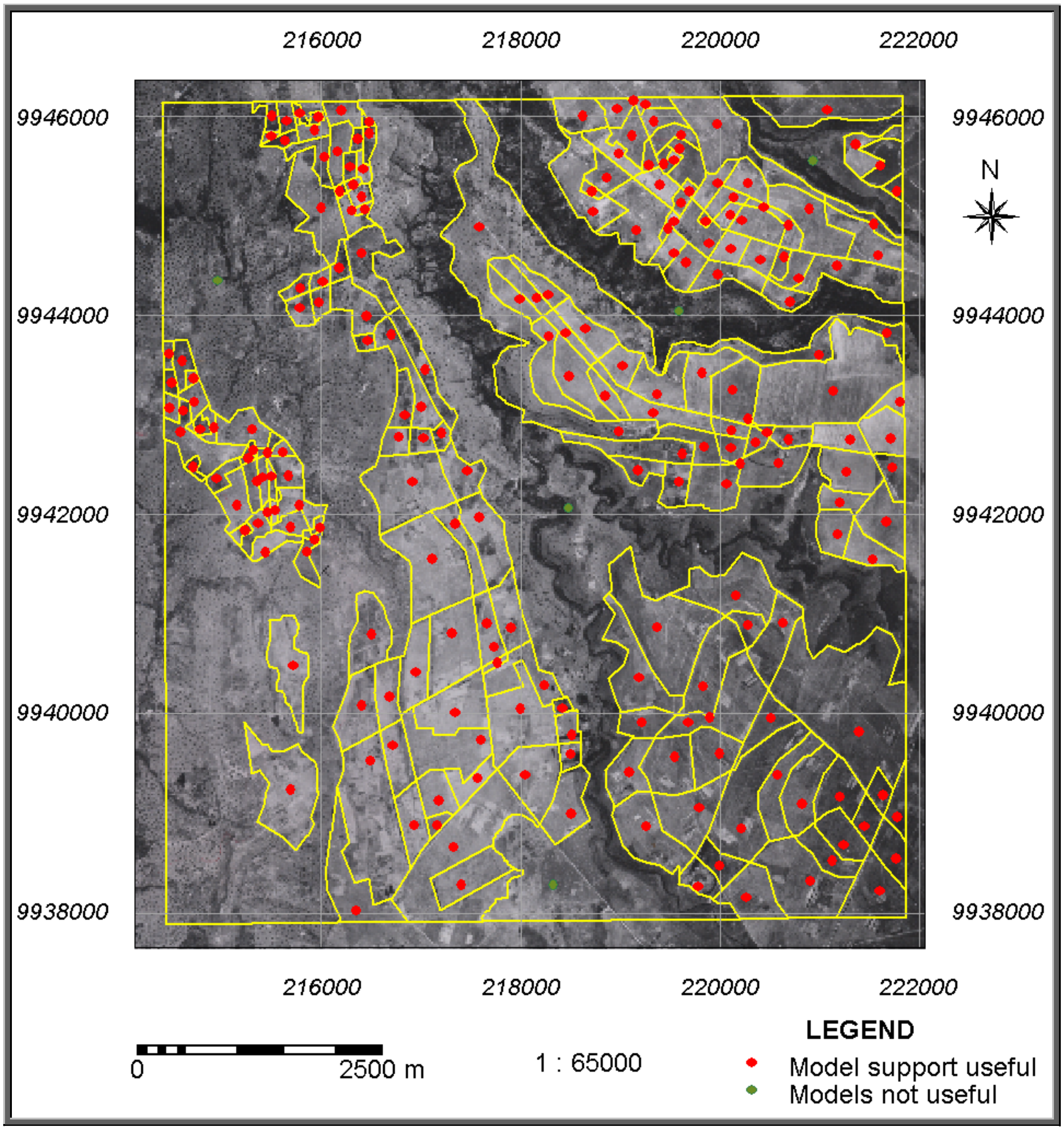


Figure 7-2: Identification of land units and parcels where erosion modelling could be meaningfully applied

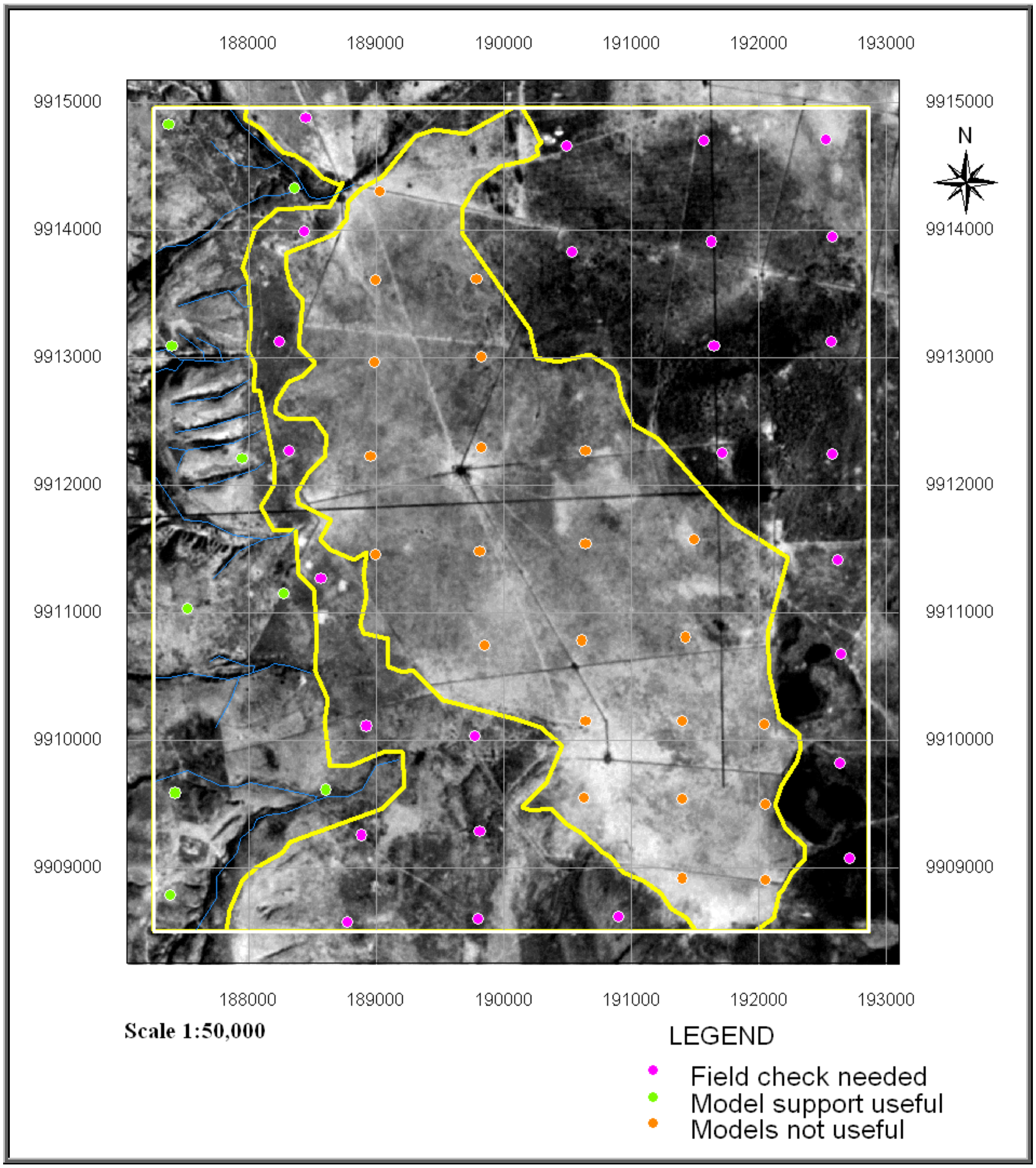


Figure 7-3: Identification of land units for erosion model use by using surface features

Chapter 8 - Conclusions

Erosion is a diffuse process and widely varies spatially and temporally. There are many types of approaches available for surveys and mapping erosion. To some extent, erosion surveys can be used to review erosion qualitatively by using aerospace images, according to some features related to erosion and making expert decisions using previous knowledge of erosion status related to each class of parameters. Further classification is restricted due to scale limitations. Field observations can be used for further classification of qualitative erosion status, but effort should be taken to interpret variations among units. Field observations and measurement can be used for quantifying erosion rates in some land units. Sediment depths of farm ponds and small reservoirs can give annual sediment yield estimates, if the reservoir is de-silted annually or by measuring the sediment volume. Estimation for erosion can be calculated from rill dimensions if they exist. As the rill estimate gives only the soil removed due to rill erosion it is an under estimation. But clean weeding in field with row crops limits the quantitative and qualitative evaluation of erosion due to frequent disturbance to topsoil.

Those land units for which classification of erosion by empirical rules or judgement was not feasible, potentials for model use was evaluated, applying models for selected sites and by sensitivity analysis. Models evaluated in this research are Universal Soil Loss Equation, the Morgan model and EUROSEM model.

According to the results of *Kinangop* (K1) site, for land units with longer slope-lengths, USLE overestimates erosion rates. The Morgan model estimates are reasonable. The erosion estimates for *Ndabibi* N1 site, that has moderate slope-length, by the USLE and the Morgan model, are quite similar. The slope-length is close to 90m. For lands with longer slope-lengths, it is suggested to use the Morgan model.

As was evident from the estimation of erosion for *Longonot* (L) site, for land units with high infiltration capacity or permeability and short slope-length, application of USLE is better than the Morgan model (under estimation), despite the limitation of USLE for high permeability soils.

Model results of *Kijabe* shows that, for sites with low cover density crop cover, the Morgan model seems to be over estimating erosion rates, but evidence is not enough to confirm it.

Due to data scarcity and time limitation, the evaluation of the EUROSEM model has been limited to two sites. The EUROSEM model seems to be best for assess temporal variation of erosion rates. The model simulated that 75% of total annual erosion in *Kinangop* K1site resulted from two rain events during the considered year.

For USLE, a 50% change in slope-steepness results nearly 100% change in estimated soil erosion. Sensitivity to slope change with USLE is more for steeper slopes than for gentle slopes. Change of slope with the Morgan model has a linear effect and 50% change will create 50% change in transport capacity but for steeper slopes, detachment limitation gives a threshold. A change or shift in the structure code of USLE results in a change of nearly 100% of estimated erosion. Therefore, structure determination is important for USLE soil erodibility calculation using the USLE equation. The USLE is Sensitive to organic matter content. A 50% change in organic matter content results in 100% change of erodibility and predicted erosion. Other textural components considered for soil erodibility calculation do not show strong effect on USLE estimation. Effect of slope-length is poorly included in the USLE and Morgan model. The modelling facility of dividing the catchment or site into elements result a better representation of spatially distributed variations in EUROSEM. Cover factor is more sensitive to surface cover or mulch cover than the other sub-factors for both models. But the effect of cover factor change on estimated erosion is less in the Morgan model.

Qualitative criteria can be used to classify land units according to erosion status. Land units with very low or no erosion can easily be identified using land cover and landform. In the land units with cultivation, the interaction between rainfall, soil and cultivation practices causes much complexity, which may be difficult to evaluate. Support by models is desired because the models attempt to simulation the interaction between processes with given parameter values. Selection of a suitable model for each land unit category is critical because different types of models give varied results for the same land unit. Evaluation of models with respect to the parameter behaviour and land conditions may help for better erosion assessment.

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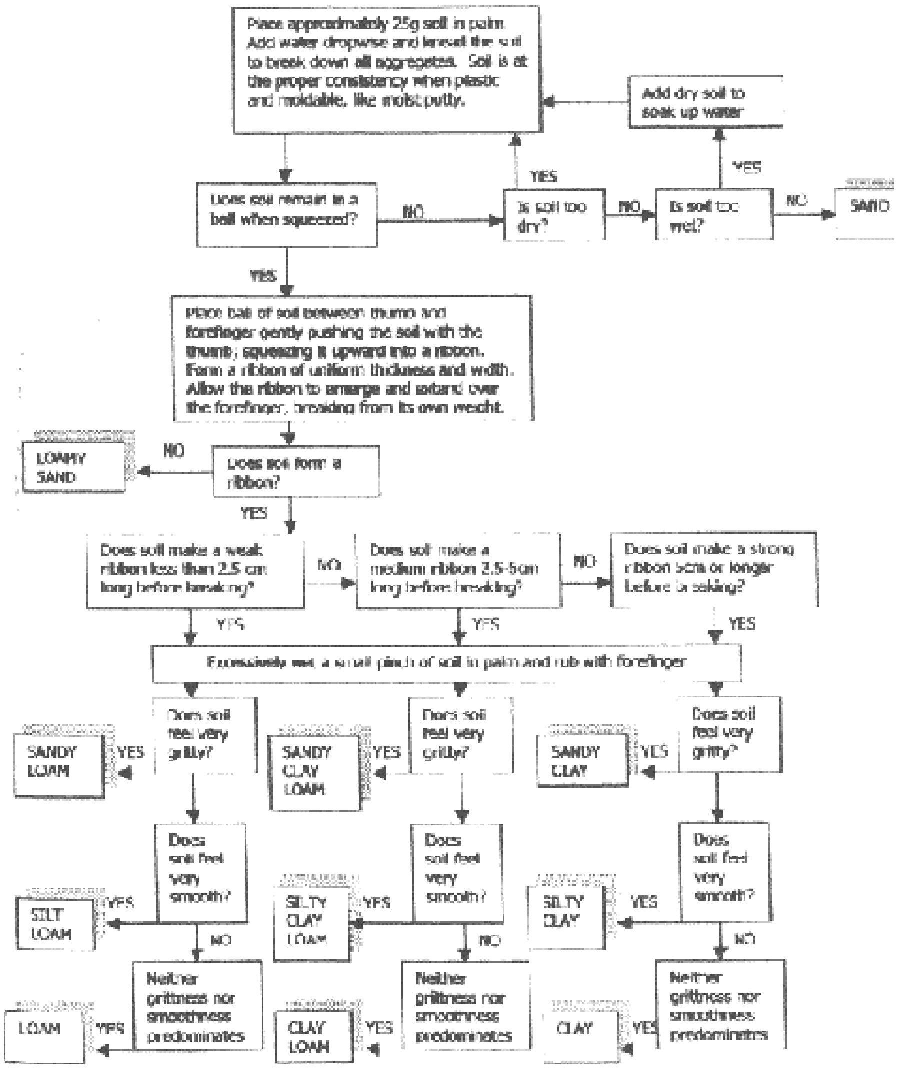
Appendices

APPENDIX I: Instructional diagram for determining soil texture by feel



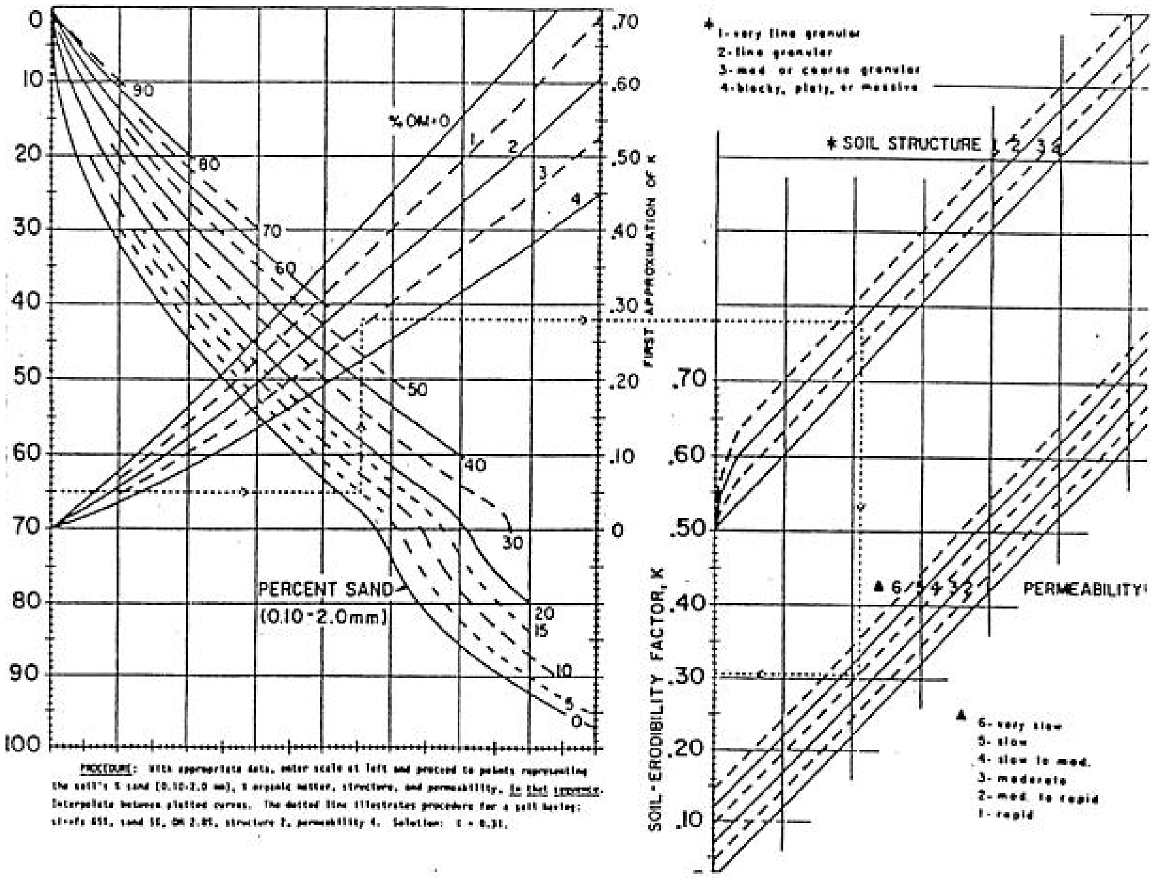
(after Spaliviero, 2000)

APPENDIX II: Lengths of crop development stages of maize and wheat

Crop	Length of crop development stages (days)					Plant Date	Region
	Initial	Development	Mid	Late	Total		
maize (Grain)	30	50	60	40	180	April	East Africa
wheat	15	25	60	30	150	July	,,
wheat	40	30	40	20	130	April	,,
wheat	40	60	60	40	200	November	,,

Source : FAO, CROPWAT

APPENDIX III: Soil-erodibility nomogram.



Soil-erodibility nomograph. Where the silt fraction does not exceed 70 percent, the equation is 100 K = 2.1 M1.18 (104) (12 - a) + 3.25 (b - 2) + 2.5 (c - 3) where M = (percent si + vfs) (100-percent c), a = percent organic matter, b = structure code, and c = permeability class

APPENDIX IV: Element wise parameters of Rainfall and soil for the Morgan model

Location	Site ID	Element ID	Total RF (mm)	Kinetic Energy (J/m^2)	Moisture at Field Capacity (v/v)	Bulk Density (Mg/m^2)	Rooting Depth (m)	ET_a/ET_o	Soil Moisture Storage (mm)
Kijabe	J1	A	126	1987	0.40	0.99	0.05	0.1	6.26
	J1	B	126	1987	0.40	0.99	0.05	0.1	6.26
	J1	C	126	1987	0.40	0.99	0.05	0.1	6.26
Kijabe	J2	A	80	1243	0.40	0.84	0.05	0.1	5.31
	J2	B	80	1243	0.40	0.84	0.05	0.1	5.31
	J2	C	80	1243	0.40	0.84	0.05	0.1	5.31
Kinangop	K1	B	688	9964	0.40	1.05	0.05	0.7	17.57
Kinangop	K2	A	688	9964	0.40	0.71	0.05	0.95	13.84
Longonot	L1	A	310	6645	0.28	1.02	0.05	0.7	11.95
	L1	B	310	6645	0.28	1.02	0.05	0.7	11.95
	L1	C	310	6645	0.28	1.02	0.05	0.7	11.95
	L1	D	310	6645	0.28	1.02	0.05	0.7	11.95
Ndabibi	N1	A	480	7607	0.28	0.93	0.05	0.7	10.89
	N1	B	480	7607	0.28	0.93	0.05	0.7	10.89
	N1	C	480	7607	0.28	0.93	0.05	0.7	10.89
	N1	D	480	7607	0.28	0.93	0.05	0.7	10.89
	N1	E	480	7607	0.28	0.93	0.05	0.7	10.89
	N1	F	480	7607	0.28	0.93	0.05	0.7	10.89
Ndabibi	N2	A	480	7607	0.20	0.93	0.05	0.7	7.78
	N2	B	480	7607	0.20	0.93	0.05	0.7	7.78

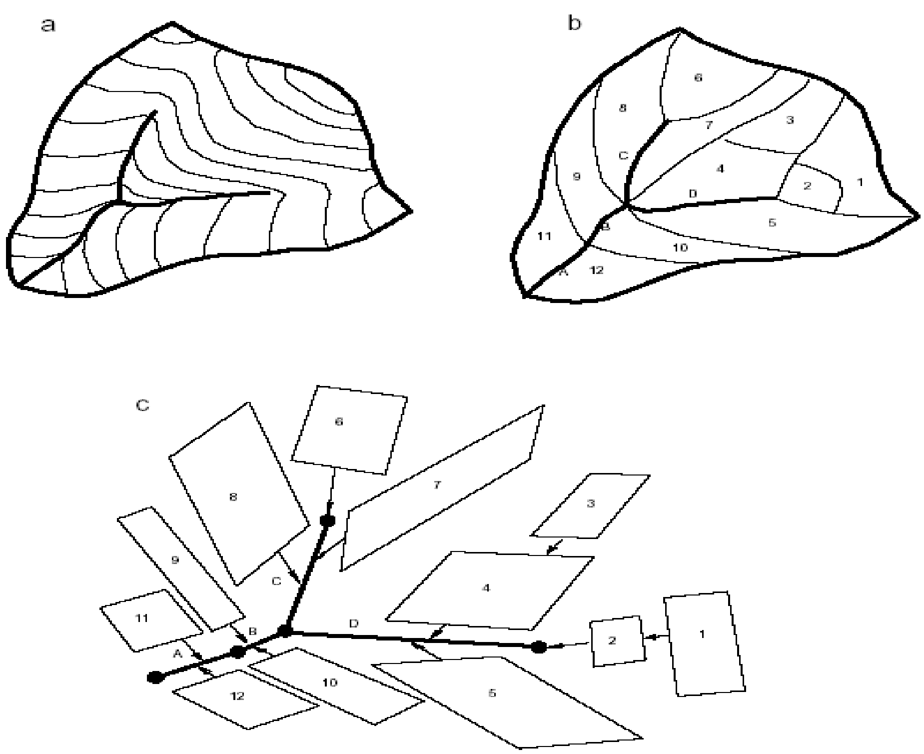
APPENDIX V: Splash detachment calculation for each element

Location	Site ID	Element ID	No of rain days	Rain per day (mm)	Run off volume (mm)	Soil Detachability (g/J)	Rainfall Interception Factor %	Splash Detachment (kg/m^2)
	ID		n	Ro	Q	K	A	F
Kijabe	J1	A	8	15.8	85	0.4	1	0.756
	J1	B	8	15.8	85	0.4	1	0.756
	J1	C	8	15.8	85	0.4	1	0.756
Kijabe	J2	A	9	8.8	44	0.4	1	0.473
	J2	B	9	8.8	44	0.4	1	0.473
	J2	C	9	8.8	44	0.4	1	0.473
Kinangop	K1	B	144	4.8	17	0.4	25	1.142
Kinangop	K2	A	144	4.8	38	0.4	35	0.693
Longonot	L1	A	60	5.2	31	0.3	25	0.571
	L1	B	60	5.2	31	0.3	25	0.571
	L1	C	60	5.2	31	0.3	25	0.571
	L1	D	60	5.2	31	0.3	25	0.571
Ndabibi	N1	A	56	8.6	135	0.3	25	0.654
	N1	B	56	8.6	135	0.3	25	0.654
	N1	C	56	8.6	135	0.3	25	0.654
	N1	D	56	8.6	135	0.3	25	0.654
	N1	E	56	8.6	135	0.3	25	0.654
	N1	F	56	8.6	135	0.3	25	0.654
Ndabibi	N2	A	56	8.6	194	0.3	25	0.654
	N2	B	56	8.6	194	0.3	25	0.654

APPENDIX VI: Soil detachment, transport capacity and soil loss by Morgan Model

Location	Site ID	Element ID	Cover Factor	Slope (Degree)	Transport Capacity (kg/m^2)	Soil Loss (kg/m^2)	Area m^2	Soil Loss from the element	Detachment rate (kg/ha)	Transport capacity (kg/ha)	Estimated soil loss (kg/ha)
	ID		C	S	G	EROSIO		kg			
Kijabe	J1	A	0.322	4.0	0.161	0.161	150	24	7561	1612	1612
	J1	B	0.322	4.6	0.184	0.184	375	69	7561	1841	1841
	J1	C	0.322	2.9	0.115	0.115	125	14	7561	1153	1153
Kijabe	J2	A	0.320	8.5	0.090	0.090	200	18	4730	900	900
	J2	B	0.320	3.7	0.039	0.039	525	21	4730	394	394
	J2	C	0.320	4.3	0.045	0.045	75	3	4730	454	454
Kinangop	K1	B	0.111	5.7	0.033	0.033	39616	132	11419	33	33
Kinangop	K2	A	0.001	4.3	0.0001	0.0001	38296	3	6926	1	1
Longonot	L1	A	0.143	11.3	0.026	0.026	750	20	5712	263	263
	L1	B	0.143	11.3	0.026	0.026	125	3	5712	263	263
	L1	C	0.143	10.2	0.024	0.024	250	6	5712	238	238
	L1	D	0.143	8.5	0.020	0.020	800	16	5712	199	199
Ndabibi	N1	A	0.182	3.7	0.214	0.214	852.5	182	6538	2137	2137
	N1	B	0.182	4.3	0.246	0.246	770	190	6538	2464	2464
	N1	C	0.182	5.1	0.295	0.295	1650	487	6538	2953	2953
	N1	D	0.182	6.8	0.393	0.393	522.5	205	6538	3925	3925
	N1	E	0.182	12.4	0.708	0.654	660	432	6538	7079	6538
	N1	F	0.182	5.7	0.328	0.328	275	90	6538	3278	3278
Ndabibi	N2	A	0.111	4.3	0.312	0.312	2400	749	6538	3120	3120
	N2	B	0.111	6.6	0.477	0.477	5400	2574	6538	4766	4766

APPENDIX VII: Illustration of elements for natural topography in EUROSEM model



APPENDIX VIII: Definitions of input variables for EUROSEM computer code

Variable	Symbol	Definition	Units
ACCUM.DEPTH		Accumulated depth of rain	mm
BW		Width of channel bottom	m
CLEN		Characteristic length of catchment. Use maximum lengths of cascading planes or longest channel	m
COH	J	Cohesion of the soil or soil-root matrix as measured at saturation using a torvane	kPa
COVER	COV	Percentage canopy cover	%
D50	d_{50}	Median particle diameter of the soil	µm
DELT		Time increment number used in calculations, usually 1 minute	min
DEPNO		Average number of concentrated flow paths (rills) across the width of the plane	
DERO		Maximum depth to which erosion can occur because of a non-erodible layer in the soil	m
DINT	IC_{max}	Maximum interception storage of the vegetation cover	mm
ELE.NUM.(J)		Element number	
EROD		Detachability of the soil particles by raindrop impact	g/J
FMIN	k_{sat}	Saturated hydraulic conductivity of the soil	mm/h
G	G	Effective net capillary drive of the soil	mm
GAGE.NUM		Rain gauge number	
ISTONE		Governs effect of rock fragments on saturated hydraulic conductivity (+1 = increase in hydraulic conductivity; -1 = decrease in hydraulic conductivity)	
J		Element number	
MANN(IR)	n	Value of Manning's n for the interrill area, allowing for roughness effects of soil particles, rock fragments, surface microtopography and vegetation cover (also used for non-rilled elements and channel elements)	$m^{1/6}$
MANN(RL)		Value of Manning's n for the rills, allowing for roughness effects of soil particles, rock fragments, surface microtopography and vegetation cover	$m^{1/6}$
MAXND		Maximum number of time-depth pairs for all rain gauges	
MCODE		Governs selection of sediment transport equations for interrill flow (0 = Govers; 1 = Everaert)	

Definitions of input variables and parameters used in EUROSEM identified by labels in the computer code (continued)

Variable	Symbol	Definition	Units
NC1		Element number of first channel contributing at upstream boundary of a channel element	
NC2		Element number of second channel contributing at upstream boundary of a channel element	
NELE		Total number of plane and channel elements	
NEROS		Allows user to call or reject erosion option within KINEROS. Set = 2 for EUROSEM	
NGAGES		Number of rain gauges (1-20)	
NL		Element number contributing flow to left-hand side of channel (when facing downstream)	
NLOG		Governs computation order	
NPRINT		Controls amount of information provided in the auxiliary output file. Normally set at 1 (other options are 2 and 7).	
NR		Element number contributing flow to right-hand side of channel (when facing downstream)	
NU		Element number of plane contributing to upslope boundary	
NUM.OF DATA PAIRS (ND)		Number of time-depth pairs for rainfall data	
NUM.(J)		Number of element corresponding to NLOG. Governs order in which elements are treated in computation.	
PAVE	PAVE	Fraction of surface covered by non-erodible material, e.g. rock fragments, concrete, tarmac	
PBASE	PBASE	Percentage of basal area of vegetation expressed as a proportion between 0 and 1	
PLANGLE	PA	Average acute angle of the plant stems to the soil surface	degrees
PLANTH		Effective canopy height	m
POR		Soil porosity	% v/v
RAINGAGE		Identification number assigned to the rain gauge	
RECS	RECS	Infiltration recession factor	mm
RFR	RFR	Downslope roughness	
RHOS		Specific gravity of the sediment particles	mg/m^3
RILLD		Average depth of concentrated flow paths (rills)	m
RILLW		Average width of concentrated flow paths (rills)	m
ROC	ROC	Proportion of rock fragments in the soil by volume	

Definitions of input variables and parameters used in EUROSEM identified by labels in the computer code (continued)

Variable	Symbol	Definition	Units
RS		Governs the option of whether the width and depth of rills are uniform over the length of the element or whether they increase downslope	
S	s	Average slope of the rills or concentrated flow paths on a plane element	m/m
SHAPE		Plant leaf shape factor, 1 = bladed leaves; 2 = broad leaves. A value of 0 = no vegetation and sets stemflow to zero	
SIGMAS		Standard deviation of sediment diameter (not used in present version of EUROSEM)	
SIR	s	Interrill slope (also used for slope of plane elements without rills and for channel elements)	m/m
SPLTEX	b	Water depth exponent affecting soil detachment by raindrop impact (set to 2.0 in present version of EUROSEM)	
TEMP		Air temperature at time of rainfall	° C
TFIN		Duration of model simulation. Value must be less than the end-time of the last time-depth pair of the rainfall data	min
THETA		Weighting factor in finite difference equations, usually set between 0.5 and 1.0	
THI	θ_I	Initial volumetric moisture content of the soil	% v/v
THMAX	θ_s	Maximum volumetric moisture content of the soil	% v/v
TIME		Accumulated time from start of storm	min
W		Width of plane element (set to 0.0 for channels)	m
WEIGHT		Multiplication factor for weighting of RAINGAGE	
XL		Length of plane or channel element	m
ZL		Side slope of left side of trapezoidal channel	1:x
ZLR		Side slope of concentrated flow paths (rills)	1:x
ZR		Side slope of right side of trapezoidal channel	1:x

APPENDIX IX: Guide values for Manning's 'n' (after Morgan et al. 1998)

Land use or cover		low	mean	high
Bare soil: roughness depth	< 25 mm	0.010	0.020	0.030
	25-50 mm	0.014	0.025	0.033
	50-100 mm	0.023	0.030	0.038
	> 100 mm	0.045	0.047	0.049
Bermuda grass: sparse to good cover				
very short grass	> 50 mm	0.015	0.023	0.040
short grass	50-100 mm	0.030	0.046	0.060
medium grass	150-200 mm	0.030	0.074	0.085
long grass	250-600 mm	0.040	0.100	0.150
very long grass	> 600 mm	0.060	0.150	0.200
Bermuda grass: dense cover		0.300	0.410	0.480
Other dense sod forming grasses		0.390	0.450	0.630
Dense bunch grasses			0.150	
Annual grasses (e.g. Sudan grass)			0.200	
Kudzu		0.070	0.150	0.230
Lespedeza (legumes)			0.100	
Natural rangeland		0.100	0.130	0.320
Clipped range		0.020	0.150	0.240
Wheat straw mulch	2.5 t/ha	0.050	0.055	0.080
	5.0 t/ha	0.075	0.100	0.150
	7.5 t/ha	0.100	0.150	0.200
	10.0 t/ha	0.130	0.180	0.250
Chopped maize stalks	2.5 t/ha	0.012	0.020	0.050
	5.0 t/ha	0.020	0.040	0.075
	10.0 t/ha	0.023	0.070	0.130
Cotton		0.070	0.080	0.090
Wheat		0.100	0.125	0.300
Sorghum		0.040	0.090	0.110
Mouldboard plough		0.020	0.060	0.100
Chisel plough; residue rate	< 0.6 t/ha	0.010	0.070	0.170
	0.6-2.5 t/ha	0.070	0.180	0.340
	2.5-7.5 t/ha	0.190	0.300	0.470
	> 7.5 t/ha	0.340	0.400	0.460
	< 0.6 t/ha	0.010	0.080	0.410
Disc/harrow residue rate	0.6-2.5 t/ha	0.100	0.160	0.250
	2.5-7.5 t/ha	0.140	0.250	0.530
	> 7.5 t/ha		0.300	
No tillage: residue rate	< 0.6 t/ha	0.030	0.040	0.070
	0.6-2.5 t/ha	0.010	0.070	0.130
	2.5-7.5 t/ha	0.160	0.300	0.470
Coulter		0.050	0.100	0.130

After Petryk and Bosmajian (1975), Temple (1982) and Engman (1986)

APPENDIX X: Guide values for soil hydraulic characteristics

Texture (*)	Porosity (POR) (v/v)			Residual saturation (THR) (v/v)	Maximum saturation (THR) (v/v)	Net capillary drive (G) (mm)		
	low high		mean	mean	mean	low high		mean
Sand	0.37	0.44	0.50	0.020	0.42	22	101	207
Loamy sand	0.37	0.44	0.51	0.035	0.41	41	147	323
Sandy loam	0.35	0.45	0.56	0.040	0.41	98	248	526
Loam	0.38	0.46	0.55	0.030	0.43	185	375	937
Silt loam	0.42	0.50	0.58	0.015	0.47	220	485	1043
Sandy clay loam	0.33	0.40	0.46	0.070	0.33	220	617	1070
Clay loam	0.41	0.46	0.52	0.070	0.39	250	533	1174
Silty clay loam	0.42	0.47	0.52	0.380	0.43	370	720	1470
Sandy clay	0.37	0.43	0.49	0.110	0.32	373	768	1730
Silty clay	0.43	0.48	0.53	0.060	0.42	430	812	1700
Clay	0.43	0.48	0.53	0.090	0.39	460	890	1830

APPENDIX XI: Guide values of roughness ratio for different tillage practices

Tillage implement	Roughness ratio (RFR; cm/m)
Mouldboard plough	30-33
Chisel plough	24-27
Cultivator	15-23
Tandem disc	25-28
Offset disc	32-35
Paraplow	32-35
Spike-tooth harrow	17-23
Spring-tooth harrow	25
Rotary hoe	21-22
Rototiller	23
Drill	20-21
Row planter	13-22

APPENDIX XII: Guide values for maximum interception storage for mature plants

Vegetation/Crop type	DINTR (mm)
Fescue grass	1.2
Molinia	0.2
Rye grass	2.5
Meadow grass, clover	2.3
Blue stem grass	2.3
Heather	1.5
Bracken	1.3
Tropical rain forest	2.5
Temperate deciduous woodland: winter	1
Temperate deciduous woodland: summer	2.5
Needleleaf forest: pines	1
Needleleaf forest: spruce, firs	1.5
Evergreen hardwood forest	0.8
Apple	0.5
Soya beans	0.7
Potatoes	0.9
Cabbage	0.5
Brussels sprouts	1
Sugar beet	0.6
Millet	0.3
Spring wheat	1.8
Winter wheat	3
Barley, rye, oats	1.2
Maize	0.8
Tobacco	1.8
Alfalfa	2.8

After Horton (1919), Zinke (1967), Rutter and Morton (1977) and Herwitz (1985)

APPENDIX XIII: Guide values for plant characteristics for mature plants

Plant type	Height (m)	Stem angle (°)	Shape factor
Rye grass	0.1-0.9	45-60	1
Timothy grass	0.5-1	70-75	1
Oat grass	0.5-1.5	20-90	1
Bermuda grass	0.3-0.6	50-60	1
Kikuyu grass	0.2	40-70	1
Guinea grass	2-3	20-60	1
Napier grass	2-6	70-90	2
Rhodes grass	0.5-2	50-80	1
Vetiver grass	1-3	60-80	2
Prairie grass	0.8-1	40-80	1
Buffel grass	0.1-1	50-80	1
Elymus	0.3-0.5	50-90	1
Bent grass	0.4-0.5	60-80	1
Wheat, barley, oats	0.5-1.5	80-90	1
Maize	2-3	50-80	2

After Cobley (1956), Bogdan (1977), Tindall (1983), Doorenbos and Kassam (1986), De Rougemont (1989) and Langer and Hill (1991). These references should also be consulted for crops not listed.

APPENDIX XIV: Basal area (PBASE) for different vegetation type

Land use or cover	Cover condition	Proportional basal area (PBASE)
Fallow: after row crops		0.1
Fallow: after sod		0.3
Row crops	poor	0.1
	good	0.2
Small grain	poor	0.2
	good	0.3
Hay - legume	poor	0.2
	good	0.4
Hay - sod	poor	0.4
	good	0.6
	excellent	0.8
Pasture or range (bunch grass)	poor	0.2
	fair	0.3
	good	0.4
Temporary pasture - sod	poor	0.4
	fair	0.5
	good	0.6
Permanent pasture or meadow	poor	0.8
	good	1.0
Woods and forest		1.0

After Holtan (1961)

APPENDIX XV: Guide values for soil detachability

Texture (*)	Detachability (EROD; g/J)		
	low	mean	high
clay	1.7	2.0	2.4
clay loam	1.4	1.7	1.9
silt	0.8	1.2	1.6
silt loam	0.8	1.5	2.3
loam	1.0	2.0	2.7
sandy loam	1.7	2.6	3.1
loamy sand	1.9	3.0	4.0
fine sand	2.0	3.5	6.0
sand	1.0	1.9	3.0

(*) Soil texture classes according to the USDA system.

APPENDIX XVI: Guide values for soil cohesion (kpa) at saturation

Texture (*)	uncompacted			compacted		
	low	mean	high	low	mean	high
clay	10	12	14	29	33	44
clay loam	9	10	14			
silty clay	9	15	11			
silty clay loam	10	9	26			
sandy clay loam	8	3	10			
silt loam	2	3	5	6	9	17
loam	2	3	4	7	7	8
fine sandy loam	2	3	3	5	6	8
sandy loam	2	2	4	4	7	10
loamy sand	2	2	3	6	8	9
sand	2	2	3	8	8	9

(*) Soil texture classes according to the USDA system

After Vickers (1993)

APPENDIX XVII: Input data for EUROSEM model

Site and element wise parameter input data for EUROSEM model

Site Id	Element Number	Length (m)	Slope %	Longest Length of Cascade	Element Order	Corresponding Element Number	Up Element Number	Length	Width
SID	J	L	S	CLEN(M)	COMP.ORDER (NLOG)	ELEMENT NUM (J)	NU	XL(m)	W(M)
J1	1	6	7	26	1	1	0	6	25
J1	2	15	8		2	2	1	15	25
J1	3	5	5		3	3	2	5	25
J2	1	8	6	32	1	1	0	8	25
J2	2	21	9		2	2	1	21	25
J2	3	3	4		3	3	2	3	25
K1	1	279	10	279	1	1	0	279	148
K2	1	370	7.5	370	2	2	0	370	150
L	1	30	20	30	1	1	0	30	25
L	2	5	20	5	1	1	0	5	25
L	3	10	18	10	1	1	0	10	25
L	4	32	15	32	1	1	0	32	25
N1	1	15.5	6.5	86	1	1	0	15.5	55
N1	2	14	7.5		2	2	1	14	55
N1	3	30	9		3	3	2	30	55
N1	4	9.5	12		4	4	3	9.5	55
N1	5	12	22		5	5	4	12	55
N1	6	5	10		6	6	5	5	55
N2	1	16	7.5	52	1	1	0	16	150
N2	2	36	11.5		2	2	1	36	150

Site and element wise parameter input data for EUROSEM model (continued).

Site Id	Element Number	Manning's n	Hydraulic Conductivity	Effective Capillary Drive	Bulk Density	Porosity	Initial Moisture	Max Moisture	Stone % v/v	Infiltration recession factor	Max interception
SID	J	RLMANN / IRMAN	FMIN(mm/h)	G(mm)	BD	POR	THI	THMX	ROC	RECS(mm)	DINT(mm)
J1	1	0.194	18	530	0.99	0.63	0.35	0.39	0	15	0.1
J1	2	0.194	13	530	0.99	0.63	0.35	0.39	0	15	0.1
J1	3	0.194	14	530	0.99	0.63	0.35	0.39	0	15	0.1
J2	1	0.204	49	530	0.84	0.68	0.35	0.39	0	15	0.2
J2	2	0.204	16	530	0.84	0.68	0.35	0.39	0	15	0.2
J2	3	0.204	49	530	0.84	0.68	0.35	0.39	0	15	0.2
K1	1	0.223	4.5	530	0.71	0.73	0.35	0.39	0	25	0.8
K2	1	0.382	3.3	530	1.05	0.60	0.35	0.39	0	5	1.2
L	1	0.226	240	248	1.02	0.62	0.35	0.41	0.01	25	0.8
L	2	0.226	240	248	1.02	0.62	0.35	0.41	0.01	25	0.8
L	3	0.226	240	248	1.02	0.62	0.35	0.41	0.01	25	0.8
L	4	0.226	240	248	1.02	0.62	0.35	0.41	0.01	25	0.8
N1	1	0.225	100	248	0.93	0.65	0.35	0.41	0.02	25	0.8
N1	2	0.225	100	248	0.93	0.65	0.35	0.41	0.02	25	0.8
N1	3	0.225	100	248	0.93	0.65	0.35	0.41	0.02	25	0.8
N1	4	0.225	130	248	0.93	0.65	0.35	0.41	0.02	25	0.8
N1	5	0.225	210	248	0.93	0.65	0.35	0.41	0.02	25	0.8
N1	6	0.225	210	248	0.93	0.65	0.35	0.41	0.02	25	0.8
N2	1	0.225	130	375	0.93	0.65	0.35	0.43	0.01	25	0.8
N2	2	0.225	130	375	0.93	0.65	0.35	0.43	0.01	25	0.8

Site and element wise parameter input data for EUROSEM model (continued).

Site Id	Element Number	No of rills	Average bottom Width	Average Depth	AverageSide slope	Down slope roughness	% of canopy cover	Leaf shape	Plant angle	% of basal area	Plant Height	Median diameter of soil	Detachability (g/J)
SID		DEPNO	RILLW(M)	RILLD(m)	ZLR	RFR	COVER	SHAPE	PLANG	PBASE	PLANTH (cm)	D50 (micron)	EROD
J1	1	0	0	0	0	15	0.05	1	80	0.1	10	389	2
J1	2	6	0.05	0.07	0.01	15	0.05	1	80	0.1	10	389	2
J1	3	7	0.05	0.07	0.01	15	0.05	1	80	0.1	10	389	2
J2	1	0	0	0	0	15	0.08	1	80	0.1	15	389	2
J2	2	5	0.05	0.06	0.01	15	0.08	1	80	0.1	15	389	2
J2	3	6	0.05	0.07	0.01	15	0.08	1	80	0.1	15	389	2
K1	1	0	0	0	0	1	0.6	2	50	0.1	150	290	2
K2	1	0	0	0	0	8	0.9	1	50	0.2	15	249	2
L	1	16	0.08	0.1	0.01	20	0.6	2	50	0.1	150	624	1.7
L	2	10	0.08	0.12	0.01	20	0.6	2	50	0.1	150	624	1.7
L	3	17	0.1	0.12	0.01	20	0.6	2	50	0.1	150	624	1.7
L	4	20	0.1	0.12	0.01	20	0.6	2	50	0.1	150	624	1.7
N1	1	0	0	0	0	10	0.7	2	50	0.1	150	541	2.4
N1	2	0	0	0	0	10	0.6	2	50	0.1	150	541	2.4
N1	3	18	0.04	0.05	0.01	10	0.6	2	50	0.1	150	541	2.4
N1	4	22	0.05	0.075	0.01	10	0.6	2	50	0.1	150	541	2.4
N1	5	30	0.05	0.12	0.01	10	0.5	2	50	0.1	150	541	2.4
N1	6	30	0.05	0.05	0.01	10	0.4	2	50	0.1	150	541	2.4
N2	1	0	0	0	0	10	0.7	2	50	0.1	150	549	2.4
N2	2	0	0	0	0	10	0.7	2	50	0.1	150	549	2.4

APPENDIX XVIII: Rainfall input data file prepared for EUROSEM simulation

```
EUROSEM   Rainfall Kinangop - October 15
     Gage Network Data
****************************
 NUM. OF RAINGAGES MAX. NUM. OF TIME-DEPTH DATA PAIRS FOR ALL GAGES
     (NGAGES)          (MAXND)
            1                  29
#
 There must be NELE  pairs of (GAGE  WEIGHT) data
*
 ELE. NUM. (J)    RAINGAGE    WEIGHT
      1                  1                  1.0
#
      Rainfall Data
*****************************
 There must be NGAGES sets of rainfall data. Repeat lines from * to * for each gage inserting
           a variable number of TIME-DEPTH data pairs (see example in User Manual).
#
#
  GAGE NUM.    NUM. OF DATA PAIRS (ND)
     1                         29
#
 There must be ND pairs of time-depth (T D) data: NOTE: The last time must be greater than
TFIN (the total computational time).
#
  TIME(min)  ACCUM. DEPTH(mm)
      0.0   0.0
      2.0   1.0
      8.9   2.0
      14.6 3.0
      16.1 4.0
      17.6 5.0
      18.6 6.0
      20.1 7.0
      21.3 8.0
      22.7 9.0
      23.8 10.0
      24.8 11.0
      26.8 12.0
      27.9 13.0
      29.3 14.0
      29.9 15.0
      30.5 16.0
      31.3 17.0
      32.3 18.0
      33.6 19.0
      35.5 20.0
      37.9 21.0
      50.0 22.0
      60.0 22.0
*
```

APPENDIX XIX: Catchment parameter input data file for EUROSEM simulation

```
EUROSEM V. 3.5/96 Parameter Input File:K1_1015_par.dat -Kinangop K1(maize)
#
*********************************
*********** S Y S T E M ***********
*********************************
* NELE  NPART  CLEN(M)  TFIN(min) DELT(min)  THETA   TEMP
  1       0     270.0     60.0       0.2        0.7        22.0
#
*********************************
********* O P T I O N S **************
*********************************
 NTIME  NEROS
  2        2
#
**********************************************
****  C O M P U T A T I O N   O R D E R  *********
**********************************************
 There must be NELE elements in the list. NLOG
 must be sequential. ELEMENT NUM. need not be.
#
 COMP. ORDER    ELEMENT
   (NLOG)     NUM. (J)
   ------     --------
     1          1
#
 **********************************************
 ******  E L E M E N T - W I S E   I N F O ***********
 **********************************************
   There must be NELE sets of the ELEMENT-WISE  prompts and data
   records; duplicate records from * to * for each element.  The
   elements may be entered in any order.
*
J   NU    NR   NL    NC1  NC2  NPRINT
1    0     0     0     0     0    1
----------------------------------------------------------------
   XL(M)   W(M)    S     ZR    ZL   BW(M)  MANN(Rilll) Mann(IR)
   273.0    148.0   0.11  0.0   0.0   0.0      0.223        0.223
----------------------------------------------------------------
   FMIN(mm/h)  G(mm)  POR  THI   THMX   ROC   RECS(mm) DINT(mm)
    4.5          530.0  0.73  0.35  0.39    0.0    25.0      0.8
----------------------------------------------------------------
   DEPNO   RILLW(m)  RILLD(m)  ZLR    RS    RFR   SIR
   0.10       0.0        0.0     0.0    0.0    1.0    0.11
----------------------------------------------------------------
   COVER  SHAPE PLANGLE  PLANTBASE  PLANTH(cm) DERO(m) ISTONE(+/-)
    0.90     2    50.          0.1       150.0     2.0       -1
----------------------------------------------------------------
   D50(u)   EROD   SPLTEX   COH    RHOS   PAVE   SIGMAS  MCODE
   290.0     1.6      2.0      9.0      2.65     0.0      1.00         1
*
```