ASSESSMENT OF EROSION IN THE TURASHA CATCHMENT IN THE LAKE NAIVASHA AREA – KENYA.

BY

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DEDICATION

for

Lord Jesus my Saviour, Mr. Issaria Ringo and my mother Eliluyana Makyawo, my beloved wife Mary and our sons and daughters.

ABSTRACT.

A study was undertaken to assess soil erosion by means of Remote Sensing (RS) and Geographical Information System (GIS) in the catchment of the Turasha river, which drains via the Malewa river in Lake Naivasha. The assessment was carried out based on the terrain map units (TMU), which combines the effect of rainfall, topography, soils, land cover and management practices. Interpretation of aerial photo's (1: 50,000) covering the study area, was carried out according to geo-pedological approach. The area covers 63.199 ha and was divided into four landscapes: Mountain, Piedmont, Plateau and Valley, which were further divided into 12 map units at landform level. Different characteristics of each unit were studied independently, results summarized in tables, interpreted and then discussed accordingly. A soil map was produced at the scale of 1: 50,000. By using the Universal Soil Loss Equation (USLE) model, the soil loss in tons/hectare/year was estimated for each map unit. By using ILWIS 2.2 software, an erosion hazard and a susceptibility map were produced.

The general pattern of the soils in the study area was found to be related to topography and parent material. On flat areas (interfluves), Planosols were found with imperfect to poor drainage conditions and a clay pan subsoil with a bleached and coarser topsoils. On sloping ground better-drained soils were found such as Andosols, Phaeozems and Luvisols. Gleysols were found in the wet bottomlands.

It was observed that the erosion hazard ranges from very low (0-5t/ha/y), to low (5-12t/ha/y) and medium (12 – 25 t/ha/y), which covers 70%, 23% and 7% of the area respectively. The relative low values of the erosion hazard are attributed to the current land use, which contribute to the better vegetation cover and result into a very low C-factor of USLE (mainly <0.1).

It was also found that topography covers gentle undulating slopes (0-5%) and undulating slopes (5-10%) which cover the area of 60% and 15% respectively. With the presence of vegetation and many drainage waterways, the slope length (overland flow production) was reduced. Relatively low slope percentage and / or shortened slope length resulted into the low topographic factors (LS with the average < 1) which contribute also to the low erosion hazard.

Soil erodibility was found to be relative low, ranging from low to moderate. Low erodibility was found to be attributed to the relatively high amount of clay and high organic matter in the topsoils. Rainfall drops have to overcome the adhesive or chemical bonding forces by which the mineral comprising clay and soil organic matter are linked.

Rainfall was found to increase from west (788mm/year) to east (1167mm / year) with an erosivity of 325N/h and 427N/h respectively. Rainfall in the East was found to be above 50mm throughout the year, which ensures the presence of vegetation at all times, which implies that even during heavy storms no erodible materials are available for transport due to vegetation cover.

Owing to the importance of controlling soil erosion in the study area due consideration was given to the on-site effects (mainly loss of fertile topsoil) and off-site effects (especially sedimentation to Lake Naivasha). Therefore low soil loss tolerance of 5 – 12t/ha/y was chosen instead of 25t/ha/y generally recommended for tropical environments. Based on the selected soil tolerance, map unit Va112 showed relatively high erosion severity (14.34t/ha/y) which calls for conservation measures to consider.

Validation of the model used (USLE) was based on the field observations of erosion features such as sheet and rill erosion, gullies, landslides and truncated profile exposure of subsoil and showed very low occurrence of these. Validation of the model based on the sediment yield was found to be very low in relation to Malewa River (only 142 tons/year). It has been proven that erosion assessment of the individual land units lead to better understanding of the soil erosion in Turasha catchment and as such this approach could prove successful also in other areas.

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Enschede, March 1999.
Ringo.

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CHAPTER 1

1. INTRODUCTION.

1.1 General introduction.

Land degradation is the process which leads to the loss of biodiversity and production capacity of the land. According to FAO/UNEP (1982), it is a process which leads to a deminition of the current and / or potential capacity of the soil to produce qualitative and / or quantitative goals or services as the results of one or more degradation processes. Land degradation is largely human-induced and thus includes a strong socio-cultural component. Land conservation and rehabilitation requires technical know-how based on the type of soil degradation in question. The assessment and monitoring of soil erosion for proper land use management may require different types of data to be collected and combined. For that matter the use of Remote Sensing (RS) and Geographical Information System (GIS) is indispensable.

1.2 Problem Identification.

Soil erosion caused by water is one type of soil degradation which is a major environmental concern in East African countries, where about 80% of the population lives in rural areas. The Naivasha lake basin, being one of the productive areas in Kenya, is affected by this land degradation caused mainly by over-intensive agriculture, overgrazing and deforestation especially in the upper part of the catchment, viz. the western slopes of the Aberdares (Hamududu, 1998). According to previous studies, population increase has lead to more marginal lands put into cultivation. Intensive cropping on hill slopes has resulted in an increase in soil erosion and reduced soil moisture storage, which in turn has led to lower agriculture productivity and added to sedimentation in Lake Naivasha which according to Hamududu (1998), is estimated about 142 tons per year.

Soil erosion results in losses of nutrients from agricultural land, pollution of water bodies, and causes physical crop and infrastructural damage. Brind (1959), predicted that the capacity of the lake Naivasha was being reduced at all levels due to the silting which can increase the water surface available for evaporation. Sediments are carried down in the river, especially the Malewa River (LNROA, 1993) which is the main contributor of the total inflow of surface water to Lake Naivasha. Harper et al. (1990) and Stuttard et al. (1996) in their recently studies observed that, the changes in the water level of lake Naivasha which might be contributed by sedimentation. Even longer ago Tetlay, (1948) observed that the lake Naivasha fluctuates widely, by as much as 11.3m, while the general trend was towards a decrease in levels, area and volume. All these observations call for special attention to be taken for proper management of the lake Naivasha basin, especially by assessing soil erosion severity and to indicate appropriate conservation measures to be undertaken.

Apart from the loss of soil and sedimentation in the water bodies, erosion also contributes to a lowering of the ground water table which results to the drying up of springs and wells (Msaky, 1996). Nill et al (1996) observed that, the seriousness of the erosion problem is more pronounced in the arid and semi arid areas (especially in grazing land) where, at times, high rainfall intensities, susceptibility of the soils to erosion and mismanagement of land, have accelerated and magnified soil losses by erosion and consequently reduced crop yield potentials. This probably applies also to the Lake Naivasha environment.

Because of the importance of Lake Naivasha basin in supporting intensive irrigation-based agriculture, geothermal power production, fishery and tourist industries, it is worth to invest in safeguarding its environment. However, effective soil erosion assessment and conservation measures require a modern scientific approach where data bases can be obtained to facilitate monitoring, evaluation and impact assessment of the land conservation efforts through GIS approach (Msaky 1996). Although an erosion assessment for the basin of lake Naivasha was done (Hamududu 1998), there is still a need to go into greater details through subcatchment approach for the effective studies, especially in the relationships between land use \ land use changes and different soil types in the landscape and their effect on erosion hazard. The Turasha river catchment, being the main tributary to River Malewa which in turn is the main contributor to the total inflow of surface water to lake Naivasha, was taken as the research area for this study.

1.3 RESEARCH HYPOTHESIS.

The erosion assessment of individual land / soil units leads to a better understanding of the erosion hazard in the Turasha catchment.

1.4. RESEARCH OBJECTIVES.

1.4.1 General objectives:

To assess soil erosion by means of Remote Sensing (RS) and Geographical Information System (GIS) and recommend proper land use management, in the catchment of Turasha River.

1.4.2 Specific objectives:

i) To study different types of soil and land use in relation to their effects on soil erosion.
ii) To identify major causes of soil erosion in the area.
iii) To produce an erosion hazard map under existing land uses.
iv) To indicate land use alternatives which may counteract soil erosion.

1.5 RESEARCH QUESTIONS.

i). How does each soil type differ in their proneness to erosion?
ii). How do land use changes and current land use types accelerate soil erosion?
iii). What type of land management is required to control that erosion?

CHAPTER 2.

2. BACKGROUND INFORMATION.

2.1 Location and population.

2.1.1 Location.

The study area is situated in Nyandarau District, Central Province. The area is in UTM zone 37 South, lying between coordinates 209150, 238025 North and 9919190, 9955600 East. The area is bounded by latitude 0°24′04"S and longitude 36°23`23"E. and is located 80km northwest of Nairobi (Figure 1). Its eastern boundary is Aberdare range while in the northeast it is bounded by Kipipiri Mountain. To the west the Karati scarpment and to the South the edge of South Kinangop Plateau forms the boundary.

The Turasha catchment is a sub-catchment of the Malewa River within its upper part and is part of the Naivasha drainage basin (see Figure 1). The River Turasha drainage catchment covers an area of 63.199 ha, with the small river tributaries such as Kititiri, Engare Mugutyu, Muruaki and Sasini. About 80% of the area is situated within the Kinangop Plateau and lies at levels between 2100 - 2700m above sea level. Kinangop Plateau comprises approximately 73% of the River Malewa catchment which is the main contributor of the total inflow surface water to Lake Naivasha.

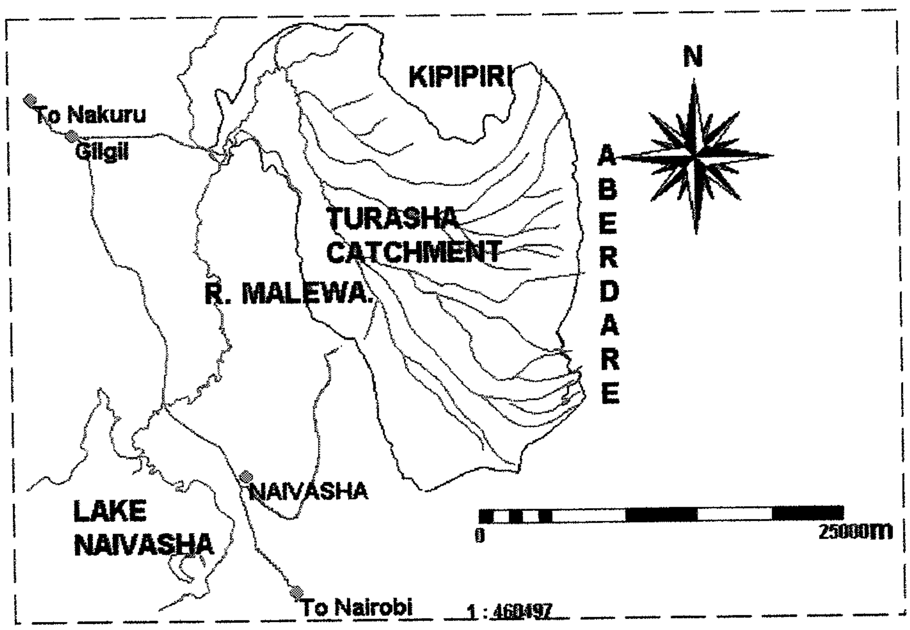

Figure 1: Location of the study area.

2.1.2 Population.

No precise figure can be given about the population. By the year 1978 the whole Kinangop plateau was estimated to have about 10,000 house-holdings and most of these families are from diverse agricultural backgrounds (Nyandat, 1984). The house-holdings (families) found in Turasha catchment fall under the Kinangop scheme settlement which took place in early sixties. In additional there are people employed from the "outside" as administrators, forestry and health workers.

2.1.3 Accessibility, schools and healthy centres.

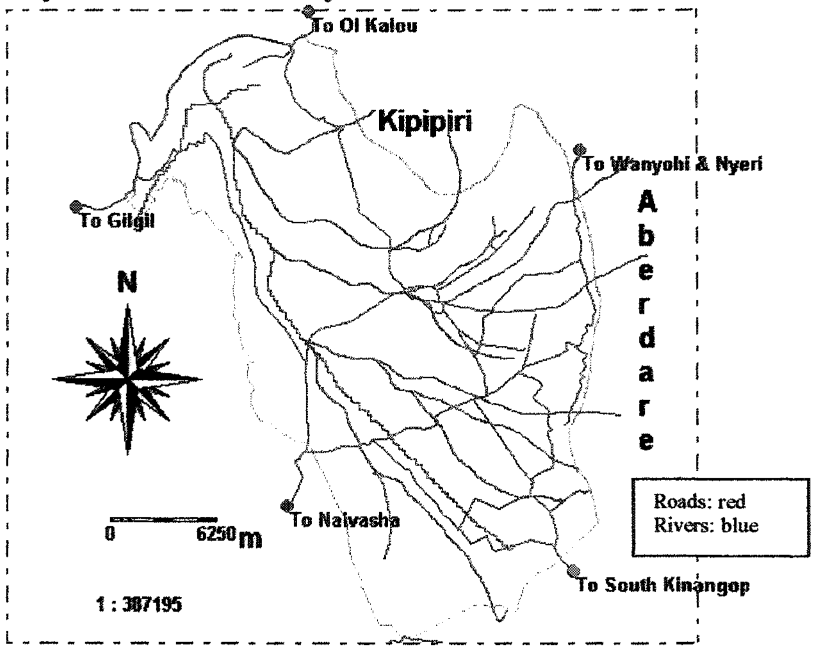

Figure 2: Main roads in the study area.

There are no tarmac roads in the study area. This implies that the accessibility of the area is fairly good in dry weather but generally poor to very poor during the rain season, when only four-wheel drive can pass often with a lot of difficulties. The roads in the catchment were demarcated in early sixties during the implementation of a settlement scheme / project and reflect the well planned road network (Figure 2). However lack of road maintenance is making the existing roads to be quite unreliable and in some portions impossible to pass during rainy season.
Main roads outlet are the Kipipiri road which connects the study area to Gilgil, Naivasha via the Karati road, and the Thika road which proceeds to Wanyohi or Nyeri and another road connecting the area to South Kinangop. Animal (mainly donkey) traction seems to be a dependable means of transporting agricultural products.
There are two health centres and two large market centres viz. at North Kinangop and Njabin townships. They are also small market centres and shops, which are fairly well distributed. Similarly, many mainly primary schools are available and are well distributed throughout the area.

2.1.4 Marketing.

The main agricultural production that prevails in the area is dairy production and wool. This is supplemented by the cultivation of potatoes, carrots, cabbages, pyrethrum, kale, wheat, green peas and leek. According to Nyandat (1984), the main outlet of those agricultural products was through the co-operative union especially for milk, wool and pyrethrum, but the marketing system is no longer effective. There were also agricultural processing companies - Pan African food limited which entered into contracts with farmers through their co-operative unions. The company used to assist farmers to acquire credit for fertilizers and seeds as well as to find the reliable market for the horticultural products. Also the service from that company has ceased, and the factory is lying idle in Naivasha. Currently the reliable outlets for vegetables are private traders who collect vegetables directly from the farmers for sale in urban centres, mainly in Nairobi, Naivasha and Nakuru. There is no fixed price system between the private traders and the farmers. They strike a balance at each delivery. The price may be extremely low during the peak production season but, could also be very high during the off season. There is a need to find a reliable marketing system especially through co-operative union owned by farmers themselves, other wise the middlemen seemed to cheat farmers in price bargaining (Otichilo, personal communication).

2.2 Geology.

2.2.1 Introduction.

Geology is the scientific study of earth's crust, rocks, strata, etc and of the history of its development (Mohr, 1954). For the whole understanding of the problems concerning soil genesis, some knowledge of petrography is indispensable because, whatever their locality, all soils are either directly or indirectly derived from rocks, and therefore from rock forming minerals (Mohr, loc. cit.). Consideration should be given to the rock as whole, because its structure, texture and hardness together determine its physical resistance to katamorphism. According to Thompson (1958), the rocks in Naivasha basin can be divided into two main groups; (1) lava and pyroclastics and (2) lacustrine deposits whereas for convenience of description the area can be divided into three parts namely; (a) the Kinangop plateau, (b) the Mau escarpment, and (c) the Rift Valley. Turasha Catchment is part of the Kinangop plateau and contains mainly pyroclastic rocks.

2.2.2 Lithology of the study area.

The geological information of the survey area was extracted from various geological reports: (Shackleton, 1945), (Thomson et al, 1958), (Thomson, 1964) and (Mc Call, 1967). The geology of the area is relatively "young", the oldest rocks date back to the Miocene period.

The northwest of the study area is mainly covered by recent superficial deposits. These are underlain by Pliocene tuff. The tuff includes vitric pumice tuffs, ignimbrites and welded tuffs with lacustrine sediments, graded tuffs and diatomites. The northeastern part consists mainly of basalts such as vesicular olivine basalt of Pliocene-Miocene age and olivine basalts of Miocene age. Basalt and agglomerate of the Simbara series (predominantly in Kipipiri Forest area) and the Laikipian type of basalt in the lower eastern fringes of Kipiripiri Mountain belong to periods ranging from Miocene to Pleistocene.

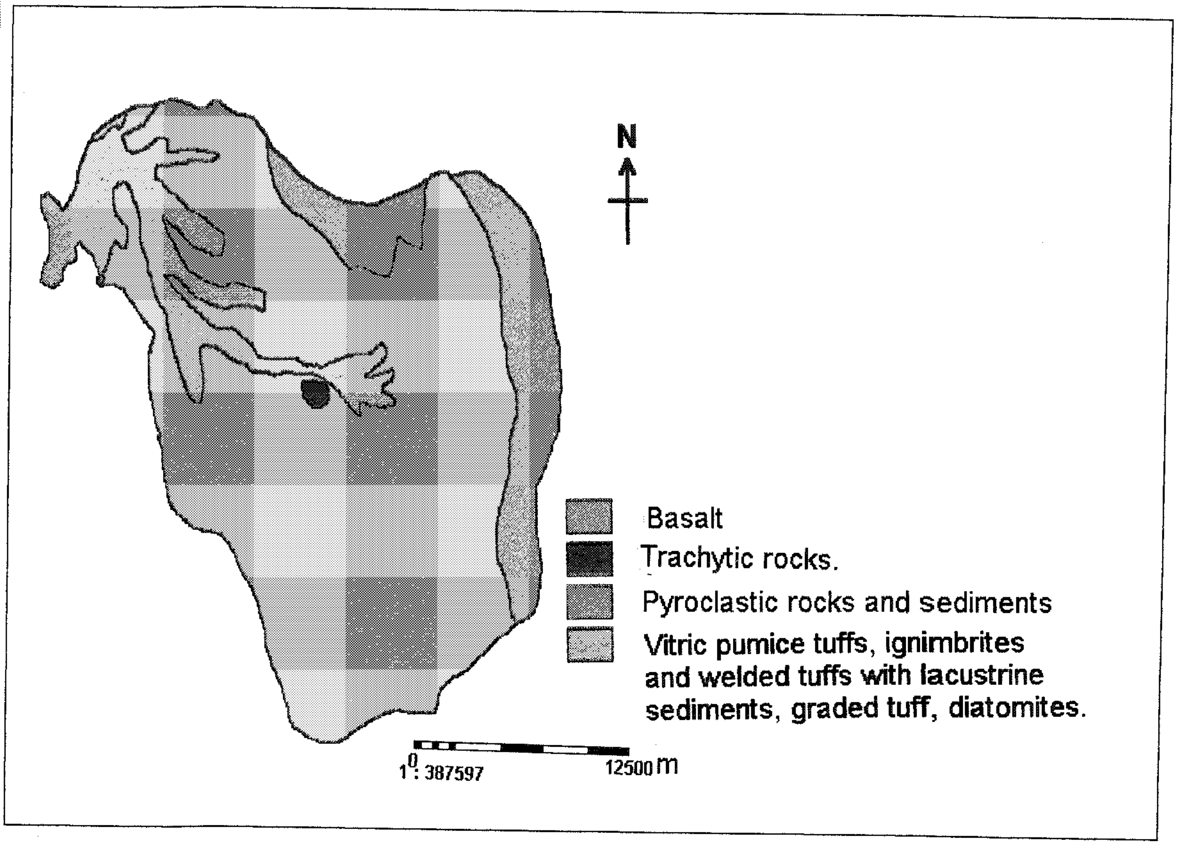

Figure 3: Geological map of Turasha Catchment.

Alluvium covers some parts along the rivers. Many of the gullies have smooth floors as a result of the deposition of alluvial sediments. These sediments are dominated by sand and gravel. Alluvial deposits associated with the Turasha river are dominated by greyish brown silt, within which there are intervals of reddish brown ferrugious coarse sand and granule gravel, and pale grey clay.
The remaining central and southern part is covered by pyroclastic rocks and sediments / volcanic ashes of upper to Middle Pleistocene periods. Others include Tcrachytic rocks of the younger Aberdare vents of the Upper to Middle Pleistocene periods.
The majority of the rocks are rather acidic as induced by the composition of the magma (high SiO_2 content), which resulted in explosive volcanism alternating with lava flows. The stratigraphy is summarized in Table 3. In Table 1 the major mineral composition of some major rocks is presented.

Table 1: Chemical analysis of basalt, trachytes and pumice rocks.

BASALTIC ROCK		TRACHYTES		PUMICE	
Mineral	%	Mineral	%	Mineral	%
SiO_2	40.70	SiO_2	60.74	SiO_2	70.35
Al_2O_3	3.90	Al_2O_3	15.58	Al_2O_3	16.53.
Fe_2O_3	4.97	Fe_2O_3	3.66	Fe_2O_3	-
FeO	14.63	FeO	3.55	MgO	Tr
MgO	30.78	MgO	0.38	CaO	0.54
CaO	3.14	CaO	0.97	Na_2O	-
Na_2O	0.36	Na_2O	6.59	K2O	-
H_2O+	0.51	K2O	4.68	H_2O	-
H_2O-	0.10	$H_2O+(+1100)$	1.20		
TiO_2	1.14	$H_2O-(-1100)$	1.21		
P_2O_5	Trace	TiO_2	1.05		
MnO	0.17	P_2O_5	0.07		
Cr_2O_3	0.10	MnO	0.26		
NiO	0.10				

Source: Thompson et al. (1958).

2.2.3 Volcanism - (Pyroclastics).

The result of many features and soils in Lake Naivasha Catchments are due to volcanic activities. Explosive volcanism, especially from rhyolitic and andestic eruptions, produces large volumes of shattered, fragmented rocks which are collectively known as pyroclastics (Selby, 1996). The fragments are classified according to size: material with diameter smaller than 4 mm is termed ash, and in its compacted form volcanic tuff; fragments of 4 – 32 mm are termed lapilli and large than 32 mm are blocks. A collective term for an air fall deposit containing a mixture of fragments of these size is "tephra". Blocks which originated as lava and have been thrown into the air while still molten become rounded or decorated with spiral patterns as they travel; such rounded and patterned forms are called volcanic bombs. Consolidated blocks are known as volcanic breccia. Tephra deposits fall around and downwind from an eruption centre. The deposit from a single eruption is usually well bedded with the largest pyroclastics at the base of the bed and a progressively finer grain size towards the top. Upon succeeding volcanic explosion the layers of sediments built up of the Kinangop are shown in Table 2 and Plate 1.

Table 2: Succession of the Kamasian sediments in Turasha Valley in Kinagop.

Period.	Sediments.	Approximate thickness (feet)
Kanjeran	16. Grey soil	-
	15. Grey agglomerate	30
Kamasian (Middle-Pleistocene)	14. Welded tuff	5
	13. Yellow to buff – coloured tuff	50
	12. Grey pumiceous agglomerate	30
	11. Narrow band of brownish pumiceous agglomerates	2
	10. Grey tuff	9
	9. Grey agglomeratic tuff	8
	8. Grey agglomeratic with included black scoriaceous fragments	18
	7. Fine grey ash	4
	6. Buff-coloured massive agglomerate	20
	5. Light grey ashes	6
	4. Buff-coloured agglomerate with black scorianceous inclusions	35
	3. Maroon to greyish tuff	20
	2. Grey slightly pyroclastic trachyte	15
	1. Coarse grey agglomerate	-

Source: Thompson et al. (1958).

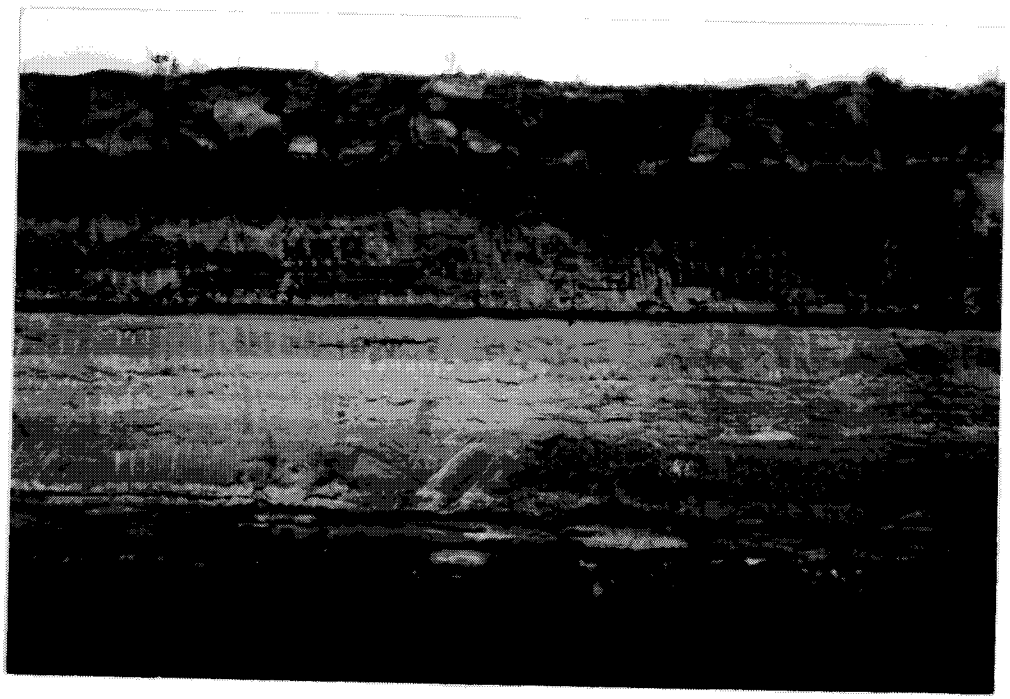

Plate 1: Layers of sediments build up upon during successive volcanic explosions.

Volcanic rocks can be classified according to their nature of composition i.e acid or basic. The volcanic rock which contain less SiO_2 are basic, more unstable and easily weathered while those with high SiO_2 are acid, more stable and less weathered. With the possible exception of the Mount Longonot volcanic formation, the most recent pyroclastics are of more acid composition (Thompson et al. 1958).
Welded tuffs form an important marker horizon and exhibit a considerable amount of welding, but do not show the signs of flow that are commonly associated with the more extreme form of welded tuff called ignimbrite. They are more resistant to erosion than any other volcanics except the lavas. The soil parent material is discussed in para 2.6

Table 3: Summarized stratigraphy.

Name of formation(Fmn)	Age	Major Outcrop	Lithology
Kinangop Tuff	3.4-4.5 Ma Bp Pliocene- Early Pleistocene	Eastern rift marging	Ignimbrite succession; mostly welded trachytic tuffs, palaeosols and weathered zones at top of most beds.
Laikipian Basalts	Early Pleistocene- Upper / Middle Pleistocene	The Aberdare National Park	Non-porphyritic basalts
Alluvial deposits	<0.45 Ma BP Mid/Late Pleistocene- Holocene	Gullies and small internal draining basins.	Silt, fine sand, some ferrugious coarse sand and boulder gravel.

Source: Graham, (1998).

2.3.4: Tectonism.

According to Selby (1996), the largest structural controlled landforms are Rift Valleys formed as down-faulted graben bounded on either flank by fault scarps along the edges of uplands. The 3000 km long East African rift-valley system extends from Malawi in the South and diverges into two arms encompassing the one km high plateau containing Lake Victoria, then extends through Ethiopia to the Red Sea. Along much of its length the African rift system is marked by clearly defined escarpments 400-2000 m high, which are the resulted of normal faulting in simple scarp or steep-like sets. The western Rift Valley was formed about 50 million years ago.
The African Rift valleys are uniformly 30-90 km wide but the floors of the valleys vary in depth because of traverse twisting and obstruction by late Caenozoic volcanism. The deepest parts of the valley are often occupied by lakes. Many of the lakes in the eastern rift have no outlet and are therefore highly saline. Lake Naivasha being an exception as it is a fresh water lake.
Initial uplift of Kenyan domes occurred during the late Cretaceous and early Tertiary and was occupied by crustal thinning and volcanic action, but the formation of graben

allowed up to 1000 m of sediment to accumulate in parts of the rift. Major uplifts of the Kenyan dome formed large escarpments during the Pleistocene.

2.3: Geomorphology.

The geomorphological history of the study area is characterized by Rift Valley development and the occurrence of volcanism together with the modification by climate.

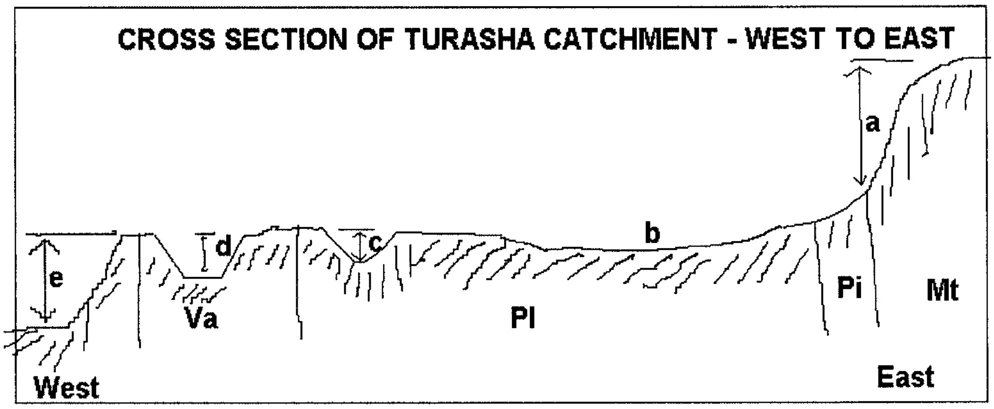

Figure 4: Landscapes, relief, topography and elevation.

The relief of most of the area is flat to flatly undulating (slightly dissected **(b)**, alternating by dissected plateaus **(c)** and incised valleys **(d)**, which are 50 to 100m deep. To the west **(e)** the area is marked by a drop in elevation from 2300 to 2020m, while in the east **(a)** the Kipipiri rise rises about 850m above the surrounding area. The landscape of the study area can be divided into four groups according to geopedological approach (Zink, 1988), namely: Mountains **(Mt),** Piedmont **(Pi),** Plateau **(Pl)** and Valley **(Va),** as shown in Figure 4 above.

2.3.1 Mountain.

This is an elevated, rugged, deeply dissected land portion characterized by important relative height differences in relation to lower-lying surrounding landscape units. At the Northeast there is Kipipiri Mountain while in the East there are the Aberdare ranges. Generally these areas are characterized by steep slopes (>30%). Generally the country rock of this landscape is basalt (Rachilo, 1978). The mountain and hill slopes occur over great lengths (more than 500m), however the length of slope available for overland flow may be shorter due to forest cover and occasionally rock outcrop.

2.3.2 Piedmont.

This is a sloping land portion lying at the foot of more elevated landscape, such as a mountain or hill. The lithology in this unit are pyroclastic rocks and sediments (Rachilo, 1978) while the soils in this area are developed on colluvium mainly derived from basalt. In the study area, this unit consists of the footslope of the Aberdare ranges and Kipipiri Mountain which have a slope range of 5 – 16% (undulating to hilly). Slopes length is considerable and the shape straight to slightly concave, again vegetation may restrict overlandflow.

2.3.3 Plateau.

Geomorphologically the major part of the survey area consists of a plateau. By definition, this landscape is a large, flat, unconfined, relatively elevated land portion which is commonly limited on at least one side by an abrupt escarpment to the lower land (Zink, 1988). The surface topography remains table-shaped or gently undulating. To the northwest of the study area, the plateau is very much dissected whereas in the central part continuing to the south, it is slightly dissected. Hence, the dissected and slightly dissected plateaus give rise to very contrasting soils and topography (slope length, shape and percentage). In the slightly dissected areas the main rock are pyroclastic sediments (tuffs), with a flat to gentle undulating relief (0 – 5%). This area contains bottomlands and many streams. The land toposequence can be subdivided in the interfluve, convex shoulder, a fairly straight backslope, associated with a slightly concave footslope, and flat bottom lands close to the stream (see Figure 6 and plate 2).

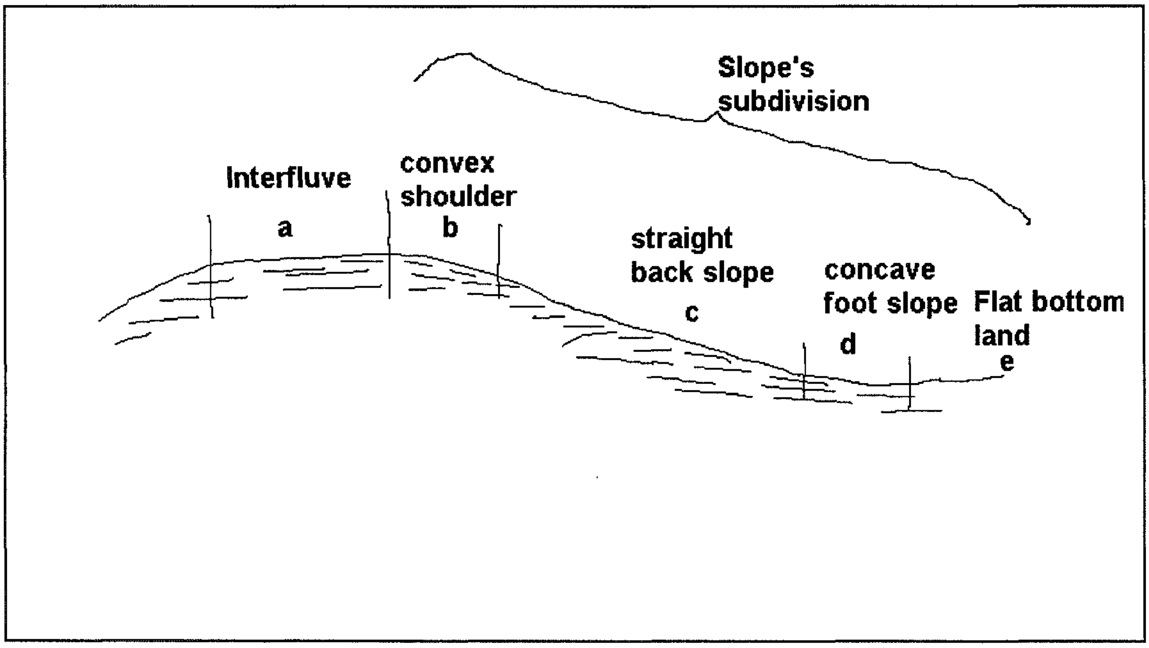

Figure 5: Toposequence in slightly dissected plateau (smooth incisions).

Plate 2: Central part of Turasha catchment, view South along the Kipipiri road. Note slightly undulating topography, poor dirt roads and mixed land use.

For the dissected plateau, the slope ranges from flat to undulating (0-8%), where scarp like features occur, slopes are steeper (>8%); see Figure 7 and plate 3. The geology of the area is pyroclastic rocks (tuffs).

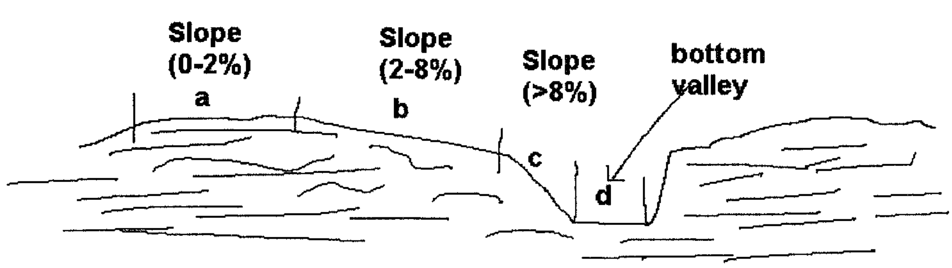

Figure 6: Toposequence in severely dissected plateau (sharp incisions).

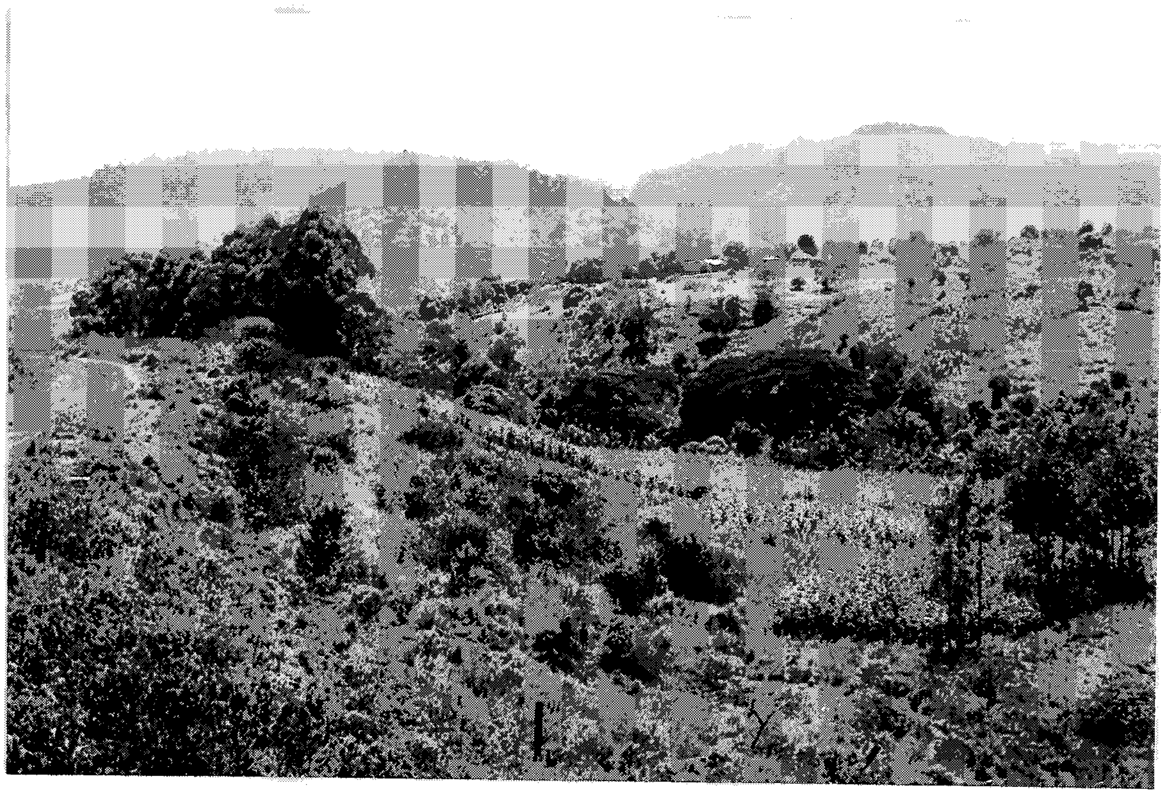

Plate 3: Lower Turasha catchment, severely incised plateau with intensive rainfed agriculture (in well dermacated plots).

Figure 5 and 6 shows the landform / mapping unit characteristics which occupies more than 80% of he study area.

2.3.3 Valley.

These are deeply incised in the plateau landscape with steep sides (10%). Geology of the slope are pyroclastic rocks. At the bottom valley alluvial sediments occur. The nature of the slope is such that the relief of the whole unit is undulating to hilly (5 – 30%). The nature of its landform is somehow with that in dissected plateau (Figure 6) but is more incised, steeper and shorter slopes.

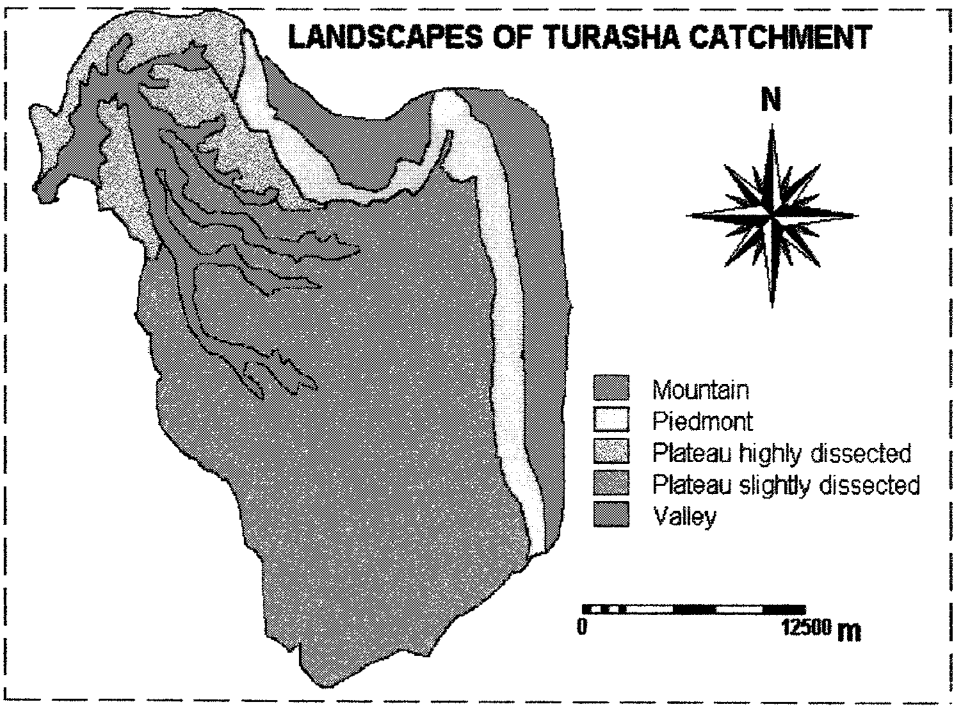

Figure 7: Landscape map of the study area.

2.4 Hydrology.

2.4.1 Introduction.

The science of hydrology focuses on the global hydrology cycle. It is the geoscience that describe and predicts: (1). The spatial and temporal variations of water substance in the terrestrial, ocean and atmospheric water system. (2). The movement of water on and under the earth's land surfaces, the physical and chemical process accompanying that movement, and the biological process that conducts or affects that movement (Dingman, 1994).

2.4.2 Surface and subsurface hydrology.

The survey area is very much dissected by drainage ways, the majority of which have their sources in Aberdares and Kipipiri Mountains. To the northeast part of the area the tributaries Sasini and Kititiri occur, while in the east the Rumaru, Mandarasi and other small river flow, which later join together at the central part to form Kititiri and Engare Mugutyu. In the south there are a number of small tributaries which join together to form the Muruaki River. They all flow into the Turasha River which on its turn joins the Malewa, which eventually discharges into Lake Naivasha (see Figure 8). In the central and to the south of the area are the drainage ways generally have flat valleys. There are quite a number of dams built to retain water along some of the rivers, for example, along river Engare Mugutyu. The Turasha is a perennial river, but some of its distributaries may dry up in the summer.

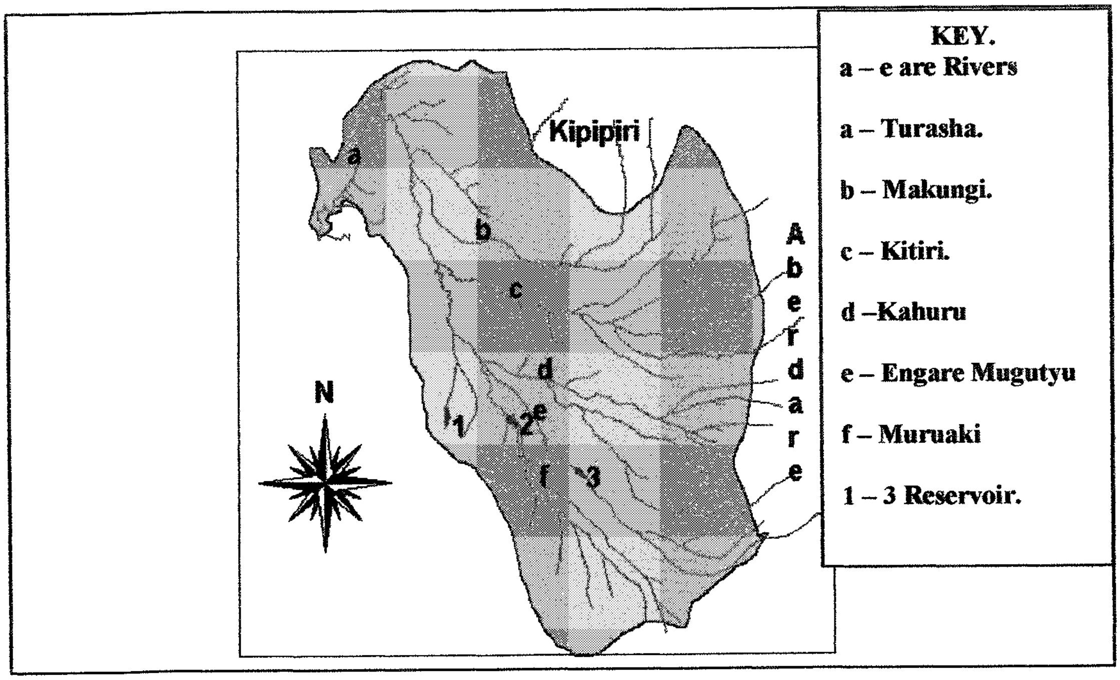

Figure 8: Drainage networks.

The outflow (discharge) of the Turasha river measured at point "a" (Figure 8) shows a considerable variation according to the rainfall pattern.

Table 4: Long term monthly average discharge of the Turasha River.

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
2gc4	1.5	1.46	1.92	5.18	7.64	3.26	2.98	3.26	3.53	3.31	4.09	2.61

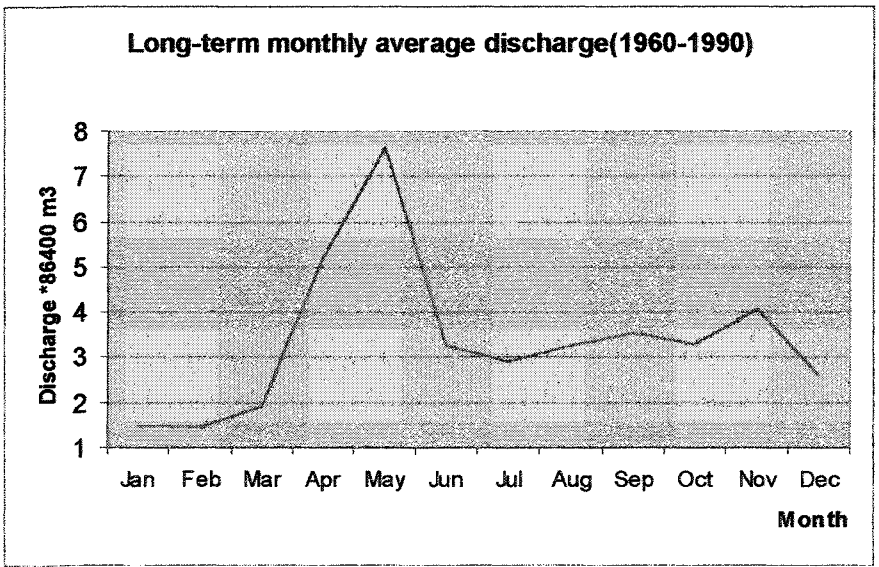

Figure 9. Long-term monthly average of River Turasha discharge.

From Figure 9 and Table 4 above, the maximum discharge of Turasha River is in May and November which reaches the average discharge of 7.64*86400M^3 and 4.09*86400 M^3 respectively. Minimum discharge occurs in February and January, which drops to 1.46 M^3 and 1.5M^3 respectively.

When the discharge are compared with rainfall amount from different stations (Table 5 and Figure 10) it shows almost the same trend. Rainfall amount is almost equal at the same peak in April and May while the peak of discharge is in May. This gives an impression that some rainfall amount available in late April takes time to flow up to the point of measurement in May. Also it may show that some rains falling in April are soaked in the soil to the extent of failing to produce enough runoff to reach in the waterways. In May the soils are saturated with water so that more runoff is available to reach the waterways and ultimately to the point of measuring the discharge.

Table 5: Monthly rainfall amount from eight stations.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
316	341	586	1161	1221	803	580	691	687	647	657	447

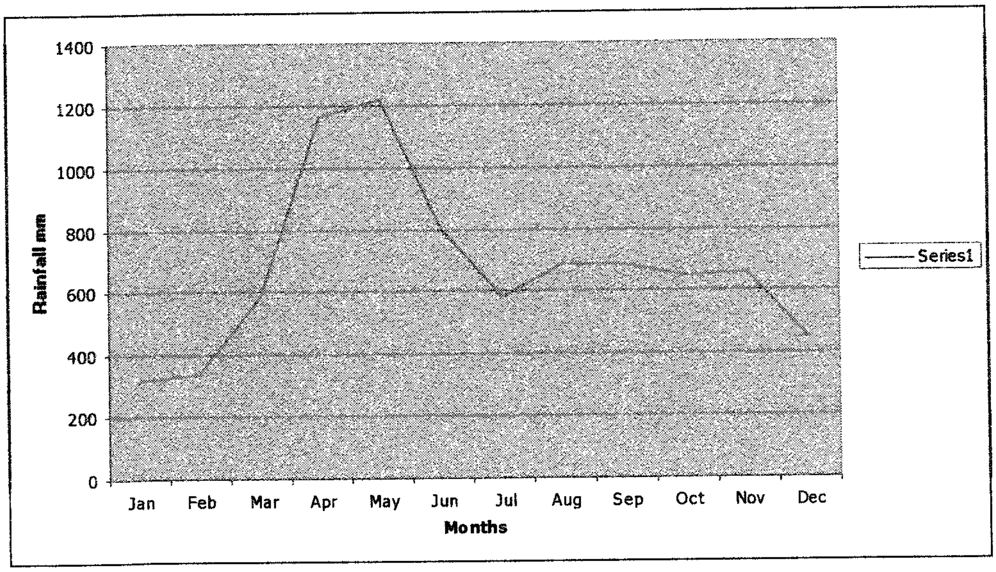

Figure 10: Total rainfall amount from different stations.

2.4.3 Drainage pattern.

The major drainage pattern can be classified as sub-parallel (Farshard and Bergsma, 1989) controlled by an overall west and to north facing slope.

2.5 Natural vegetation and Landuse

2.5.1 Introduction.

The history of the landuse in the study area dates back before the colonial era (prior to 1890) when the area was used by pastoral Masai as a grazing land (Haper et al., 1990). Under foreign rule the Kinangop plateau served as a buffer zone between the Kikuyu people to the east and the Masai to the west. Despite adverse soil and climate conditions the cultivation of various cereals and vegetables was undertaken. The land use has changed over time depending on the land tenure (legal right to own the land). During the colonial regime in Kenya, the area was put under white appropriation and was part of the "Kenya White Highlands". After independence in 1963 the land was returned to the people, which led to it being broken up into in to small holders settlements.

2.5.2 Arable agriculture.

The prevailing topography in most of the study area is very gently slope to undulating. According to Nyandat (1984) this type of topography coupled with the prevailing climate in the study area made it possible to mechanize small grain cereals such as wheat, barley and oats before the area was broken up to small-holder farmers. As rainfall is distributed throughout the year and the temperature appropriate, not only two crops of wheat were possible in a year but also the wheat could be grown together with other crops such as barley, oats and pyrethrum. According to Odingo (1971), the land occupied by major crops in the Kinangop in 1960 before the small-farm resettlement was as follows (Table 6).

Table 6: Land occupied by major crops in Kinangop.

CROP	AREA (ha)	% OF CULTIVATED LAND	REMARKS.
Wheat	840	10 – 19	Mostly in North Kinangop
Barley	560	5 – 9	-
Oats	400	More than five	-
Pyrethrum	Extensive	20 – 25	On higher lying parts
Linseed	400	No data	-
Grass leys	480	20	-

Source: Odingo, (1971).

Pyrethrum was apparently an important cash crop for mixed farming enterprises (with dairy farming) and rotated with small cereals (Nyandat, 1984). High capital, technology and machinery enabled the white settlers to maximize economic returns in agricultural production. Cumbered seedbeds were prepared to improve the drainage.

In recent times, the production of wheat was encouraged through a loan provision from the Kenya Agricultural Finance Corporation, whereas the growing of barley was supported by Kenya Breweries. Because of the generally poor land preparation and the adverse effect of drainage, yields were low to the extent of becoming unprofitable. Moreover, the Department of Settlement (1976), claimed that wheat and barley took the land which could be used for grazing and pyrethrum production, hence caused low

production to those products which they favoured more. Barley is no more produced in the area and wheat is just produced at subsistence level.
Currently the main cropping system continuing in the area is mixed cropping (crops and livestock keeping) and intercropping of many annual crops such as potatoes, peas, beans, cabbage, carrot, onion and kale in the eastern part, central and South of the study area. In the northwestern part where the plateau is more dissected, the same type of the crops may be found, but with additional of maize growing. According to Nyandat (1984), the diversity of the crops in the area is evident as well as the variation of the areas under various crops from year to year, through which the farmers try to secure successful harvest and profit (minimize risks of crop failure). Crop rotations or proper intercropping has disappeared and many farmers do not use fertilizers, although they may know the importance of it. Lack of improved soil drainage systems i.e cumbered seedbeds is one of the most limiting factor in agricultural activities.
Flowers are produced as pure stand crop on some footslope areas to take advantage of the fertile and well-drained soils in that place.
On the hillslopes cultivation is according to the contour line, while the fields are generally demarcated by vegetation.

2.5.3 Livestock Production.

Before the break up of land in the Kinangop area for settlement in 1961, cattle and wool-sheep production figured prominently. Livestock farming contributed greatly to the successful mixed farms with dairy cattle playing an important role. Odongo (1971) reported that the grass ley farming was fairly successful in the Kinangop area and the area of planted grass leys per 100 dairy cattle was about 8.1 to 15.8 ha, i.e. 6.3 to 12.3 livestock units (LU) per hectare.

According to Nyandat (1984), mixed farming including cattle and sheep continued to be given prominence in the study area even after the land resettlement. This mixed farming was considered to be essential in order to provide the farmers with diversified enterprises to safeguard him economically. The settlement plan was therefore designed to include two or more dairy cows to give the settlement farmer the opportunity to earn a regular income. However planted grass leys which enabled a high stocking rate of 6.3 and 12.3 LUs per hectare in 1960_s no longer exist. They have given way to natural pasture whose composition and quality are questionable. The dominant grasses of the grazing lands are: *Eragrostic atrvirens, Digitaria scalarum, Alchemilla gracilipes, Setaria aurea, Ficine filiformis* and *Thesius sp*.B. Other grasses which are commmon are: *Eragrostic schweinfurthii, Helichrysum cymosum, Trifolium semipilosum var semipiluan, Crepis carbonaria, Medicago sp., Monopsis stellarroides varschimperiana, Lobelia ancepts and Pennisetum clandestinum.*
This type of vegetation and land cover are very effective in soil erosion control, to the extent that is difficult to find any sign of erosion in that type of land use.

Plate 4: Northeast part of the area showing sharp transition between plateau and piedmont landscape. In the background Kipipiri hill. Note grazing on major part of the plateau.

2.5.4 Tree production.

Except on the mountain and some part of the valley landscape, the rest of the study area is almost devoid of natural trees, which have been cleared to provide land for cultivation and grazing. On the plateau the main purpose of planting the trees appear to be as windbreak, for building timber and firewood. Some of the exotic trees that are planted in the area are: *Cupressus lusitanica, Eucalyptus saligna, Eucalyptus globulus, Eucalyptus paniclata* and *Pinus.* Eucalyptus species are known for their adaptability to poor drainage. Some parts of the mountain areas are exploited for wood (legally or illegally). However the major part is a forest reserve for conservation or research purposes.

2.5.5 Natural vegetation.

According to Scott et al, (1971) most of the central part of the Kinangop plateau proper is under *Pennisetum schimperi* grassland. Along the western fringes of the Aberdares and Kipipiri mountain mixed bamboo forest in addition to undifferentiated broad leaved vegetation occurs mainly on ridges. Whereas the valley sides in this area (near to where river Turasha is joining River Malewa) are covered mostly with undifferented *Acacia* species, the valley bottoms are mainly *Pennisetum schimperi* grassland with scattered trees and shrubs.

2.6 SOILS.

2.6.1 Introduction.

Soils in the study area can be termed as volcanic soils where they tend to differ according to genesis and position in the landscape. According to exploratory soil map and agro-climatic zone map of Kenya by Sombroek et al., (1982) and a report of a soil conditions in the Kinangop area (Rachilo 1978), soils in the study area can be described according to their position in the landscape and lithology from which they have developed. They are classified according to FAO/Unesco (1972)

2.6.2 Soils of the mountain.

The soils found on the mountain (Mt) and major scarps are developed from on olivine basalts and ashes of major older volcanoes. They are generally well drained, very deep (1.20 – 1.80m), dark reddish-brown to dark brown, very friable and smeary, clay loam to loam, with a thick acid humic topsoil; in places shallow to moderately deep and rocky. The are classified as humic Andosols, partly lithic phase.

2.6.3 Soils of the piedmont.

On the Piedmont (Pi) the soils are developed on colluvium from various volcanic rocks (mainly basalts). They are mainly found on the footslopes (gently sloping to sloping: slopes 2-8%) such as at the foot of the Aberdares and at the base of the Kipipiri Mounatain. These soils can be described as well-drained, deep to very deep, reddish brown, friable clay, with an acidic humic topsoil (ando-humic Acrisols). Soils developed on undifferentiated volcanics are also found in this landscape around the vicinity of the Kipipiri Mountains. They are classified as ando-luvic Phaeozems which are described as well drained soils, very deep, dark reddish brown to very dark greyish brown, friable and slightly smeary clay, with a humic topsoil.

2.6.4 Soils of the plateau.

Soils found on the plateau (Pl) are developed on ashes and pyroclastic rocks of recent volcanoes. Soils classified as ando-luvic Phaenozems are found in parts of the dissected plateau and are described as well drained soils, moderately deep (50-80cm) to very deep (120-180cm), dark brown, friable and slightly smeary. Texture varies from clay loam to clay. The major soils found in the study area are Planosols. Solodic occur extensively in the slightly dissected plateau.
Generally these soils on the plateau are imperfectly to poorly drained (due to the clay hard pan), deep with an AEBC profile development (mostly with bleached E horizon due to eluviation) and a subsoil horizon of clay accumulation.

2.6.5 Soils of valley.

The valley (Va) landscape contains soils developed on undifferentiated Teriary volcanic rocks (olivine basalts, rhyolites, andesites). Major soils found on the slopes are Lithosols; with calcic Xerosols, lithic, bouldery and saline phase and rock outcrops. The soils are well drained, shallow, dark reddish, friable, very calcareous, bouldery or stony, loam to clay loam; in many places saline. At the valley bottom deep soils occur in flat portions.

2.7 CLIMATE.

2.7.1 Introduction

Climate is one of the most important factors for soil formation. The prevailing climatical condition of an area no doubt determines for the large part its agricultural capability (Rachilo, 1978). Köppen and Geiger (1948) classified climate based on temperature and precipitation while Thornthwaite and Mather (1955) based it on the difference between precipitation, and the mean potential evapotranspiration. Sombroek et al. (1980) summarized major aspects of the climate which affect plant growth as the balance between rainfall, temperature and evaporation. Climate deals with atmospheric conditions as well as the soil temperature and moisture.
The climate is described according to data obtained from eight stations (see Figure 11) It appears that the western part of the area is somewhat drier than the eastern half. The station records are summarized in Table 7.

2.7.2 Atmospheric climate.

2.7.2.1 Rainfall.

The Kinangop Plateau forms a large part of the survey area and is situated in the rain-shadow of the Aberdares. The variations of rainfall are increasing from East to West. Rainfall occurs throughout the year but has a bimodal type of rainfall with a primary maximum from March – June in the East and April - March in the West. Secondary rainfall in the east occur in August – November while in West occurs in August, September and December.

Table 7: Long Term Average Rainfall (mm) and annul potential evaporation.

Station Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Years	Total	Eo	
(A). Geta Forest station	54	45	82	156	159	97	98	115	124	107	92	69	14	**1198**	**1496**	E
(B). Kinangop nursery	33	37	84	184	174	128	93	121	99	81	92	43	11	**1168**	**1495**	A
(C). Mukungi estate	36	43	74	184	159	106	87	112	97	106	84	54	18	**1142**	**1550**	S
(D). N. Kinangop Forest. St	43	51	90	171	162	108	73	92	103	95	94	58	53	**1140**	**1481**	T
(E). Njabini Rural T.	65	57	114	218	176	74	62	68	63	102	118	73	21	**1189**	**1495**	W
(F).Nanga Geri	43	52	58	87	158	113	37	29	42	41	60	78	72	**825**	**1550**	E
(G).Csaenthorns	12	30	34	50	126	100	66	68	96	62	69	56	50	**808**	**1692**	S
(H). Malewa Schem	30	26	50	111	107	77	64	86	63	53	48	16	14	**732**	-	T

Source: Summary of rainfall in Kenya (EAMD, 1974).

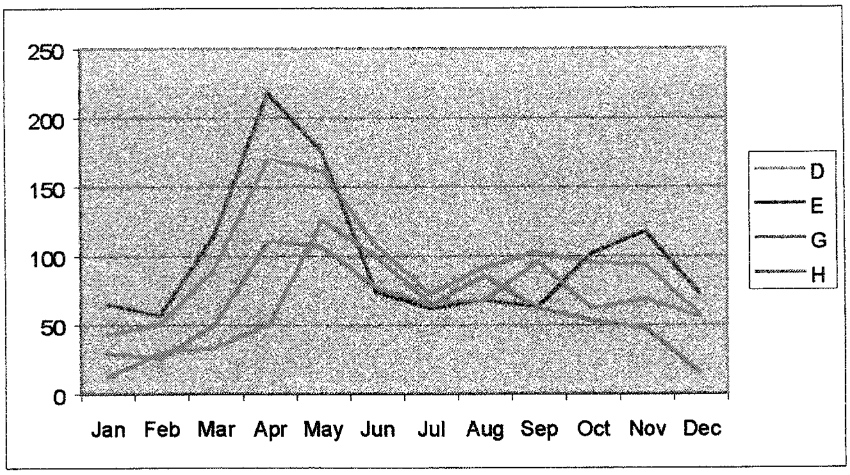

Figure 11: Mean monthly rainfall amount and characteristics in east (D), south (E), west (G) and north (H).

Figure 11 shows some representative rainfall characteristic graphs and Table 8 summarize long rainfall probability in the study area. Long rainfall period ranges from 670mm to 1140mm, where east receives more rainfall than west.

Table 7: Long rainfall probability in the study area.

Name	Elev. In m.	Observation period for rain.	Mean annual obs. Period in mm	Rainfall long period mm	Expected minimum rainfall in mm.	
					4 out of 5 years 80%).	2 out of 3 years 67%).
N. Kinagop F	2629	1920 - 1975	1140	1140	940	1090
Nanga Geri	2436	1930 – 1972	825	820	650	740
Njabini	2588	1951 – 1974	1175	1180	880	1060
Malewa	2481	1969 – 1975	680	670	550	630
Geta F.	2588	1959 – 1975	1175	1160	850	950
Mkungi	2511	1936 – 1957	1261	1250	970	1150

Source: Nyandat, (1984).

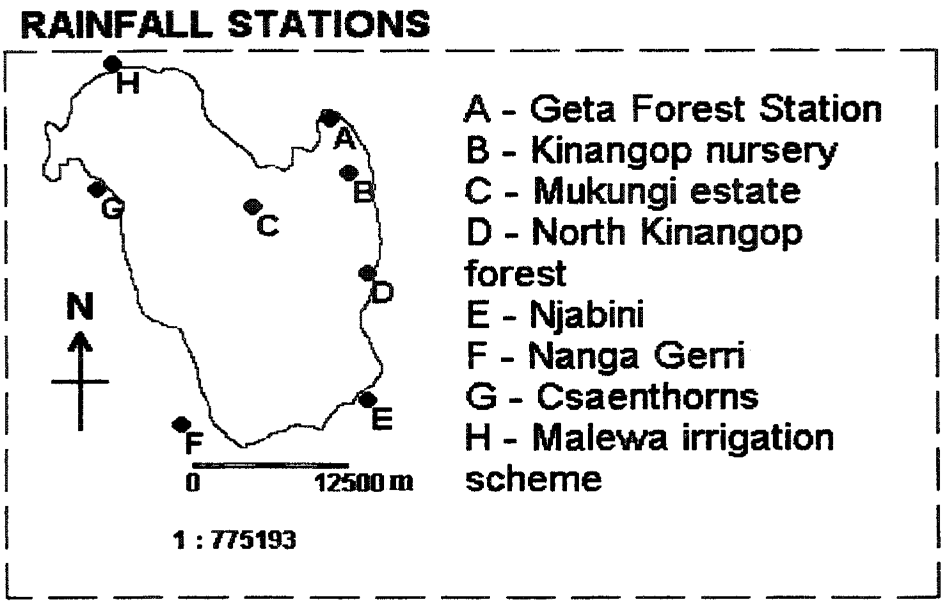

Figure 12: Location of rainfall stations.

2.7.2.2 Temperature.

Little data on temperature exist for the area and where exist is only for short period. The available data on temperature however provide fair indication on the type and variability of the temperature in the area. A main climatic problem is the low night temperature which is brought about by cold air which flows from Aberdares down to Kinangop during clear night causing night frost nearly every month in the area. In general the temperature ranges variation is very little as shown in Table 9. Frost is almost all over the study area especially in the east and south of the study area.

Table 8: Temperature on Kinangop

S.N	Name	Elev. In M	Mean maximum. temp. °C	Mean Minimum. Temp. °C	Absolute. Minim temp. °C	Months with possible Frost	
						2m above	On the ground
1.	Kinangop Mtarakwa F.	2546	12.4	5.8	-1.7	Aug. - March	Jan. - Dec
2.	Mkungi Estate	2511	14.6	6.2	-1.1	Feb.	May - March
3.	S. Kinangop For. St.	2629	12.7	5.7	-2.2	Jun--Oct + Dec-March	Jan. – Dec.
4.	Kinanop Sasumua D.	2478	14.6	7.8	0.0	Jan.-Feb+Jun	May - March
5.	Geta Forest Station	2588	11.9	5.4	-1.1	Jun+Dec - March	Jan.– Dec

Source: (Jaetzold, 1976).

2.7.2.3 Evapotranspiration: Humid and arid months.

In addition to precipitation, it is important to know how much of it is lost through evaporation and transpiration. This then will help in determining the water balance (Rachilo, 1978). In the Turasha catchment the annual potential evaporation (Eo) ranges from 1481 – 1692mm the trend showing to increase from East to West (Jaetzold, 1976).

Table 10: Evapotranspiration (ET) and (0.5ET).

	NORTH KINANGOP F.			NJABINI			NANGA GERI		
MONTHS	R	Et	0.5ET	R	Et	0.5ET	R	Et	0.5ET
J	44	112	56.0	40	88	44.0	48	132	66.0
F	52	113	56.5	26	89	44.5	52	133	66.5
M	80	114	57.0	100	90	45.0	80	134	67.0
A	168	115	57.5	216	91	45.5	148	135	67.5
M	164	116	58.0	144	92	46.0	100	136	68.0
J	100	117	58.5	64	93	46.5	36	137	68.5
J	68	118	59.0	40	94	47.0	32	138	69.0
A	88	119	59.5	40	95	47.5	40	139	69.5
S	108	120	60.0	40	96	48.0	38	140	70.0
O	94	121	60.5	68	97	48.5	50	141	70.5
N	90	122	61.0	96	98	49.0	68	142	71.0
D	68	123	61.5	60	99	49.5	64	143	71.5

Source: Rachilo (1978).

2.7.2.4 Growing period.

Evapotranspiration and rainfall enable the determination of the length of the growing period. According to FAO (1984) the growing period is the period when temperature and soil moisture permits crop growth. It is defined when the rainfall exceeds 0.5EP and ends when the rainfall drops below that value. By using the data obtained from Table 10, the growing period in Njabini and North Kinangop (East) starts in mid February to December while in Nanga Geri (West) is from February to Mid June. Figure 13, 14 and 15 represent evapotranspiration graphs for Njabini, North Kinangop and Nanga Geri respectively.

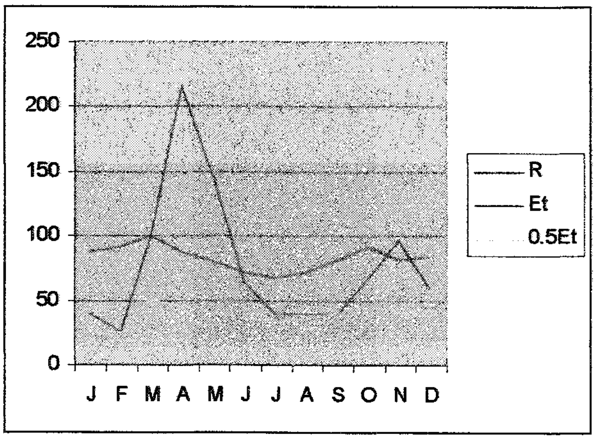

Figure 13: Njabini (E) – East part of the study area.

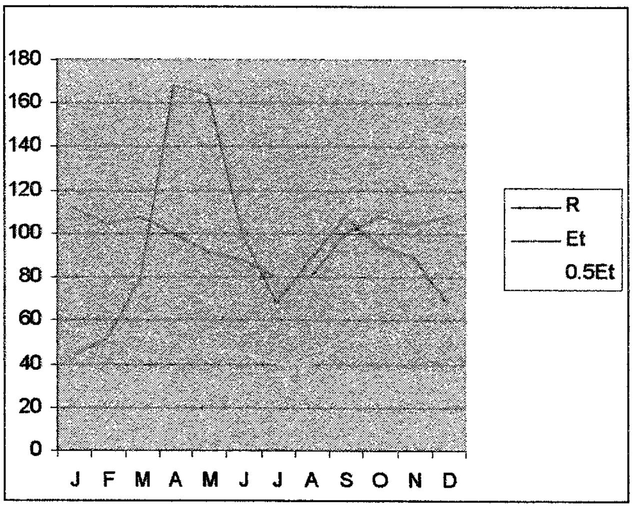

Figure 14: North Kinangop (D) - East of the study area.

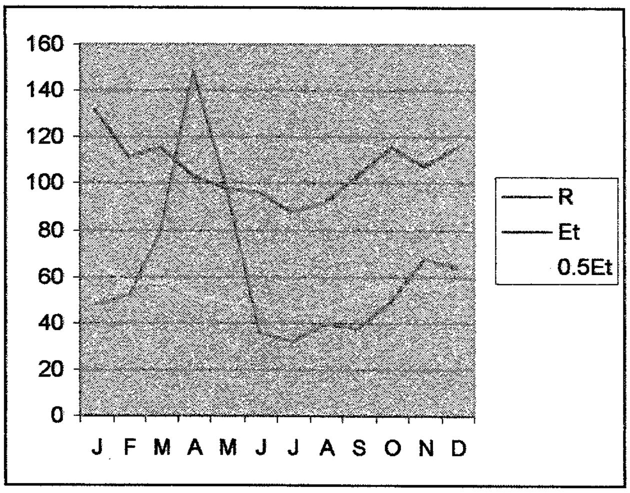

Figure 15: Nanga Geri (F) - West of the study area.

2.7.3 Soil Climate

Soil climate refers to soil moisture and soil temperature regime. Is one of the important parameters used as diagnostic properties at various categoric levels of soil classifications.

2.7.3.1 Soil moisture regime (SMR).

The term soil moisture regime refers to the presence or absence either of ground water or water held at a tension of less than 1500kPa, in the soil or in the specific horizons, by periods of the year (USDA, Key to Soil Taxonomy, 1996). They refer SMR to conditions at a depth of 10 to 90cm. Six soil moisture regimes are distinguished, ranging from extremely dry to prolonged saturation with ground water. In the study area the soil moisture regime is udic. Soils with an udic moisture regime are moist throughout the most of the year but they may have one or more short periods of dryness. These soils, however, are not dry longer than 90 cumulative days.

2.7.3.3 Soil temperature regime (STR).

The control section for soil temperature is either at a depth of 50cm from the soil surface or at a depth of 50cm from the soil surface or at the upper boundary of a root-limiting layer. The soil temperature classes, defined in terms of the mean annual soil temperature classes and difference between mean summer and mean winter temperature (USDA, Key to Soil Taxonomy 1996). As no soil temperature readings are available for the area, the air temperature is taken usually, increased by 1°C. In the study area, the mean summer temperature is 13°C and winter is 6°C. Thus the STR is classified as Mesic (SSC, USDA, Soil Taxonomy, 1996) which means that the mean annual soil temperature is between 8 to 15°C.

CHAPTER 3.

3. LITERATURE REVIEW.
3.1 General Observations on tropical soils.

The importance of agriculture to the economies of developing countries is well known. The main contributors to these economies are small-scale farmers who depend largely on low inputs for crop production. These farmers are faced with a number of problems; one of them being soil erosion caused by water. The rapid erosion of soil by water has been a problem since man began cultivating land (Morgan, 1986). The factors which influence the rate of erosion are rainfall intensity and runoff, slope, erodible material, i.e soil type, plant cover and presence or absence of conservation measures.

The fertility of tropical soils is variable but in generally low and has declined under the existing continuous cropping on the same piece of land. The organic matter decomposes rapidly in a warm, moist climate (Thamhane et al. 1970). This leads to less vegetative cover and ultimately to increase soil erosion susceptibility. Without combating the problem of soil erosion, even the use of fertilizers or other agricultural technologies aiming at crop yield improvement, will fail.

3.2 Previous observations in Naivasha basin.

According to previous studies by Hamadudu (1998), about 75% of Kenya is semi-arid and the remaining 25% is heavily populated, leading to intensive use of land. The population pressure has forced farmers to move to drier areas that are characterized by low and erratic rainfall, which is sporadic and sometimes of higher intensity and hence may lead to heavy soil losses through erosion. Such conditions, when coupled with continuous cultivation on the same piece of land and without proper soil management (water and soil conservation measures) have, to a great extent, contributed to decreased productivity of the crop-livestock-forest enterprises (Mbwile et al 1994). There is a need to assess how these relationships have affected land use changes and in turn accelerate soil erosion before embarking on the proper land use management.

Hamadudu (1998), observed that in some areas in the Lake Naivasha basin there is no accelerated erosion which can be easily noticed under the normal rainfall. However he further commented that as the rainfall years are not the same, a very wet year would result in very high erosion in this area. The areas east of Longonot are apparently severely affected by soil erosion. There is a need to make more detailed studies through a catchment approach to monitor this erosion trend on the bases of rainfall changes and erosion potential of the area.

One of the most advocated methods to combat soil erosion in developing countries especially in Africa and in particularly Kenya, is through agroforestry. According to Nair (1987), one possible solution to reduce pressure on the indigenous forest and meet demand for wood products is to plant more trees in the existing farming systems. Trees can provide services such as soil erosion control and soil improvement (Rao et al (1991).

However in Africa, this approach has proved little successful. According to Kerkhof (1990), a survey of project experience of agroforestry in Africa has shown that many (hundreds) of agroforestry projects are now under way but they face a difficult task, when there are few examples to follow and no simple quarantined techniques. Many projects with the good intention to check soil erosion do not succeed because they lack genuine participation of all stakeholders concerned (Siderius personal communication) and reliable databases to facilitate monitoring and evaluation of their objectives and make appropriate changes to avoid failure. Through scientific research one may assess the trend, cause and effect as well as the severity of soil erosion; and then propose proper sustainable land use management.

Hamududu (1998) carried out studies for the erosion assessment of the Naivasha Basin using several models / approaches, one of them being the Terrain Mapping Units (TMUs) approach. This methodology combines the effect of rainfall, topography, soils land cover and management on the erosion process. The TMUs were found to be a very useful way of describing the terrain characteristics in a GIS environment. Meijerink (1988) observed that TMU is a natural association of similar geology, geomorphology, morphometry and soil distribution. The units are normally identified through interpretation of aerial photographs and satellite images, supplemented by knowledge from the field and existing thematic maps.

3.3 Land Degradation

There are several definitions of land degradation but all try to comment on the negative effect to the quality of land / soil due to natural occurrence and mainly because of the miss-management by man. Lal and Stewart (1990) define soil degradation as an outcome of depletion by human activities and their interaction with natural environments. They distinguished three principal types of degradation viz. biological, chemical and physical. They assigned the following flow-chart in which the processes of soil degradation and the factors influencing soil degradation are shown (respectively Figure 16 and 17).

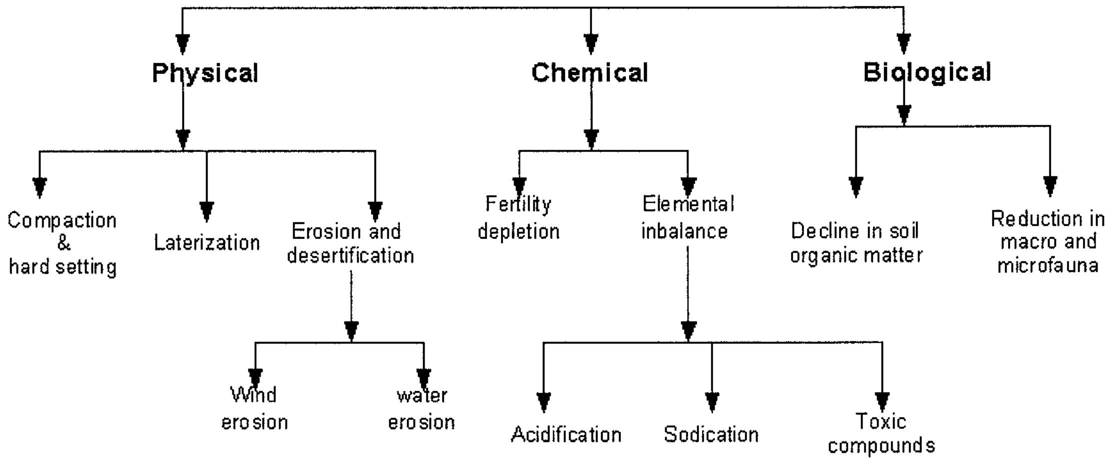

Figure 16: Process of soil degradation (Source: Lal and Stewart 1990).

3.3.1 Soil erosion caused by water.

This type of land degradation is defined as the detachment and movement of soil (soil particles) from the land surface by water (Bergsma et. al. 1996). Accelerated soil erosion is the one influenced by man through overgrazing, cultivation on steep land without conservation measures, road constructions, monocultures, etc. Nill et al. (1996) put soil erosion caused by water in the vicious circle, that it is caused by the degradation of soil properties which reduce its structural stability, hence reduced fertility and plant growth which in turn cause less plant cover and again lead to increased soil erosion caused by water. Plant cover according to Wischmeier & Smith (1978) and Shaxson (1981), is very effective against rain erosion.
Processes and factors of soil erosion should be linked in order to define types, cause and its effect in a particular area. This may be the reason why FAO (1982) defines land degradation as a complex process in which several features can be recognized as contributing to a decrease of production capacity. Lal and Stewart (1990) described the interdependence of soil erosion on biological (land use, climate and land) and social economic factors to consider in erosion assessment for proper land use management (see Figure 17).

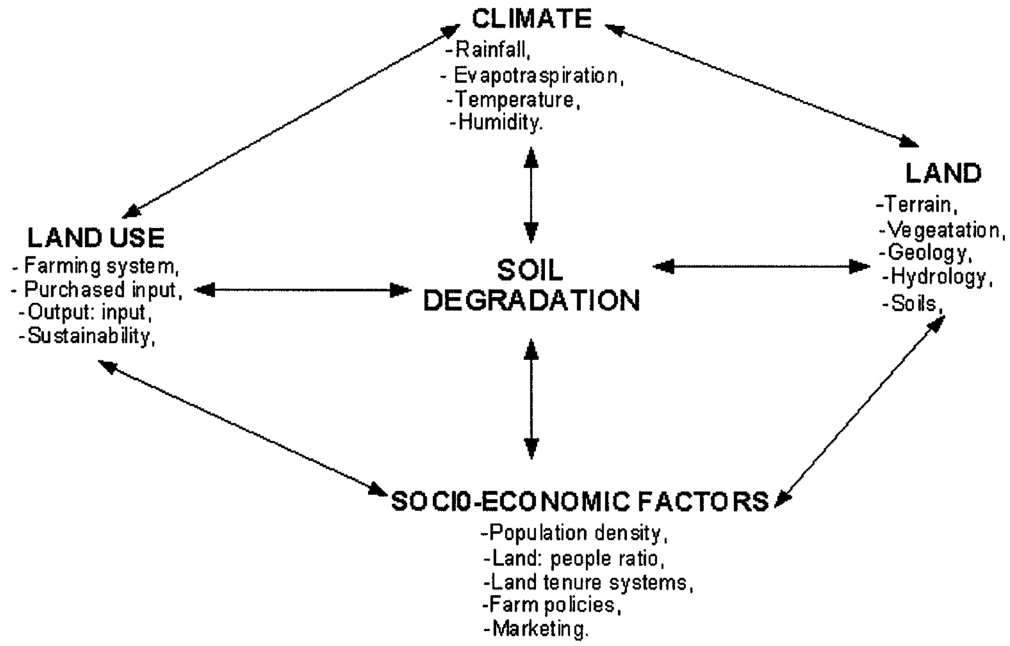

Figure 17: Interdependence of the factors influencing soil degradation. (Source: Lal and Stewart 1990).

3.3.2 Features of soil erosion.

Auzet et al. (1990) classified the various forms of erosion with respect to soil particle detachment condition on slope and in the valley floor into: -

i). Interrill erosion: soil particle detachment mainly by raindrops and running water without initiating incision.

ii). Rill erosion: incised flow lines due to splash and / or sheet runoff. Detachment is mainly by shear stress exerted by runoff on the bed and the wall sides of the rill.

iii). Concentrated flow erosion in the valley floor: detachment is mainly due to shear stress exerted by runoff concentrated in the valley floor or hollows without a permanent channel, and various mechanisms acting on the side walls.
iv). Gully erosion

Bergsma et. al. (1996) by quoting Richter (1965), Carson and Kirkby (1972) and Bergsma (1974), grouped rain erosion features systematically according to slope steepness and the amount of overland flow.

Table 11: schematic grouping of main rain erosion features.

SLOPE	EROSION FEATURES					DEPOSITION FEATURES.
			badland			
STEEP	+ rills	+shallow gullies	+ deep gullies	+ very deep gullies	+ ravines	fans
GENTLE	/ rills	+ rills	+ shallow gullies	+ deep gullies	+very deep gullies	
VERY GENTLE	*Rainwash (directional)	/ rills	/ braids	/wide braids	/flood raids	colluvium, slope wash deposits.
FLAT	. rainsplash, (non-directional)	* rainwash (directional)	/ wide braids	sheet flood	zone	sheet deposits
	LOW	MEDIUM	HIGH	VERY HIGH		DECREASING
	OVERLAND FLOW VOLUME					

Source: Bergsma et al., 1996.

Legend: . = dominantly splash, flow in discontinuous microdepressions.
* = dominantly flow in discontinuous microchannels
. and * = interrill erosion
/ = dominantly flow in permanent channels
\+ = dominantly flow in permanent channels
^ = deposition by gravity and wash.

3.4 Factors of rain erosion.

Rainfall, soil properties, topography, land cover and management are considered as universal in relation to soil erosion caused by water. Loran, Zink and Beek (1988), summarized in a table the input requirements and where to obtain the data required for Universal Soil Loss Equation (USLE).

Table 11: Summarized input requirement for USLE.

INPUT REQUIREMENTS	DATA OBTAINED FROM.
R – Rainfall erosivity factor. • Total storm energy. • Maximum 30 minute intensity.	• Rainfall data from Meteorological station.
K – Soil erodibility factor • % very fine sand and silt • % Sand • %Organic matter • Soil structure • Soil permeability	• Soil data from soil survey / field work and survey report.
LS – Topographic factor • Slope length • Slope steepness	• Geopedological soil map • Field measurements • References
C – Vegetation cover factor	• Field observations • Measurements.
P – Management / conservation practices	• Field observations • Measurements.

Source: Loran et al., (1988).

3.4.1 Rainfall erosivity.

One driving force for water erosion is rainfall. The raindrops which pound on the soil surface either infiltrate into the soil or leave the field as surface runoff (Nill et al. 1996). According to Hudson (1981), rainfall erosivity is the potential capability of the rainfall to cause soil erosion which varies in space and time. Flanagan et al. (1988) investigations showed that soil loss is largely determined by rain volume, energy load, intensity and their distribution in single storms. According to Wischmeier (1977) the erosive potential of a rainstorm and its associated runoff is a function of the rainfall energy, the maximum prolonged intensity and their interaction. Actual soil loss occurs when there is erodable material available.

The erosivity index "R" of the Universal Soil Loss Equation (USLE) according to Wischmeier (1977), is the annual sum of each shower's product of rainfall energy and its maximum 30 minute sustained intensity. Wischmeier & Smith (1958) found that soil loss increased linearly with a storm's total kinetic energy (E) times its maximum 30 minute intensity (I_{30}):

$$\mathbf{R} = \sum_{j=1}^{m} (E*I_{30})(N/h) \quad \textbf{(1)}$$

and

$$\mathbf{E} = \sum_{j=1}^{n} (11.89+8.73\log_i)*Pi10^{-3}(kJ/m^2)$$

With **R** - long-term mean annual erosivity (N/h)

E - kinetic energy of a storm j (kJ/m2)

$\mathbf{I_{30}}$ - maximum storm intensity of storm j during 30 min (mm/h)

Pi – rain volume during interval i (mm).

n – number of storm intervals with equal intensity (-).

m - number of erosivity storm per year (-).

Wischmeier and Smith, (1978) modified the equation to become:

$R = (E.I_{30})/100$ .... **(2)**

Where R = rainfall erosivity index, E = rainfall kinetic energy (mt/ha/cm rainfall); and I_{30} = maximum 30 minute rainfall intensity (cm/h). The kinetic energy was derived from the measurements of rainfall intensity observed over an incremental time period of 30 minutes applied to equation:
$E = 210.3 + 89 \log I$; .... **(3)**
Where:
I = rainfall intensity (cm/hour),
E = value is obtained from an automatic raingauge.

However it is very difficult to obtain this type of data from raingauges in many African countries, so another method of estimating erosivity should be sought. Delwaule (1973) further simplified the calculation of erosivity by substituting rainfall energy by rainfall amount (Pi) and Lal (1976) introduced the use of shorter intervals for the maximum intensity (I_{max}):

$EI_{30} = Pi * Imax(2mm /h)$.. **(4)**

- For I_{max} he chose the maximum 7.5-min intensity.

Dinka (1996) used the erosivity regression equation developed by EL-Swaify et al. (1985), which predicts rainfall in the Hawaian islands:

$R = 28.5 + 0.35(p)$..**(5)**

Where, p = annual rainfall in mm.
R = annual erosivity (EI_{30}) in m-t/ha/yr.
This equation has been successfully applied in the tropics, especially in Asian countries.

Roose (1977) worked on the idea of erosivity regression equations to extrapolate the findings of erosivity from the reliable rainfall stations to the nearby areas. As an empirical approach for the estimation of erosivity in West Africa he proposed:

$R = (0.85(+/-)0.05*P_{ann}$ (N/h).. **(6)**

where P_{ann} = annual amount of rainfall.
(N/h) = Newton / hour.

He verified his regression for 20 rainfall stations and drew an iso-erodent map of West Africa. Further iso-erodent maps were compiled for Zimbabwe, Kenya, Tanzania and Uganda, based on KE>1.
According to Nill (1996), there is no evidence as to how far the regression can be used apart from the specific sites for which they were calculated. In additional he stated that

the quality of the rain will generally not change in the same geographic areas within some kilometres. Based on this fact, the erosivity regression equation suggested by Bresch (1993) for the Kenya hinterland at an altitude of over 1250m will be used in this study. The equation stated that:

$$\mathbf{EI_{30} = 0.269*P_{ann}+113\ (N/h)} \quad (7)$$

Where; $\mathbf{P_{ann}}$ = annual amount of rainfall.
(N/h) = Newtons / hour.

3.4.2 Soil erodibility.

The erodibility of soil refers to the resistance of the soil to both detachment and transport by the eroding agent. Hudson (1964) defines erodibility as the specific property of soil which can be quantitatively evaluated as the vulnerability of the soil to erosion under specific circumstances. To Imeson (1985) soil erodibility is the inherent susceptibility of a given soil to erosion by water, the response of soil to impacting raindrops and slope wash process. According to Thornes (1980) it is the relative ease with which a soil erodes under specific conditions of slope as compared with other soils under the same conditions. The term soil erodibility is limited to interrill and rill erosion.
The higher the erodibility "K" the easier the soil is erodible. Wischmeier and Smith (1978) established a regression equation or nomograph for the parameters to estimate K value for a given soil of which the K value is not known. Their regression equation is given as: -

$$\mathbf{K = 2.8*10^{-7}\, M^{1.14}*(12\text{-}OM)+0.043\ (SC\text{-}2) + 0.033*(4 - PC)} \quad (8)$$

Where M = (%silt+%very fine sand)*(100-%clay),
OM = % organic matter (%OC*1.72),
SC = structure code,
PC = permeability class.
The equation shows that soil erodibility increases with increasing silt plus very fine sand content of the soil. It decreases with increasing clay and organic matter content. According to Foster et. al. (1985) soil aggregate stability and infiltration rates can be affected by aggregate size and density, soil texture and soil structure. In general, small aggregates are more stable than larger one, because the organic matter content is higher in the smaller aggregate. Romkens et. al. (1977) observed that high aggregate densities generally indicate a high clay content and increased aggregate strength.

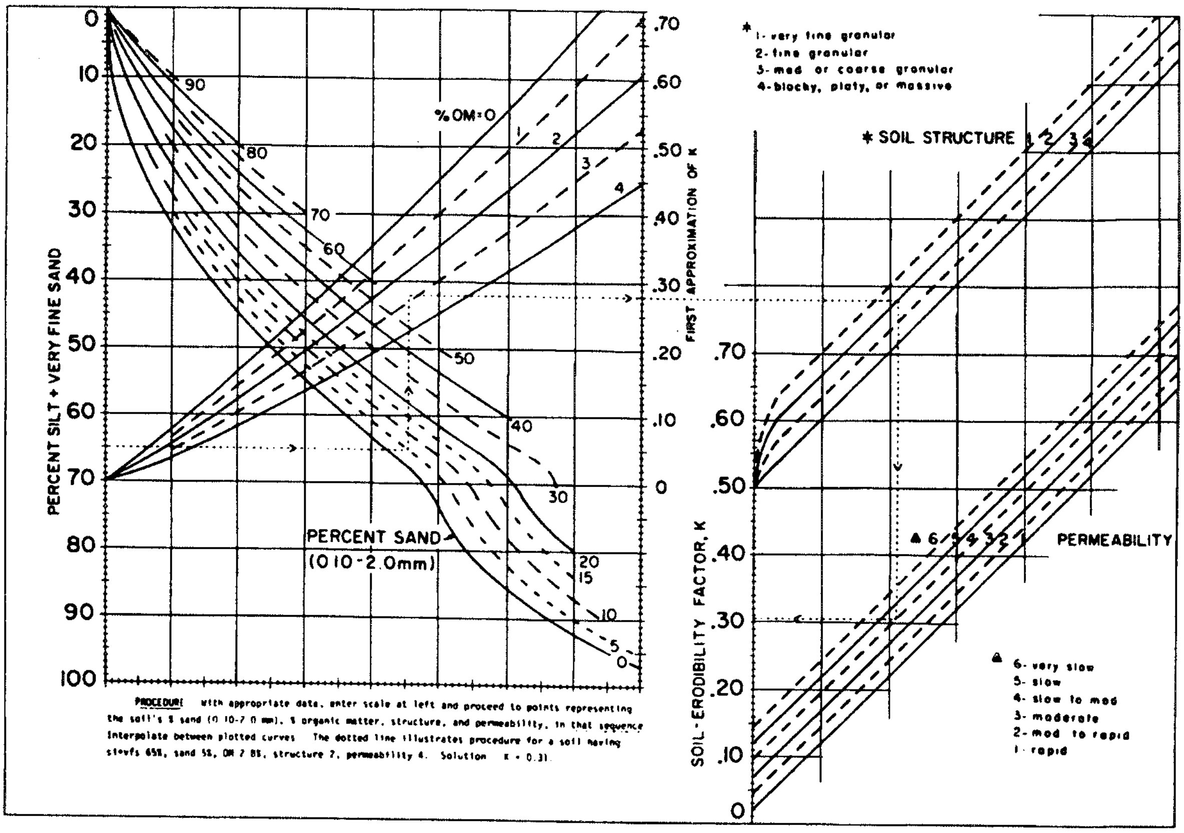

Figure 18: The soil erodibility nomograph.
Source: Wischmeier and Smith (1978).

Dangeler and El-Swaify (1976) rated the K-value into six classes;

Table 13: Rate of K value.

CLASS	RANGE	MEAN
Very low	0.00 – 0.10	0.05
Low	0.10 – 0.20	0.15
Moderate	0.20 – 0.32	0.26
Moderate high	0.32 – 0.43	0.37
High	0.43 – 0.55	0.49
Very high	0.55 – 0.64	0.61

Source: Dangeler and El-Swaify (1976)

3.4.2.1 Soil texture.

Laboratory studies show that medium and coarse particles are easily detached from the soil mass and that clay particles resist detachment (Morgan, 1988). This may be due to the raindrop energy which has to overcome the adhesive or chemical bonding forces by which the minerals comprising clay particles are linked. Soils high in silt and low in clay are highly erodible (Nill et al. 1996). Wischmeier & Mannering (1969) observed that erodibility decrease with a decrease in silt, regardless whether the corresponding increase is in the sand or clay fraction. The high erodibility of silty soils is explained by their weak structural stability. They rapidly form surface seals upon raindrop impact. Erosion is less on clayey soils due to their better aggregation and on sandy soils due to their non-sealing surface. The large pores between sand particles permit rapid water movement hence reducing soil erosion. Fine sand (0.05 – 0.1 mm diameter), however, behaves like silt and is therefore attributed to the silt fraction for soil erosion aspects Wischmeier & Smith, (1978) and Metternicht (1996).

3.4.2.2 Soil organic matter.

Soil organic matter (SOM) influences soil loss by improving soil structure, root penetration, water holding capacity and infiltration (Nill et al. 1996). Wischmeier & Smith (1978) observed that with increasing SOM, erodibility decreases. The role of SOM as a binding agent is more important on soils deficient of other structuring components, which implies that the importance of SOM decreases with the increase of clay content. Valentin and Janeau (1989) found that structural stability was only improved by SOM if the ratio of SOM to clay was >= 0.07. It has been found that in tropical cropping systems SOM is high after the fallow and declines rapidly during the cropping period (Nill 1993). To obtain organic matter percentage for the use in USLE, the determined carbon (C) from the laboratory are multiplied by a factor of 1. 72.

3.4.2.3 Soil structure.

Soil structure refers to soil aggregate stability. Erodibility decreases with increasing aggregate stability as seal formation is delayed and infiltration increased (Ekwue, 1991; Falay & Lal, 1979). Large stable aggregate makes soil difficult to detach and to transport, hence make it more permeable to water. Kaswamila (1995) mentioned some factors which influence the size and stability of aggregates to be texture, kind of ions on the cation exchange complex, type of clay mineral, organic matter content, cementing materials other than clay, and cropping history. Soil with an unstable structure develops coarse fragment after prolonged bare fallow periods, whereas stable soils maintain an aggregated surface (Nill et al. 1996). He conclude that the coarser the structure, the higher the structure class and stability. Schwertmann et al. (1987) modified the definition of structure classes for use in USLE in a table.

Table 14: Structure classes for use in the USLE.

Structure class	Structure	Mean aggregate size (mm)
1	very fine crumb	< 1
2	Fine crumb	1 – 10
3	Medium	10 – 40
4	Block, platy or massive	>10

Source: Schwertmann et al., (1987).

3.4.2.4 Soil permeability.

The permeability of the soil refers to its capacity and ability to conduct water. The permeability class of the soil must be determined for all horizons down to 80cm depth (Nill et al. 1996). Schwertmann et. (1987) put in a table the definition of permeability classes that he used in USLE.

Table 15: Permeability classes as used in USLE.

Permeability class	Permeability	Hydraulic conductivity (cm/d)
1	Very low	<1
2	Low	1 – 10
3	Medium	10 – 40
4	High	40 – 100
5	Very	High
6	Extremely high	>300

Source: Schwertmann et al., (1987).

Nill et al. (1996) Used the porosity of a soil to determine its permeability (see Table 16).

Table 16: Porosity and permeability.

Description	Permeability class
Very fine pores	1
Few pores	2
Common pores	3
Many pores/porous	4
Very porous	5
Very high biological activities	6

Source: Nill et al. (1996).

3.4.2.5 Parent material.

The chemical composition of a soil is to a varying degree determined by the parent material in which the soil is formed (Van Reeuwijk, 1994). He further insisted that as the parent material in turn is inherited from the parent rock, the composition of the rocks and their composing minerals should be clearly understood in dealing with issues related with soils. Brady (1964) mentioned that rocks in the earth's crust are classified as (1) igneous (2) sedimentary, or (3) metamorphic; and defined parent material as the unconsolidated and more or less chemically weathered mineral from which soils may be synthesized. He put in a table some of the more important sedimentary and metamorphic rocks and the minerals commonly dominant in them.

Table 17: Dominant minerals in sedimentary and metamorphic rocks.

Sedimentary rock	Dominant mineral		Metamorphic rocks	Dominant mineral
Limestone	Calcite ($CaCO_3$)		Gneiss	Varied
Dolomite	Dolomite $CaMg(CO_3)_2$		Schist	Varied
Sandstone	Quartz (SiO_2)		Quartzite	Quartz (SiO_2)
Shale	Clays		Slate	Clay
Conglomerate	Varied		Marble	Calcite ($CaCO_3$)

Source: Brady 1964.

According to Van Reeuwijk (1994), 90% of the lithosphere consists of silicates which implies that a big proportion of the soils are derived from it (silicate). All clay minerals are silicates.
Mohr (1954) found that is important to know whether the parent material is a result of a plutonic or an effusive igneous rock, and whether it is acidic or basic rock. Acid rock led to excessive SiO_3, which results to well-known minerals for their resistant to weathering such as plagioclases, albite and oligoclase. According to Bergsma (1993), rich volcanic and basic rocks are more easily prone to weathering, producing deep soils. These rocks usually provide abundant nutrients to allow rich vegetation to develop, giving a natural protection against erosion.

3.4.2.6 The antecedent soil moisture.

This is the moisture content existing before the rainfall, which affects the overland flow production. The overland flow volume is much higher when the soil is saturated, or nearly so, at the time when the rain starts to fall (Nill et al. 1996). The occurrence of drying spells between showers renews the soil's storage capacity, and the same time the surface porosity may recover to some extent by drying processes and soil animal activities.
Bergsma (1993) quoted African Soils XII-1 which observed that overland flow and soil loss was much greater when the rain fell on a soil which was already saturated, than on a less wet soil, even though the intensity of the second was much lower than the intensity of the first. It is likely that the greater effect of the second shower is also due to a (temporary) deterioration of the soil surface structure and a consequent reduction in infiltration. However at the beginning of a wet season in a subtropical / tropical climate, the first rainstorms produced most erosion because there is much loose dry soil material at that time on the land surface, which can be washed away (Nill et al. 1996).

3.4.2.7 Sealing and crusting.

3.4.2.7.1 **Sealing.**

Soil sealing is the formation of a thin, dense, platy soil surface structure of the fine soil particles under the influence of splash, slaking, swelling or sedimentation, which is relative impermeable to air and water (Bergsma et al 1996). Houghton and Charman (1986) explain that soil sealing occurrence is due to the effect of raindrop water on bare soil and results in a reduction of infiltration; runoff and the potential for soil erosion are thus increased. According to De Ploey (1981) sealing soils often generate more surface runoff, and these soils have therefore a greater hazard for rill erosion. Rainfall with a high cumulative energy causes sealing later, and to a smaller degree than lower cumulative rain energies.

Soils that break up into smaller stable micro-structural elements give high splash losses and low rates of surface sealing, while soils that disintegrated into primary particles more readily seal and give rise to lower splash erosion rates (Farres 1986). Pla Sentis (1981) found that soil conditions which induce sealing are a low content in organic matter, a clay fraction with reduced activity, high silt content, dominance of fine and flat particles in the sand fraction. The effect of sealing is its reduction of the rainfall acceptance, as the surface infiltration is reduced (Bergsma te al., 1996).

3.4.2.7.2 Crusting.

A soil crust is the surface soil layer, ranging in thickness from a few mm to perhaps as much as 3 cm, that is much more compact, hard and brittle when dry, than the material immediately beneath it (Bergsma et al. 1996). All seals are crusts but not all crusts are seals (Siderius, personal communication). Crusting is a sign of soil degradation caused by deterioration conditions for plant cover and soil structure formation which are brought about by overcropping, overgrazing or overtillage. One rain shower can form it. The types of crust are used to describe types of the surface for zone, which have different hydrological properties (Casenave and Valentin 1989). Crust strength can be measured by a penetrometer or a torvane.

Bergsma et al. (1996), summarized the negative effect of crusts as causing reduced rainfall infiltration, increase downslope soil erosion through sheetwash and rill formation, mechanical impedance of seedling emergence, lack of aeration just below the crust, more forces needed for tillage operations and the need for second tillage. Favourable effects of crusts are the protection against wind erosion, more economic distribution of furrow irrigation water and water harvesting.

3.4.2.8 Soil loss tolerance (SLT).

Soil loss tolerance is the maximum rate of annual soil erosion that may occur and still permits a high level of crop productivity to be obtained economically and indefinitely (Wischmeier and Smith 1978). The determination of soil tolerance is intended to compare the expected soil loss with the soil loss tolerance. If the soil loss is less than or equal to soil loss tolerance, the soil loss can be still accepted. But if the soil loss is more than soil loss tolerance, measurement to reduce soil erosion should be taken into consideration until a level of equal or less than the soil loss tolerance has been reached.

Hudson (1986) mentioned some important factors to be considered in determining soil loss tolerance. They are: thickness of topsoil, soil physical properties, decreasing organic matter and nutrient loss. The maximum soil loss tolerance for tropical regions according to Arsyad (1981) is 25 t/ha/y and for temperate regions it is estimated by Thomson

(1957) to be 13.5 t/ha/y. A common used soil tolerance rate according to Crosson (1985) and Lal (1985) is 5 – 12 t/ha/y for shallow to deep soil. However the current used rates for tolerable soil loss are far too high for fragile tropical soils with low levels of fertility (Lal, 1985).

3.4.3 Topography.

Slope length is defined as the distance from which the original overland flow begins to the point where either (1) the slope gradient decreases enough that deposition begins or (2) runoff becomes concentrated in a well-defined channel (Wischmeier and Smith, 1978).
Increasing slope length enhances soil loss as more runoff volume and velocity can accumulate on long slopes. Slope length is best estimated by pacing or measuring in the field by tape measure, while steep slopes should be converted to horizontal distance (Renard et al., 1997). The combined topographic factor (slope length * percentage - L*S) allows to adjust soil loss on a given slope length, gradient and slope form to that of the control point. The LS factor was derived from soil slopes ranging from 3 to 18% and 9 to 90m (30 to 300ft) long (Wischmeier and Smith, 1978). However the equation was regarded applicable by the authors to slopes 300m long and 50% steep. Foster et al. (1982) estimated that the LS factor can be applied in the tropics to slopes of up to 25%, whereas Hurni (1980) used the LS factor for the slope > 50%. The common used equation in USLE is the one developed by Wischmeier and Smith (1978):

$$\mathbf{LS = (l/22.1)^m * (65.41 * \sin^2\alpha + 4.56 * \sin\alpha + 0.065)}$$

With "l" - Slope length (m)
"m" - slope length exponent(-)
"α" - gradient (°)

Gradient (%)	meter
<= 0.5	0.15
0.6 – 1.0	0.20
1.1 – 3.4	0.30
3.5 – 4.9	0.40
>=5	0.5

The slope length exponent (m) depends on the gradient and is smaller for low slopes than for steep slopes. This implies that the effect of slope length on soil loss is interrelated with slope steepness.
Soil loss is also influenced by the shape of a slope. According to Nill et al. (1996) it decreases in the following order: convex > regular >concave slope form. On the convex slope, where the gradient increases in the order up-slope < mid-slope<down-slope, a large runoff volume coincides with the maximum gradient (down-slope). In contrast to a concave slope where the maximum gradient is up-slope where runoff is still smaller.

3.4.4 Land cover and use.

The cover management factor C of the USLE gives the ratio of soil loss on a cropped plot to soil loss on a barefallow control plot of identical size, slope length, gradient and soil. (Wischmeier and Smith 1978). The protection of the soil surface depends on the amount and quality of coverage. Both are crop and management specific. According to Nill et al. (1996) cover, tillage and protection techniques depend on management, in contrast to rain erosivity, soil erodibility and slope. This makes them of foremost importance to soil conservation. Bergsma et al. (1996) and Moldenhauer and Foster (1981) concluded that, of all hazard factors, cover and management for conservation are the most important influences on the rain erosion hazard because of their great potential for reducing erosion and their manipulated rate.

Evans (1980), Kirkby and Morgan (1988) explained that runoff and erosion from woodland and good pasture are small, often less than 1 and 5% respectively of the runoff and erosion from bare soil. Runoff is low because the rate of infiltration of water through vegetated surfaces are high as compared to those on bare soil, as vegetated soils often have a better structure and more stable aggregates. When the raindrop strikes vegetation the energy of the drop is dissipated and there is no direct impact on the soil surface. The remainder drips or flows down the grass stems or tree trunks to the ground surface below. The drops falling from the leaves are often larger than the original raindrops because they have coalesced (Stocking and Elwell, 1976). However there is a surface litter beneath grass or trees and this intercepts the drops falling through the plant canopy. In this case, the water reaching the soil remains clear, and the pores at the surface are not filled with the splashed soil particles. Hudson (1981) conducted experiments to investigate the importance of plant cover in reducing soil erosion. One of his conclusions was that; vegetation as land cover intercepts the rain drops so that their kinetic energy is dissipated by the plants rather than imparted to the soil.

Apart from interception, the land cover also helps efficient water infiltration into the soil (Dinka, 1997). Surface cover slows down overland flow and this allows infiltration. Soil permeability is also improved by long plant roots which break through the soil layer in the profile with highest resistance to water movement, which then enables the movement of water in the entire profile.

Kooiman (1987) observed that different crop types have different values depending on vegetative characteristics, where the difference are related to the length of the period needed to provide good cover. Crops that develop rapidly a good cover, like soybean, are more effective in reducing soil erosion than those that have slower rate of growth like cassava and maize. Lal (1979) concluded that, in general leguminous crops have the ability to restore and improve soil structure and consequently reduce erosion as compared with soil depleting crops such as cassava and maize. Cropping systems, tillage operations and crop management may have a negative or positive influence on soil erosion depending on how it is conducted. For example mixed cropping reduces erosion rates by increasing the total rate of canopy development and by providing residues after the harvest of one of the crops. Mixed cropping reduced erosion 100-500 times the bare fallow rate and was more effective than double cropping.

In order to calculate soil loss from crops, cropping system and vegetation in general, Wischmeier (1975) proposed to divide the influence of the vegetation cover into sub-factors. He defined a sub-factor for:

1. the influence of the canopy cover**(c1)**
2. the influence of mulch or of vegetation close to the soil surface **(c2)**
3. tillage and residue effects of the former vegetation **(c3)**.

The **C** factor is calculated as the product of the three subfactors: **C = c1 * c2 * c3.**

According to Nill et al. (1996), for tropical countries, the subfactor method is especially valuable because for many crops no experimentally determined data are available. The problem is further complicated by the fact that in Africa there exists a large variety of small holder systems, which are difficult to compare to the American standards (e.g hand tillage, mixed cropping, heaping, bedding, etc).

3.4.5 Land management.

By definition, the supporting practice factor (P) is the ratio of soil loss with a specific support practice to the corresponding loss with upslope and downslope tillage. These practices principally affect erosion by modifying the flow pattern, grade or direction of surface runoff and by reducing the amount and rate of runoff (Renard and Foster 1983). For cultivated land, the support practices considered include contouring (tillage and planting on or near the contour), stripcropping, terracing, and subsurface drainage. On dryland or rangeland areas, soil-disturbing practices oriented on or near the contour that result in storage of moisture and reduction of runoff are also used as support practices (Renard et al., 1997).

3.4.5.1 General overview about land use management.

Land use management is the use of land, within the limits of economic practicability, according to its capabilities and the need to keep it permanently productive. According to Stocking (1985) the prime objective of soil conservation is to provide for permanent maintenance of the soils productive potential and secondly to improve the living standard of the people. In any method or approach considered to be undertaken for soil conservation; efficiency of the method, acceptance and cost to the target group should be sought out first. The understanding of the local conditions, the constraints of the farmer, his outlook on life are all important.

There seems to be no one factor that can be singled out as the key to a successful soil conservation program. Success generally can be attributed to a combination of factors that have lead land users to adopt them and then continued conservation practices. In summary Sanders (1988) observed the following important factors which should be considered; socio-economic factors, participation, short-term benefit to the farmers, land tenure, practicability of the conservation methods in terms of technical know-how and costs, and commitment of the government to long-term programs, supported by the necessary legislation, staff, finances, and provision of facilities worthwhile for achievement in conservation.

A modification from Bergsma (1989), shows a general order of steps from erosion surveys to conservation planing See Figure 19).

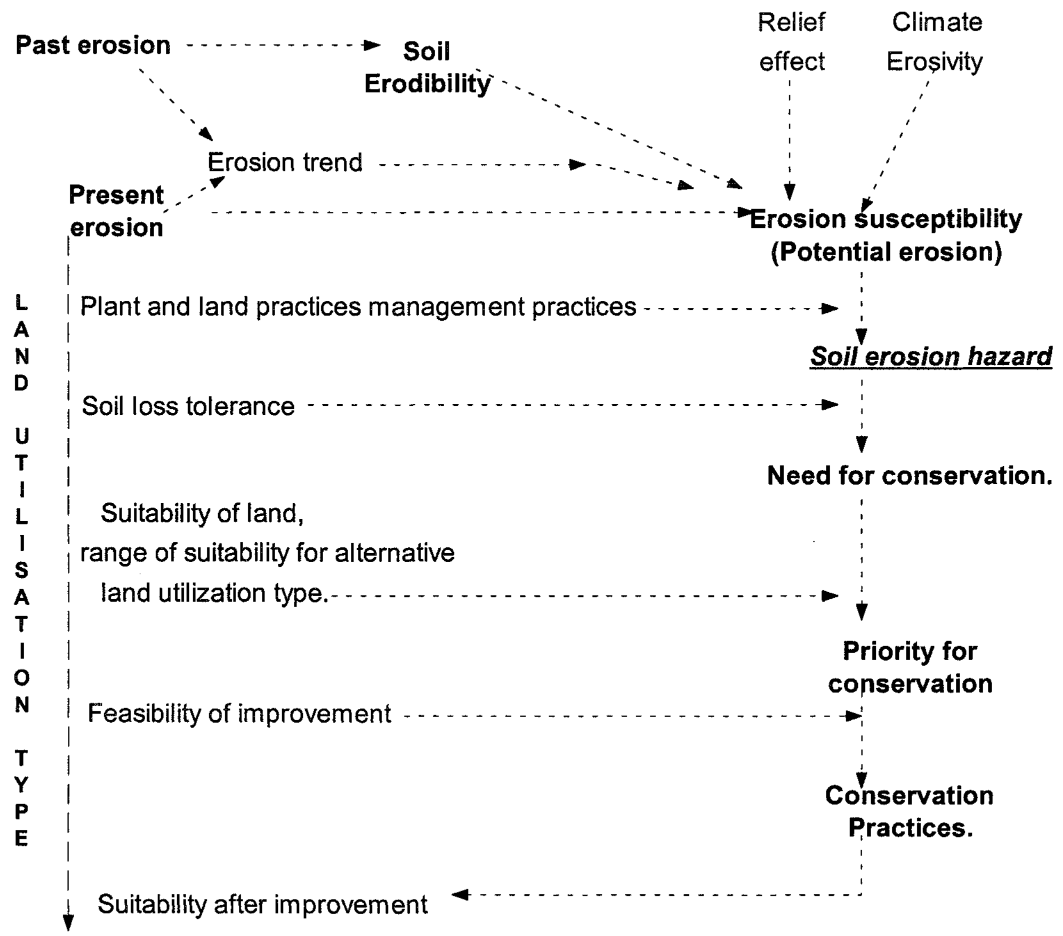

Figure 19: Steps from erosion survey to conservation planing (Source: Bergsma et al. 1996).

Common soil and water conservation practices or advised, especially in East African countries and particularly in Kenya, are: contour bunds or fanya juu grass strips, controlled grazing, cutoff drains, waterways, afforestation, check dams, tied ridging, intercropping, controlled grazing, microbasins, gully reclamation, area closure (cut and carry) and agroforestry.

3.4.5.2 Agroforestry.

To some extent agroforestry can be explained separately as a central concept of its own. By definition is the integrated land use that involves deliberate retention or admixture of trees and other woody perennials in spatial or temporal association or admixture of trees and other woody perennials in spatial association with crop or grazing-land to benefit from the natural ecological and economic interactions.

The ecological interactions between trees and crops, acting through the microclimate, and the sustaining of soil fertility, are the most distinctive features of agroforestry. Trees improve the soil fertility by maintenance of organic matter (litter, prunings and root residue), nitrogen fixation, uptake and recycling of nutrients, and other process (FAO, 1977). According to Young (1987) certain trees may halt or reverse soil degradation by

fertility enhancement properties, for example *Acacia senegal* and *Acacia albida* in the semi-arid zone.
Common agroforestry practices which may also be used in soil and water conservation, include hedge or strip rows along the contour bunds, alley cropping and intercopping and boundary demarcations (see Figure 20).

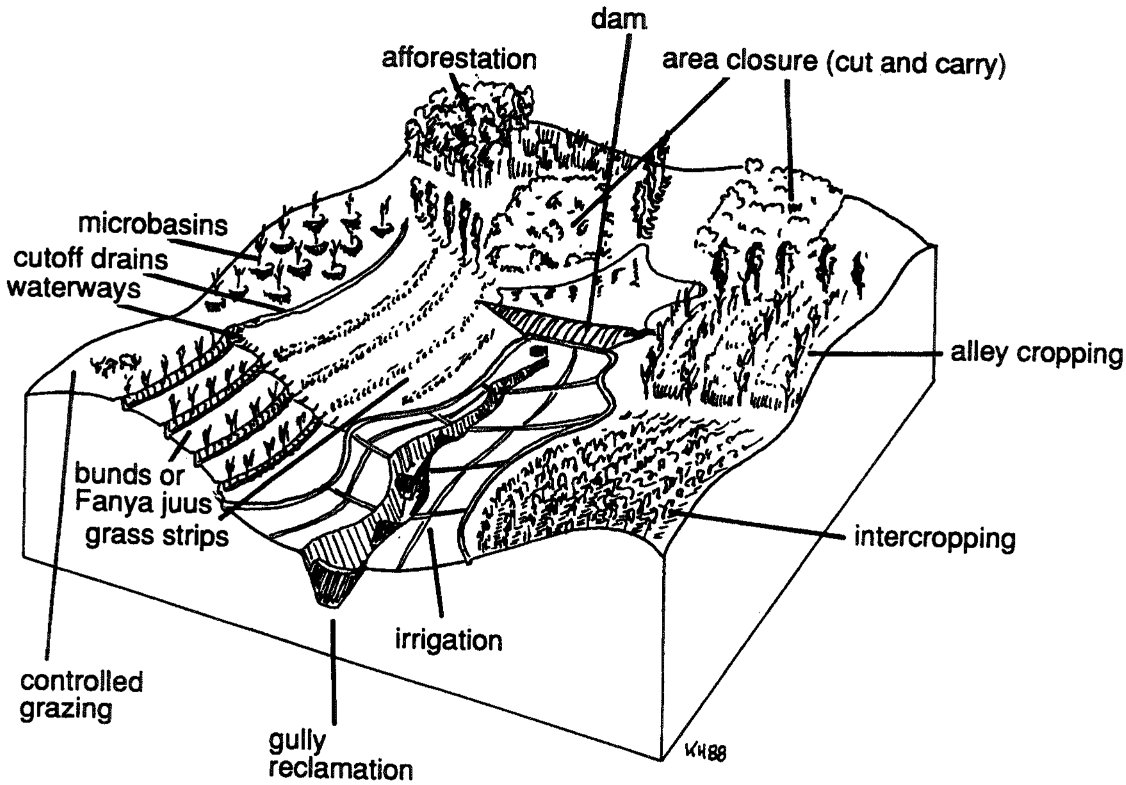

Figure 20: Soil and water conservation practices. (Source: Bergsma et al. 1996).

3.5 Effects of soil degradation.

Soil erosion by water has both on-site and off-site effects. On-site effects are those which occur at or near the site. According to Nill et al (1996) loss of topsoil, loss of organic matter, decrease in the root zone, terrain deformation (rills, gullies and mass movements) and deposition within one kilometer distance from the site are considered as on-site effects, whereas off-site effects are those which occur at least one kilometer away. Arocena (1991) summarizes the effect of land degradation due to erosion as follows (see Figure 21).

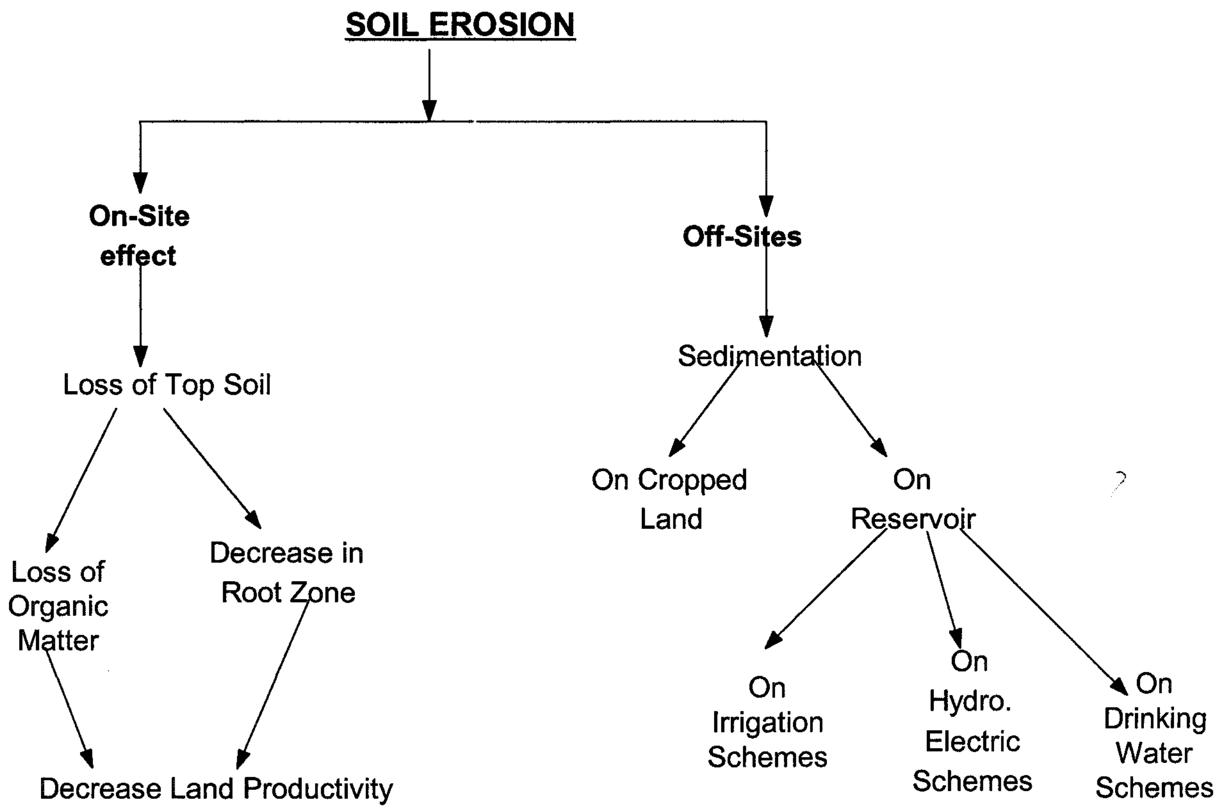

Figure 21: Effects of soil degradation due to soil erosion. (Sorce: H. Arocena-Francisco 1991).

Most important physical properties, which determine soil productivity, are texture, structure and depth of the profile. According to Nill et al. (1996) they determine the amount of water and air stored in the soil, its ability to infiltrate and conduct water, its possibility for root growth and the fines which can deliver nutrients to the plant roots. So once these physical properties are affected by erosion, soil productivity tends to be lowered. Also the loss of fertile topsoil is most harmful as the subsoil contains generally a lower amount of nutrients and soil organic matter. The fast runoff leads to a loss of water from the landscape and result in large fluctuation of the rivers. Some rivers start to become only seasonal. In additional the groundwater table is lowered which affects the vegetation and causes water shortage in wells (Nill et al. 1996).

3.6 Soil hazard map and erosion susceptibility.

3.6.1 Soil hazard map.

The soil erosion hazard map shows the sensitivity of the land to the prevailing agents of erosion, or the rate of soil loss expected in the near future. According to Bergsma et al. (1996) the rate of soil loss expected in the near future, depends on rain erosion, which in turn depends on the combined and interactive effects of all erosion hazard factors:

climate, relief, soil profile, present erosion, cultivation systems, land use and vegetation. The influence of the factors of natural vegetation and cultivated plants, land management and cultivation system, is variable and relatively easy to change. This is because of the growing seasons with stages of crop-growth, and crop rotations and other changes in land use and farming practices. Consequently the erosion hazard is strongly variable in time. The assessment of erosion hazard is by studying the erosion hazard factors and their interactions as they are mentioned below rain erosion hazard terms by Bergsma et al. (1996).

Causal factor		**Relevant term**
Rain only		Rain erosivity
Soil only		Soil Erodibility
Climate Relief Soil (and present erosion)	} } }	Soil Erosion Susceptibility
Climate Relief Soil (and present erosion) Vegetation and land use Land management	} } } } }	Soil Erosion Hazard

The expected rate of erosion can be expressed in a quantitative way as expected soil loss in t/ha (Wischmeier and Smith, 1978) or in a qualitative way (low, moderate, high etc.).

3.6.2 Erosion susceptibility.

Erosion susceptibility is sometimes called erosion risk or potential erosion. This is the loss expected under the influence of rainfall, relief, soil and present conditions of erosion, in the absence of plant cover and control practices, that is on bare land, ploughed up-and-down the slope. According Bennema & Meester (1981), the erosion susceptibility is the characteristic of a land area which describes the erosion to be expected without protection by plants and in the absence of conservation practices. It is therefore a useful concept for planing land development, when alternative land utilization types are considered. Each alternative may result in a different erosion hazard for one unit of land having a certain erosion susceptibility.

Erosion susceptibility is the part of the erosion hazard that is attributed to the influence of relatively permanent factors such as climate, relief, soil and present erosion. Because the concept of erosion susceptibility is a (rather) permanent characteristic of a piece of land, or mapping unit, it is a land quality. In fact it is the opposite of land quality called "*resistance-to-erosion*" (Bergsma et al. 1996).

3.7 Soil erosion modelling.

3.7.1 Introduction.

Erosion models describe the erosion by mathematical equations, more or less simplified, using as input the information about erosion factors and having a output the soil loss and / or the overland flow Bergsma et al. (1996). They may be specified for a field or hill slope, or the sediment yield and discharge for a catchment area or the effect of erosion and conservation on nutrient losses, yield or benefit/cost of the land use system.
According to Morgan (1995) digital (based on the use of digital computer to process vast quantities of data) erosional models may be of three kinds: -
i) Physically-based – based on mathematical equations to describe the process involved in the model, taking in consideration the laws of conservation of mass and energy.
ii) Stochastic models – Describing erosion according to probabilistic laws, with the process developing sequentially data in time.
iii) Empirical model – Based on identifying statistically significant relationships between assumed important variables where a reasonable database exists. Three type of analysis are recognized: (a) black box – where only main inputs and output are studied; (b) grey box-where some details of how the system works is known; (c) white box-where all details of how the system operates are known.

3.7.2 USLE – Universal Soil Loss Equation.

The USLE is an empirical model with widespread use in land use planning, extension and the design of cropping systems and conservation practices. It allows the estimation of soil loss under varying climatic, topographic and management conditions on different soils with a set of relatively simple parameters.
The methodology for the estimation of soil loss is essentially based on a modified Universal Soil Loss Equation (USLE) by Wischmeier and Smith (1978). **USLE** equates soil loss per unit area with the erosive power of rain, the amount and velocity of runoff water, the erodibility of the soil, and mitigating factors due to vegetation cover, cultivation methods and soil conservation. It takes the form of an equation where all of these factors are multiplied together; **A = R*K*L*S*C*P** where:

A: Average / mean, longterm annual soil loss (t/ha/y).

R: Rainfall erosivity index (tm/ha/y).

The rainfall erosion factor to account for the erosive power of the rain related to the amount and intensity of rainfall over the year. It is expressed in the units described as erosion index units.

K: Soil erodibility index (tm/ha/y).
The soil erodibility factor, is the soil loss rate per erosion index unit for a specific soil as measured on a unit plot / landform.

L: Slope length factor (-).
S: Percentage of the slope factor (-).
LS - A combined factor to account for the length and steepness of the slope. The longer the slope the greater the volume of runoff, the steeper the slope the greater its velocity. LS = 1.0 on a 9% slope, 22.1m long.

C: Crop/management factor (-).
A combined factor to account for the effects of vegetation cover and management techniques. These reduce the rate of soil loss, so in the worst case when none are applied, C = 1.0, while in the ideal case when there is no loss, C would be zero.

P: Conservation practice factor (-).
The physical protection factor to account for the effects of soil conservation measures.

The model parameters were calculated from a defined set of natural and management conditions in the United State of America (US). However recent data show that the USLE can be applied also to a wide range of tropical soils and corrections can be made for most other soils (Nill, 1993). The most urgent need exists now is obtaining reliable data on tropical cropping systems.

The USLE was designed to predict long term annual soil loss from a given slope under specified land use and management conditions (Wischmeier, 1976). It can be used for a watershed, if these are subdivided into smaller units where the SLE factor applies (Nill et al. 1996). This idea has been applied in this study where the Turasha watershed / catchment has been divided into terrain mapping unit (TMU).

The USLE has some limitations in terms of its universal application to many areas outside US. The factors are universal but the values are not. The equation can only predict interrill and rill erosion, but not gully, channel, stream bank or mass erosion. It estimates the movement of soil particles and does not consider deposition and it was designed to model long term erosion rates, not storm based erosion. Since its development, a lot of research has been done to modify and calibrate some of the parameters of the equation to meet regional needs.

3.7.3 SLEMSA - (Soil Loss Estimation Method for Southern Africa) model.

According to Elwell (1981), the structure of the model is similar to that of USLE. Four physical systems are recognized; crop, climate, soil and topography. Tillage or management effects on the soil are accounted for in the soil system. The model is divided into three submodels, 1) reflecting crop ratio, 2) a combination of soil erodibility and rainfall energy representing the soil loss from bare field of standard topography, and 3) a

topographic ratio (see Figure 22). For each submodel a nomograph is developed. The soil loss is assessed by combining the results of the submodels through a final nomograph.
The limitation is that the model was developed for the conditions in Zimbabwe for a limited period of time and on a limited amount of research.

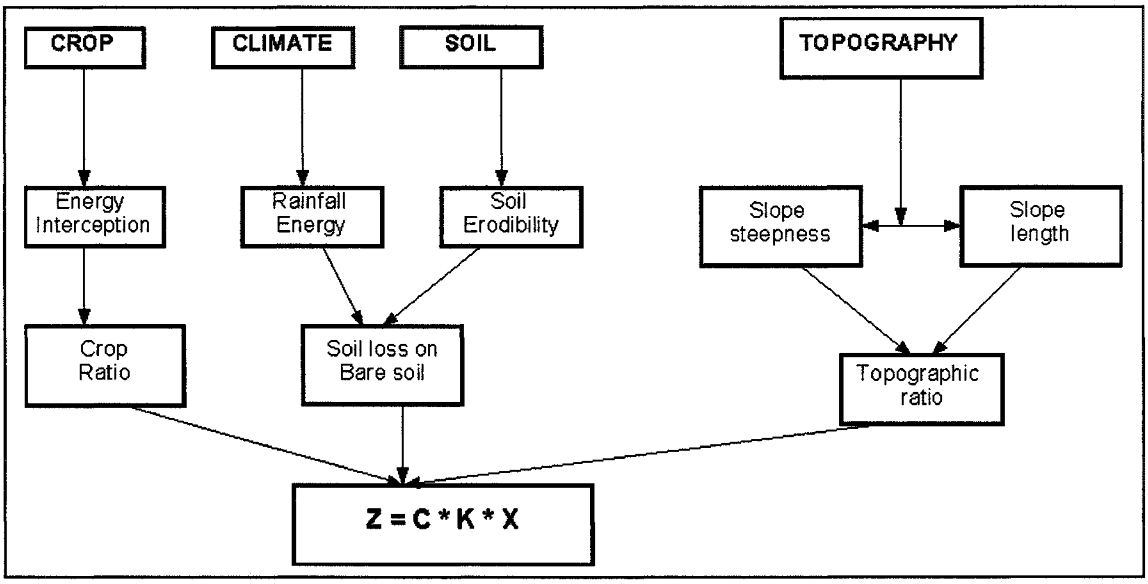

Figure 22: Frame work of SLEMSA (Source: after Stocking et al., 1988).

3.7.4 SOTER (SWEAP Program).

SOTER refers to Global and National Soils and Terrain Digital Database. SWEAP (Soter, Water Erosion Assessment Program) is a computer programme based on the SOTER database. The aim of the SOTER project is to utilize current and emerging information technology to establish a World Soils and Terrain Database, containing digitized map units and their attribute data. The main function of this database is to provide the necessary data for improved mapping and monitoring of changes of world soil and terrain resources (Engelen and Wen 1995).

The basic data source for the construction of SOTER units are topographic, geomorphological, geological and soil maps at a scale of 1:1 million or larger - mostly exploratory and reconnaissance maps based on FAO-Unesco Soil map of the World Legend (FAO, 1988). The SWEAP uses the modified USLE and SLEMSA models. The geometric database contains information on the delineations of the SOTER unit as shown in Figure 23.

With the SOTER data base a lot of erosion risk map for various countries can be prepared. However, soil erosion modelling needs field survey and not just office work. Also units / scale used in SOTER database are very large / small (1: 1,000,000), and thus only produce generalized findings.

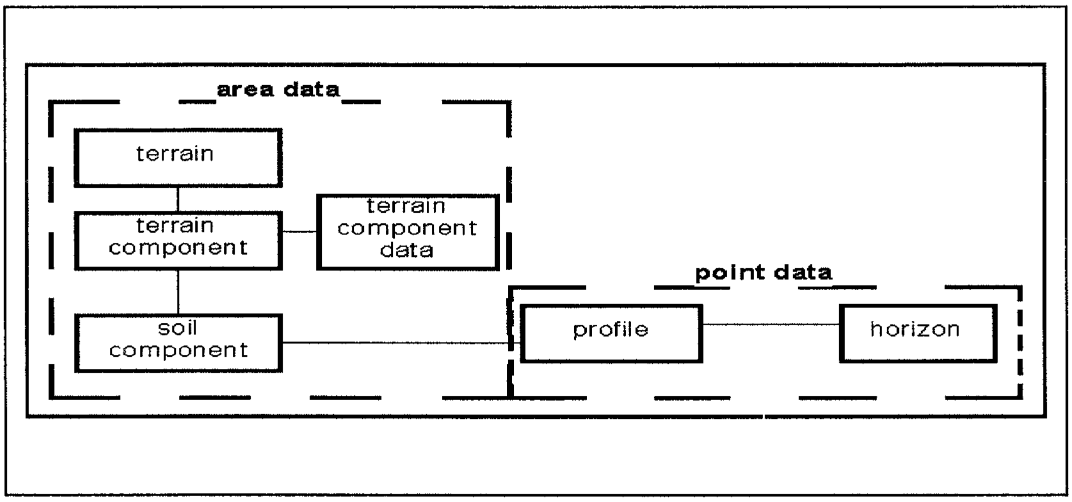

Figure 23: SOTER attribute database structure with area and point data. (Source: Engelen and Wen 1995).

3.7.5 AgNPS v5.0

This is an Agriculture Non – Point Source Pollution Model. The AgNPS erosion and runoff water quality model, like other spatial distributed environmental models such as hydrology, erosion deposition and water quality models, relies on a cellular or grid structure to capture the landscape (Young 1994). The model extracts topographic variables and land surface characteristics from basic GIS data layers such as contour, drainage lines and watershed boundaries. The input maps are rasterized and map algebra, spatial filtering and neighbourhood operations in ILWIS are used. The catchment is divide into cells depending on the user-defined grid and numbered from the northwest corner from west to east in southward direction.

Outline of the method / procedure to run AgNPS.

1. Display input data – contour, drainage and boundary maps (2) Polygonize and rasterize input maps (3)Creating digital elevation model of the study area (4)Grid overlay and unique cell numbering. (5)Aggregation model inputs (6)Creating a linking table (7)Creating a slope length map (8)Creating a slope shape map. (9)Creating a channel indicator table (10)Creating a channel length and gradient map. (11)Determining the final unique cell map of the watershed (12)Determining the channel indicator map (13)Redefining the input variables according to the final unique cell map (14) Running the conversion program (15)Running AgNPS (Mannaerts et al., 1998).

3.7.6 CREAMS model.

CREAMS – (Chemical, Runoff and Erosion from Agricultural Management Systems) is a field scale modal, developed in the USA, to assess non-point source pollution and to investigate quantitatively the environmental consequences of different agricultural practices (Knisel 1980). The modal consist of three components: hydrology, erosion and chemistry. According to Foster and Meyer (1972), the erosion component applies the continuity equation for sediment transport down slope in the form of:

DQs / dx = Di + Dr

Where: Qs = sediment load per unit width per unit time
x = distance down slope
Di = delivery rate of particles detached by interrill erosion to rill flow
Dr = rate of detachment or depositional by rill flow.

3.7.7 GUESS Model.

This model provides a continuous analytical solution of erosion / deposition processes by relating sediment flax to its causative factors. It can be used for approximating enrichment ratios and nutrient losses (Roose, 1989).

3.8 Definition of Terminologies.

3.8.1 Agro-Ecological Zone (AEZ) – The division of an area of land into smaller units, which have similar characteristics related to land suitability, potential production and environmental impact.

3.8.2 Agroforestry - is the integrated land use that involves deliberate retention or admixture of trees and other woody perennials in spatial or temporal association with crop or grazing land-land to benefit from the natural ecology and economic interactions.

3.8.3 GIS – Geographical Information System, which According to Lillesand et al. (1994) is a system of hardware, software, data, people, organizations, and institution arrangements for collecting, storing, analysing, and disseminating information about areas of the earth.

3.8.4 Land degradation - FAO \ UNEP (1982) define soil degradation as a broad term that refers to a deminition of the soil current and \ or potential capacity to produce qualitative and \ or quantitative goals or services as a result of one or more degradation process.

Lal and Stewart (1990), define soil degradation as an outcome of depletive human activities and their interaction with natural environments.

3.8.5 Rain erosivity - According to Bergsma et al. (1996) is the potential ability of rain to cause erosion due to its kinetic energy and volume.

3.8.6 Remote sensing - is the science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by device that is not in contact with object, area, or phenomenon under investigation (Lillesand et al. 1994).

3.8.7 Soil - Soil is the transformation product of mineral and organic substances on the earth's surface under the influence of environmental factors operating over long time and having defined organization and morphology. It is the growing medium for higher plants and basis of life for animals and mankind. As a space-time system soil is four-dimensional (Gething 1984).

3.8.8 Soil erodiblity - is the resistance of the soil to both detachment and transport by the eroding agent. According to Imeson (1985), soil erodibility is the inherited susceptibility of a given soil to erosion by water, the response of soil to impacting raindrops and slope-wash process.

3.8.9 Soil erosion - According to Bergsma et al. (1996) is the detachment and movement of soil from the land surface by wind or water in conditions, influenced by man.

3.8.10 Soil erosion hazard map is the erosion map showing the sensitivity of the land to the prevailing agent of erosion, or the rate of soil loss expected in future.

3.8.11 Soil susceptibility - which sometimes is called also **erosion risk** or **potential risk** is the loss expected under the influence of rainfall, relief, soil and present conditions of erosion, in the absence of plant cover and control practices, that is on bare land, ploughed up-and-down the slope.

CHAPTER 4.

4. MATERIALS AND METHODOLOGY.

Activities were divided, depending on the nature of tasks to be undertaken into three main phases. The first one concerned pre-field activities, followed by fieldwork and lastly the post fieldwork phase.

4.1 PRE-FIELD ACTIVITIES.

4.1.1 Collection of the existing information of the study area and selection of the sample area.

Search and review of relevant literature and satellite image and aerial photo interpretation were the main tasks. Proposal writing included problem formulation, objectives, hypothesis, location, geology, soils, climate, land cover. Also literature citation referring to previous studies of soil erosion and conservation with other important explanations and terminologies were the main focus of the proposal.
Interpretation of aerial photographs covering the study area was carried out according to geo-pedological approach (Zink 1988). This resulted in an aerial photo-interpretation (API) base map of the study area at the scale of 1: 50,000 with preliminary legend, which was used for fieldwork planning.

Based on this map, sample areas were selected showing different landscapes, erosion patterns, landuse and accessibility.

Advanced lectures and computer programmes were taught which would help in data collection and then analysis, interpretation and thesis write up.

4.2 FIELDWORK.

4.2.1 Reconnaissance

During the first two days trips were made around Lake Naivasha and the northern catchment. Subsequently a one day reconnaissance survey was carried out in the study area for familiarization, orientation and location of the sample areas.

4.2.2 Soil survey procedures.

As existing soil information of the study area was insufficient to comprehend the erodibility of the soils, additional soil data were collected along sample transacts. These were located on the API map for a detailed study of the sample areas. Mini-pits were dug till 50cm to establish master and diagnostic horizons. The following properties were recorded:- thickness of surface horizon, colour, structure, texture, pH, presence of concretions and mottles according to FAO guidelines (FAO, 1990). At the bottom of the mini pits, an auguring was made to describe such properties like colour, texture and pH till a depth of 170cm if possible. A special data card was used to record all soil properties and the site characteristics. The latter included topography, vegetation cover / land use, stoniness, rock outcrop, drainage and groundwater table. Soil samples were taken from 0 – 20cm from a number of observation points for the analysis of organic carbon percentage (C%) and texture, to be used in the calculation of soil erodibility determination. Previous soil classification according to FAO (Rachilo, 1978) was used and supplemented with field checks for added map units.

Cross sections were made perpendicular to the contour (topo-sequence) to check the variation in soils and its properties (see Figure 24). Undisturbed ring samples were collected from 0-20cm for the determination of pF curve.

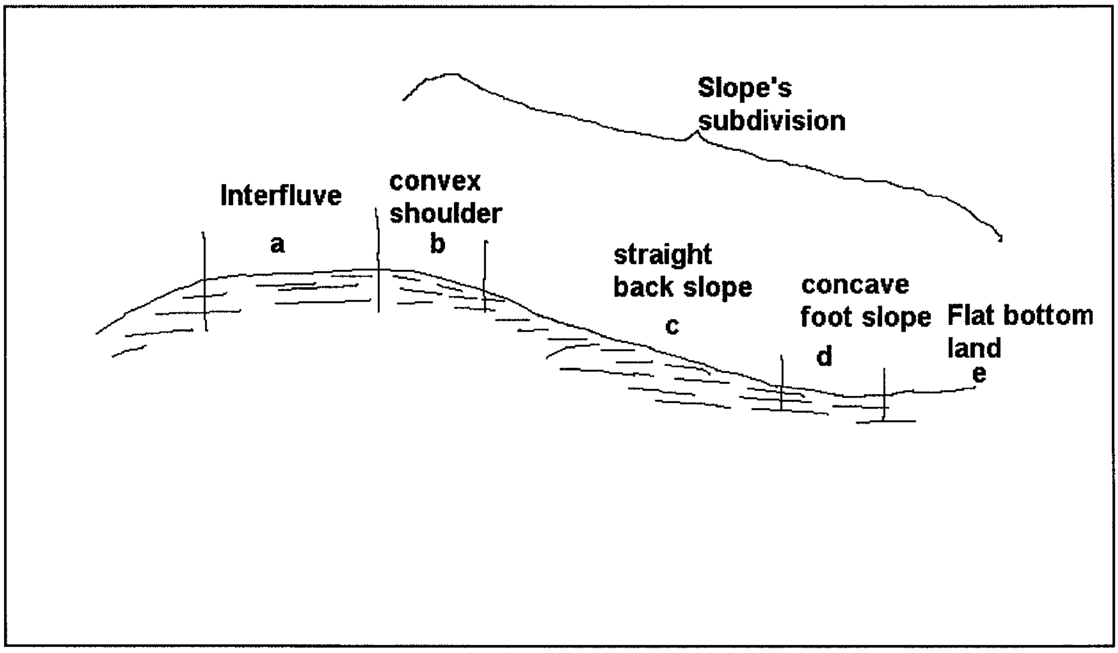

Figure 24: Representative of the cross section of the major landform in the study area.

4.2.3 Land use / cover.

The visual interpretation of AP's and satellite images was supplemented by field data. The land cover / land use was identified and described according to FAO guidelines. Observation of current landuse included the kinds of crops, cropping pattern and conservation practices. From literature review and personal communication, the history of landuse, the landuse changes and land tenure systems were recorded.

4.2.4 Topography.

The topography concerned the height differences and the slope properties. The later are of special importance in erosion studies as overland flow is governed by them. As length of slope on the topomap is not necessary the length of overland flow, special attention was given to this factor. In additional slope gradient, slope form and slope aspects were recorded. Steepness and slope length (overlandflow production length) were measured by using a clinometer and pace-factor or tape measure respectively.

4.2.5 Rainfall data.

Rainfall data were collected from different stations (see Figure 12 and Table 7). Rain erosivity was determined by using the regression method of Brech (1993) as shown in para 3.4.1.

4.3 POST FIELDWORK.

4.3.1 Soil sample analysis.

Soil samples were analysed for an organic carbon content, texture (particle size distribution) and water holding capacity (pF – curve) according to laboratory methods by the Kenya Soil Survey (KSS, 1975).

4.3.2 Digitizing maps and data base creation.

The aerial photo interpretation base map was verified and improved during the field survey, and then geo-referenced and digitized at the scale of 1: 50,000 by using ILWIS 2.2 software. Other maps such as location, roads, geology, landscapes and drainage were also prepared.
All the field and laboratory data were computerized. The soil database was structured in such a way to allow each soil erosion parameter map to be direct linked to attribute table (non spatial), in order that calculations, and querying could be performed interactively and quickly.

4.3.3 Erosion prediction model.

To predict soil loss (erosion hazard), the Universal Soil Loss Equation - USLE (Wischmeier and Smith, 1978) was applied. Input requirements and its measurements are described critically under the literature review (para 3.4 and 3.7.2). The maps of erosion hazard and erosion susceptibility are produced by linking erosion parameters such as erodibility, slope length and steepness, land cover/use and supporting practices, as shown in Figure 25.

4.3.4 Thesis writing.

Data analysis and interpretations were carried out concurrently with the thesis write up using Microsoft Word and Excel programmes. Discussions of the soil hazard assessment for soil loss, erosion susceptibility, and hazard and validation of the USLE model when compared with field evidence are presented.

4.4 Materials and tools.

The following materials were used: aerial photographs (1: 50.000), geological map (1: 50,000), topographical map (1: 50,000), existing soil maps of Kenya (1:1,000,000) and of the Kinangop area (1:100,000), Munssel colour chart, transparencies, sampling bags and writing materials (notebook and pencils) and labels.

The fieldwork tools included: GPS, compass, clinometer, surveyors tape (50m), pocket mirror stereoscope, pH meter, camera, knife, geological hammer, auger, spade and hand hoe.

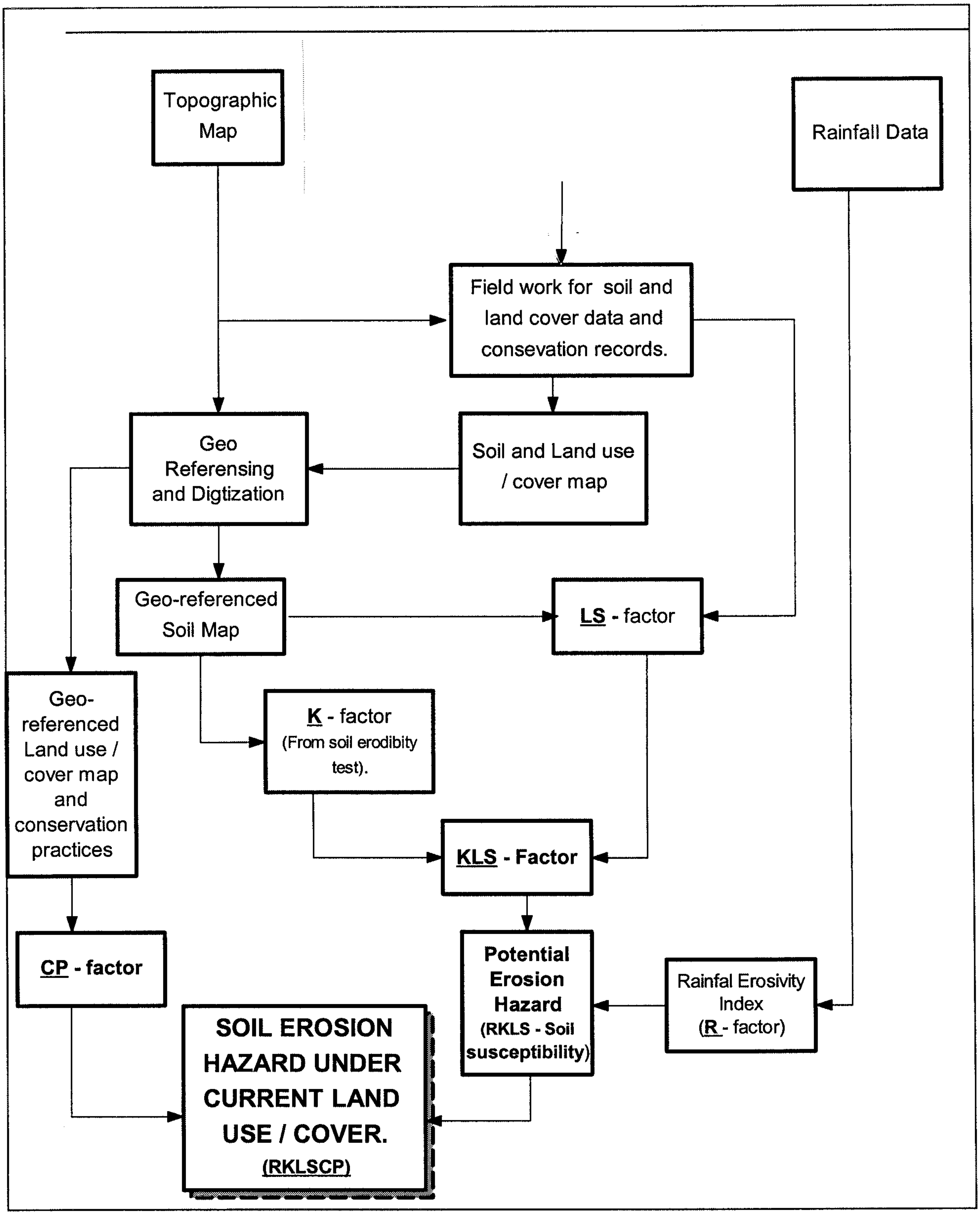

Figure 25: Chart flow of the activities leading to the production of Erosion Hazard Map.

CHAPTER 5: RESULTS & DISCUSSION.

5.1 Introduction.

Although time for the fieldwork was only three weeks, a good preparation before going to the field enabled the collection of necessary secondary data. The study area is typically rural with unreliable roads especially during rain season, which makes access difficult. However enough data have been collected to enable the assessment of soil erosion in Turasha catchment for input to the USLE (Universal Soil Loss Equation). The model is designed in such a way that it can predict long term annual soil loss from a given slope under specific land use and management conditions which make it very effective model if the catchment is divided into map unit. Input data for that model, how to obtain them and the model's equation **(A = R*L*S*C*P)** are discussed in the literature review (see para 3.4 and 3.7.2).

5.2 Soils of the study area.

Figure 26 shows the soil map of the area. The general pattern of the soils is related to the topography and parent material. On flat areas, Planosols are found mainly, which have imperfect to poor drainage. These soils have a clay pan subsoil with a bleached and coarser topsoils. On sloping ground better-drained soils are found, consisting of Andosols, Phaeozems and Luvisols according to FAO/UNESCO legend (1974). Gleysols were found on wet botttomlands.

Major soils occur intensively in the study area include Dystric Planosols which covers map units Pu111, Pu112 and Pu113 an area of 31.280ha (about 50% of the total area of the catchment). They are described as silty clay loam to clay. They are imperfect to poorly drained, deep (80 – 120cm) dark grey brownish to very dark brown. They have bleached E horizon (due to eluviation) and subsoil of clay accumulation.

Mollic Andosol occur in map unit Mo111 and occupy an area of 8.606ha. They are dark reddish brown, clay loam to clay, generally well drained, in places shallow to moderately deep and rocky. In places (patches) AC profiles development and classified as Lithosols.

Ando-ferric Acrisol occur in map unit Pi111 and occupy an area of 6.743ha. The unit has topsoil colour varies from very dark grey to very darkish grey brown and the subsoil is dark reddish brown. The unit is clayey in texture and has at some depth (approximately 80cm) a layer of iron-manganese concretions. The structure is weak, fine and medium subangular blocky. The soils are well drained and deep to very deep.

Orthic Luvisols occurs in map unit Pi112 (occupy 922ha) has black topsoil and dark reddish brown subsoil. The topsoil texture is silty loam to silty clay loam and that of the subsoil is clay loam. The soil structure is moderate, fine, medium and coarse angular blocky. The soils are well drained and deep.

Eutric Gleysol occur in map unit Va111 and covers an area of 8.382ha The soils are imperfectly drained, Deep with dark greyish brown and greyish brown topsoil colour. The structure is strong, fine, medium and coarse angular blocky. The topsoil texture ranges from silty clay loam to clay and that of the subsoil is mainly clay.

Table 18: Legend of the Geopedological map.

Landscape (level 4)	Relief (level 3)	Lithology (level 2)	Landform (level 1)	Soil type FAO/UNESCO – 1974.
Mo Mountain	Mo1Monocline	Mo11 Basalt	Mo111 Slope complex	Mollic Andosol
Pi Piedmont	Pi1 Glacis	Pi11 Colluvium of basalt	Pi111Middle slope	Ando-ferric Acrisol
			Pi112 Lower slope	Orthic Luvisol
	Pi 2 Hill	Pi21 Trachytes	Pi211Upper slope	Vertic Luvisol
Pu Plateau	Pu1 Slightly dissected plateau.	Pu11 Pyroclastic and tuff.	Pu111 Flat interfluve	Dystric Planosols
			Pu112 Low scarp	Dystric Planosols
			Pu113 Convex upper slope	Dystric Planosol
			Pu114 Straight backslope	Calcaro-pellic Vertisol
			Pu115 Concave footslope	Calcic Luvisol
		Pu12 Vitric pumice and tuff.	Pu121 Slope complex	Humic Andosol
Va Valley	Va1 Highly dissected.	Va11 Colluvium / Alluvium	Va111 Narrow Bottomlands	Eutric Gleysol
			Va112 Wide bottomland	Mollic Andosol

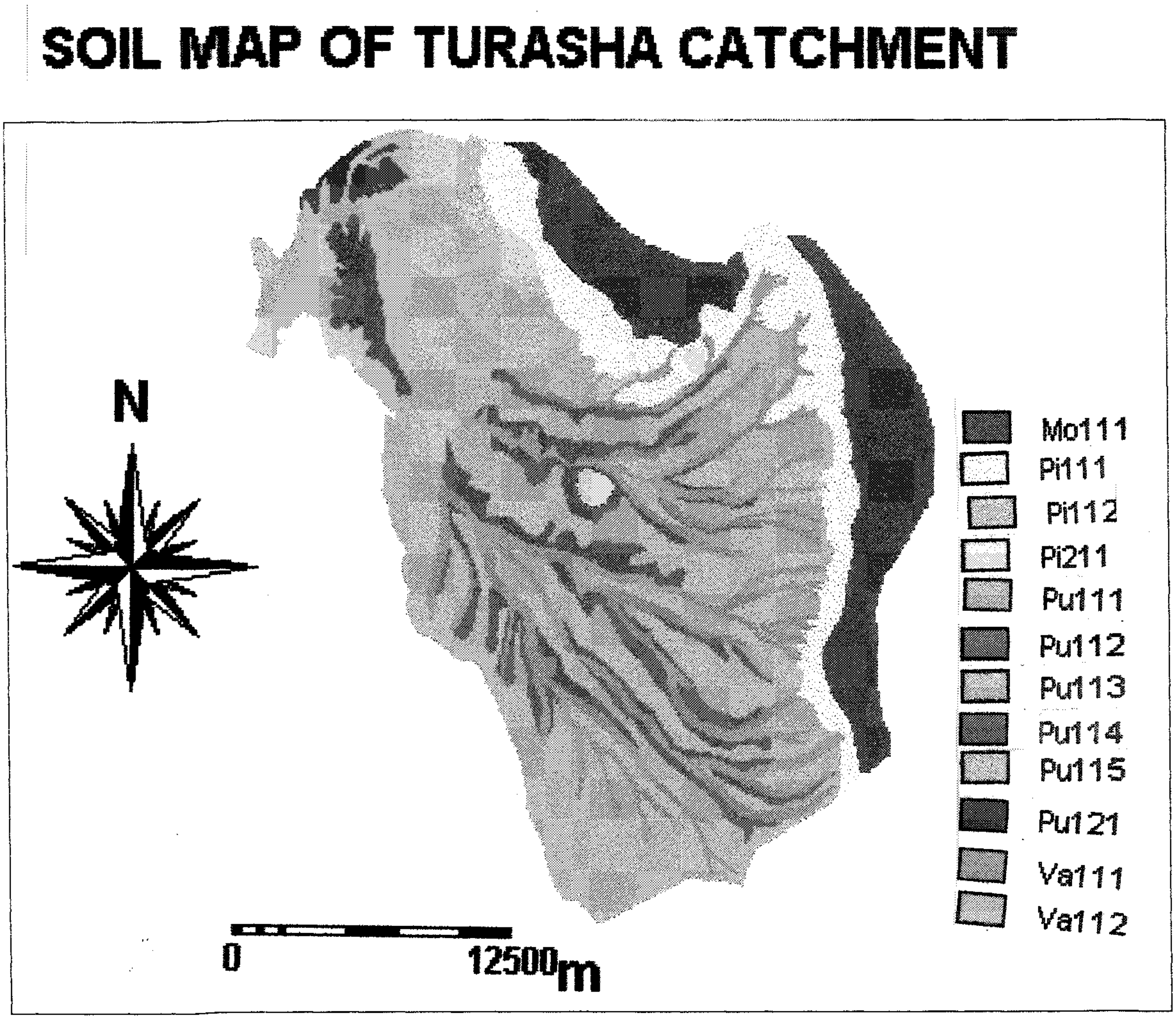

Figure 26: Soil map of the study area.

5.3 Assessment of USLE factors.

Data on the rainfall erosivity index (R), erodibility (K), slope factor (LS), land use/cover (C) and land management (P) are analysed, summarized in Tables / Figures and then discussed.

5.2.1 Rainfall erosivity index - R.

Bared on Table 7 on rainfall data and Figure 12 of the rainfall stations, the study area can be divided into two parts regarding the climatic conditions. These are eastern part, which receives an average annual rainfall of 1167mm and a western part with an annual rainfall of 788mm. Figure 27 shows the average monthly rainfall from Njabini Rural Training Centre (east) and Malewa scheme (east). The characteristics of the rainfall show that the monthly rainfall is above 50mm through out the year, which may ensure the presence of vegetation all the time. This means that even during heavy storms no erodible material is available for transport due to the vegetation cover. In the eastern part more erosion may be expected during the first rainstorm after a long dry spell (from October to March) as most of the vegetation may be depleted aided by overstocking. This is supported by the investigations which showed that soil loss is largely determined by rain volume, energy load, intensity and their distribution within single storms (Flanagan et al. 1988) and during annual seasons (Lal. 1990). After some time as rainfall continues, vegetation will regenerate once more and even under heavy storms little or no soil sediments may be available for erosion due to vegetation cover. Nill et al. (1996) observed that at the beginning of the wet season in a tropical climate, the first rains produce more erosion because there is much loose dry soil material available at that time on the land surface which can be washed away.

The recommended method for calculating the erosivity index is by using the equation of Wischmeier and Smith (1978):

$R = (E.I_{30})/100$ .... **(1)**

Where R = rainfall erosivity index, E = rainfall kinetic energy (mt/ha/cm rainfall); and I_{30} = maximum 30 minute rainfall intensity (cm/h). The kinetic energy was derived from the measurements of rainfall intensity observed over an incremental time period of 30 minutes applied to equation:

$E = 210.3 + 89 \log I;$ .... **(2)**

Where:

I = rainfall intensity (cm/hour),

E = value is obtained from an automatic raingauge.

However it is very difficult to obtain this type of data from raingauges in many African countries, so other method of estimating erosivity should be sought. Although ITC installed automatic raingauge in the study area, these cannot be used for the moment because they only recorded rainfall of three months, which is not sufficient to calculate rain erosivity accurately.

The erosivity regression equation suggested by Bresch (1993) for the Kenya hinterland at an altitude over 1250m was used in this study. The equation stated that:

$\mathbf{EI_{30} = 0.269 * P_{ann} + 113}$ **(N/h)**.. **(3)**

Where: P_{ann} = annual average rainfall.

N/h = Newton / hour.

By applying equation number (3) the following values are obtained:

i). Rain erosivity of the eastern part of the area (Piedmont and Mountains).
Total annual average rainfall = 1167mm.

$EI_{30} = 0.269 * P_{ann} + 113$ (N/h)
$EI_{30} = 0.269 * 1167 + 113 = 427$(N/h) .... (4)

The eastern part covers the following map units; Mo111, Pi111, Pi112, Pi211, Pu111, Pu112, Pu115 and Va111.

ii). Rain erosivity of the western part of the study area (Plateau and lower Valley).

Total annual average rainfall = 788mm:
$EI_{30} = 0.269 * P_{ann} + 113$ (N/h)
$EI_{30} = 0.269*788 + 113 = 325$(N/h) .... (5)

The western part covers the following map units: Pu325, Pu114, Pu115 and Va112.

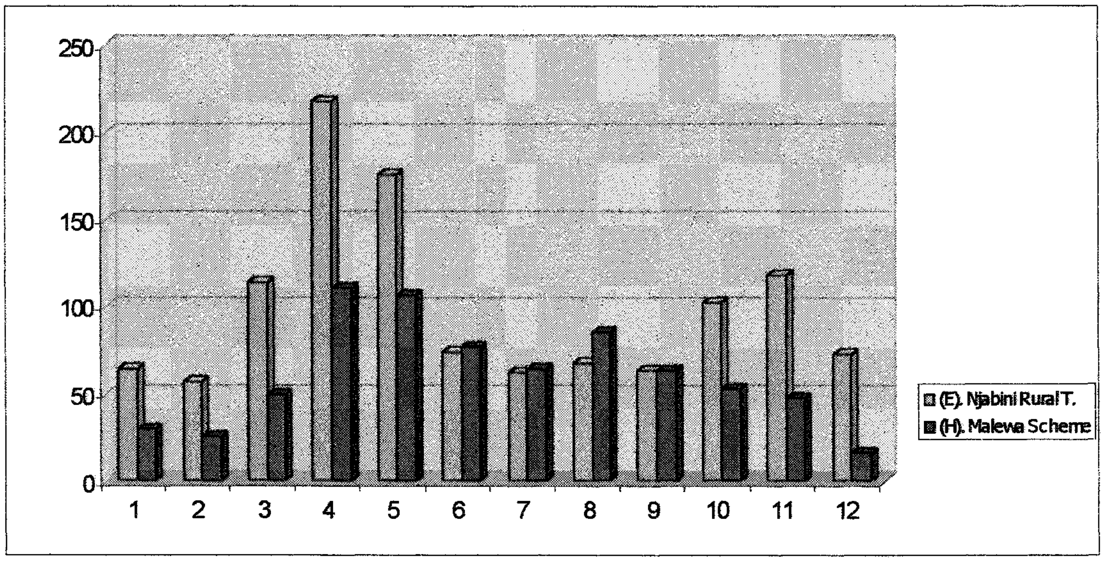

Figure 27: Monthly rainfall variation between east (Njabini) and west (Malewa).

5.1.2 Soil erodibility factor.

Soil erodibility is the susceptibility or vulnerability of soil to erosion (Hudson, 1986). The higher the K the easier the soil to erosion. The soil erodibility was calculated on the basis of topsoil properties, namely textures, structure, organic matter, and permeability. Wischmeier and Smith (1978) established a regression equation or nomograph for the parameters to estimate K value in a given soil in which K value is not known. Their regression equation is given as: -

K = 2.8*10^{-7} M$^{1.14}$*(12-OM)+0.043 (SC-2) + 0.033*(4 – PC) .... (6)

Where M = (%silt+%very fine sand)*(100-%clay),
OM = % organic matter (%OC*1.72),
SC = structure code,
PC = permeability code.

The equation shows that soil erodibility increases with increasing silt plus very fine sand content of the soil. It decreases with increasing clay and organic matter content. By using the normograph shown in Figure 18, K values were determined and put in Table 19.

Table 19: Erodibility factors and soil properties from which it was derived.

S.N	SMU	% Sand	% Silt	% Clay	Tex-ture	% Carbon	OM %	Permeability code	Structure code	K
1	Mo111	33	39	28	CL	5.5	9.8	5	3	0.19
2	Pi111	20	40	40	SiCL	3.3	5.80	4	2.5	0.14
3	Pi112	30	52	18	SiL	5.5	9.60	3.5	2	0.23
4	Pi211	22	48	38	CL	5.5	5.00	5	3	0.20
5	Pu111	21	37	42	C	1.8	3.13	6	3	0.24
6	Pu112	28	44	28	CL	3.44	6.00	5	2	0.21
7	Pu113	8	54	38	C	3.16	5.50	6	3	0.26
8	Pu114	24	24	52	C	1.6	2.78	6	3	0.18
9	Pu115	24	32	44	C	1.3	2.27	6	3	0.21
10	Pu121	22	42	36	CL	2.8	4.80	5	3	0.20
11	Va111	38	30	32	CL	1.6	2.80	5	3	0.18
12	Va112	30	22	48	C	2.65	4.60	6	3	0.17

Dangeler and El-Swaify (1976) rated the K-values into six classes;

The results of erodiblility values were classified according to Dangler and El-Swaify (1976) and put in Table 21.

Table 20: Rating of K values.

CLASS	RANGE	MEAN
Very low	0.00 – 0.10	0.05
Low	0.10 – 0.20	0.15
Moderate	0.20 – 0.32	0.26
Moderate high	0.32 – 0.43	0.37
High	0.43 – 0.55	0.49
Very high	0.55 – 0.64	0.61

Source: Dangler and El-Swaify (1976).

Table 21: Rating of K – value according to Dangler and El-Swaify (1976) and areas they occupy.

	M.U	K	Area	%	K - Class
1	Mo111	0.19	8605.7	13.6	low
2	Pi111	0.14	6742.8	10.7	low
3	Pi112	0.23	921.9	1.5	moderate
4	Pi211	0.20	333.2	0.5	moderate
5	Pu111	0.24	25265.2	4.0	moderate
6	Pu112	0.21	5555.6	8.8	moderate
7	Pu113	0.22	458.8	0.7	moderate
8	Pu114	0.18	1080.5	1.7	low
9	Pu115	0.21	456.6	0.7	moderate
10	Pu121	0.20	572.9	0.9	moderate
11	Va111	0.18	8381.8	13.3	Low
12	Va112	0.17	4823.6	7.6	low
			63198.6	**100**	

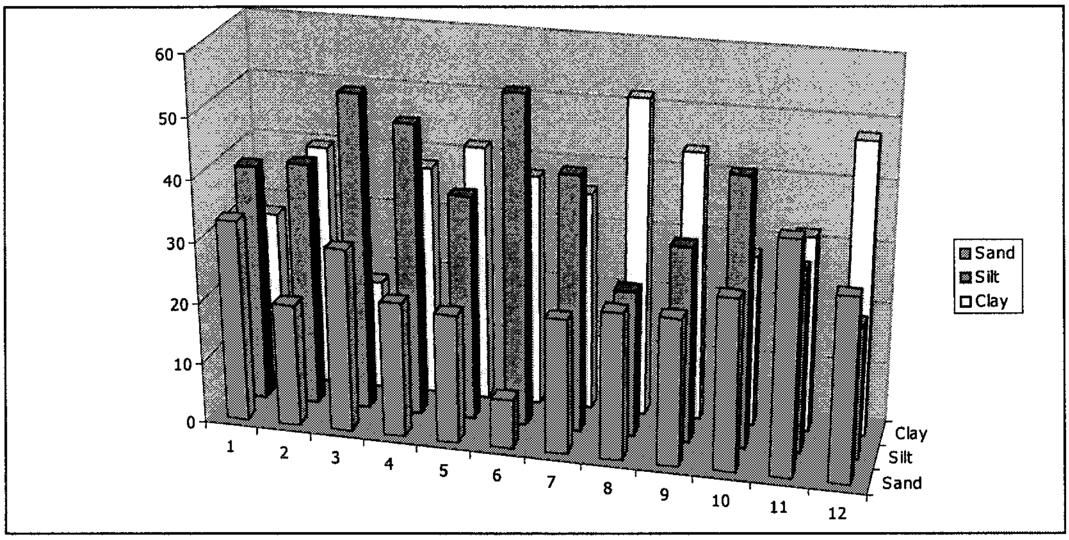

Figure 28: Grain size distribution (sand, silt and clay).

The above result in Table 21 shows that soil erodibility in the study area has a narrow range in variation: low to moderate erodibility according to the classification of Dangeler and El-Swaify (1976). Mapping unit Pi111 has the lowest erodibility (0.14) because of the relative good permeability and structure, while mapping unit Pu113 has the highest K (0.26) due to high silt percentage (54%). Generally, soil erodibility in the study area is not high because of the soil texture, which has relative high clay content (>30%) – see Figure 27. According to Evans (1980), soils with clay content ranging from 9 – 30% exhibits high K values compared to those with high clay content. High organic matter percentage (> 4%) contribute to low K values as commented by Nill et al. (1996); the higher the organic

matter percentage, the lower the erodibility. Organic matter together with clay act as a binding material to make strong aggregates which can withstand detachability from raindrops. However the increase of organic matter in this study does not show the expected results (the higher the OM% the lower the K). Wischmeier and Mannering (1969) commented the importance of SOM in lowering K values it decreases with the increasing clay content. Generally the clay content in the study area is relative high. To summarize, soil organic matter and clay reduces soil erodibility due to the raindrop energy which has to overcome the adhesive or chemical bonding forces by which the minerals comprising clay and SOM particles are linked.
A correlation between texture and K value shows positive correlation with silt content by 60%, which mean the higher the silt% the higher the erodibility. Silty soil material exhibit weak structure, which tends to slake easily upon rainfall impact and form a seal. Sand and clay content showed weak negative correlation of 49% and 23% respectively which means the higher the sand and clay content, the lower the K values. The large pores between sand particles permit rapid water movement and reduce sealing which in turn reduce soil erosion.

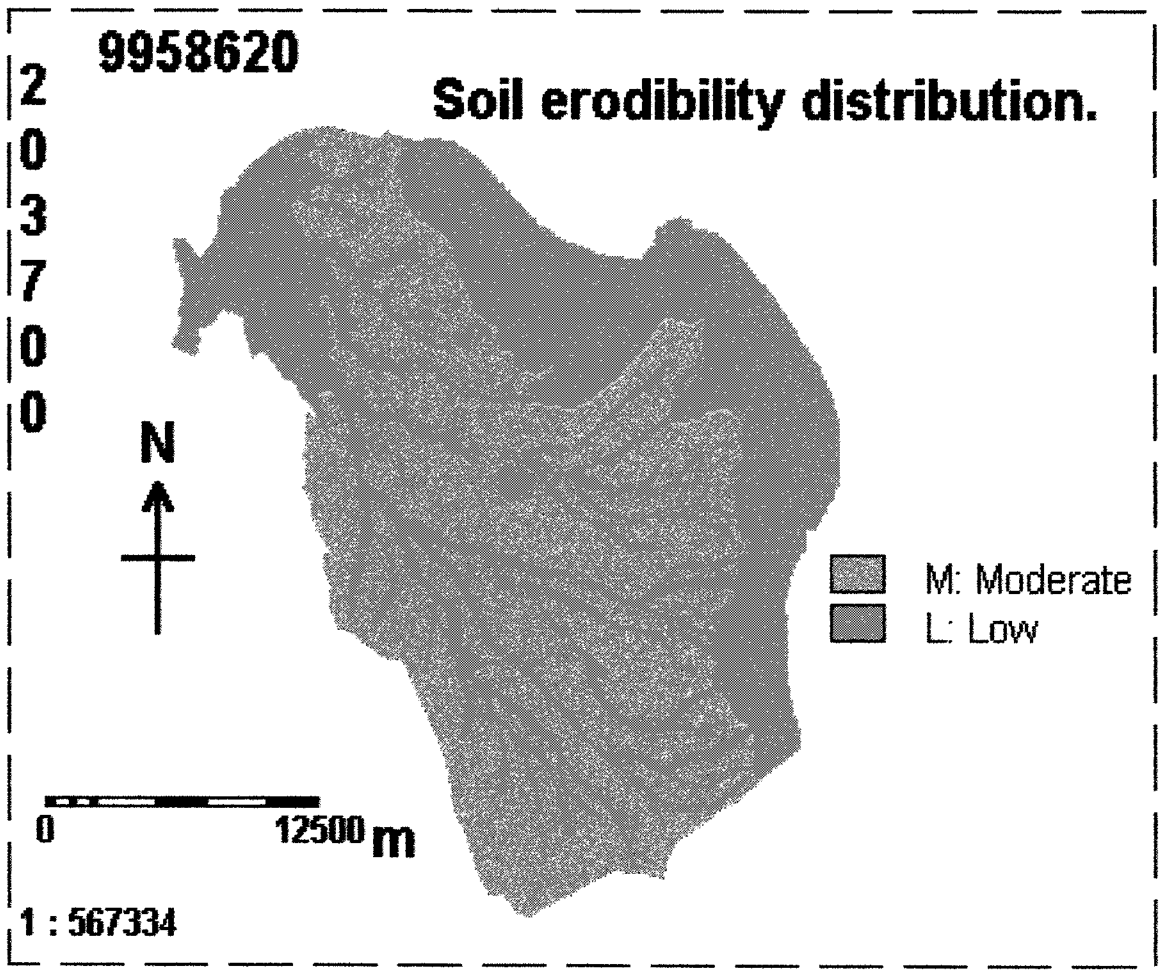

Figure 29: Soil erodibility distribution in the study area.

5.1.3 Topographic factor - LS.

Slope length in USLE is defined as the distance from the point where the runoff begins to the point where deposition occurs or where runoff enters a well-defined channel (Wischmeier and Smith, 1978). The combined topographic factor (Length*Slope - LS) allows to adjust soil loss on a given slope length, gradient and slope form to that of the control point (slope of 22.1 long and gradient of 9%). It is calculated by Wischmeier and Smith (1978) equation:

$$LS = (l/22.1)^m * (65.41 * \sin^2\alpha + 4.56 * \sin\alpha + 0.065) \quad (7)$$

With "l" - slope length (m)
"m" - slope length exponent(-)
"a" - gradient (°)

The slope length exponent (m) depends on the gradient and is smaller for gentle slopes than for steep slopes. A diagram for the determination of LS factors was used (Figure 30) and the topographic / slope factor was computed and filled in Table 22.

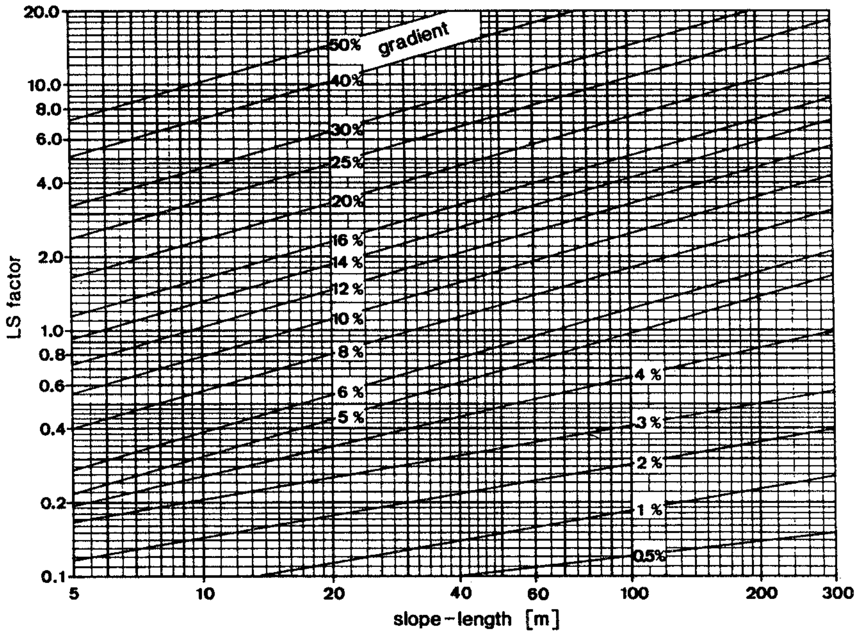

Figure 30: Diagram for the determination of LS factors.
Source: Dissmeyer and Foster (1980) as modified by Schwertmann et al. (1987).

Table 22: Slope factors (LS).

S.N	SMU	Slope % Range	Slope %	Slope length	Slope Factor (LS)	Area	%
1	Mo111	15 to >30	16	5	1.2	8605.7	13.6
2	Pi111	5 – 10	10	30	1.58	6742.8	10.7
3	Pi112	4 – 15	8	55	1.30	921.9	1.5
4	Pi211	2 – 4	3	25	0.27	333.2	0.5
5	Pu111	0 - 2	2	70	0.26	25265.2	40.0
6	Pu112	4 – 8	5	40	0.60	5555.6	8.8
7	Pu113	0 – 2	2	150	0.42	458.8	0.7
8	Pu114	2 – 6	4	95	0.71	1080.5	1.7
9	Pu115	8 – 15	8	43	0.69	456.6	0.7
10	Pu121	2 – 5	4	120	0.70	572.9	0.9
11	Va111	0 – 2	2	85	0.26	8381.8	13.3
12	Va112	10 – 30	16	10	1.60	4823.6	7.6

According to FAO guideline for soil description (1990), about 60% of the study area belongs to the slope gradient classified as flat to gentle undulating (0 – 5% slope) and about 15% is undulating which ranges between 5 – 10% slope. Mapp unit Va112 has the highest value of LS due to the high slope percentage (10 – 30%) while mapping unit Pu111 has the lowest (0.26) because of the lower slopes. Slope lengths (length of overland flow production) are shortened by vegetation and drainage channels or bottomlands. These types of topography have little effect in accelerating erosion due to the short slope length and the relatively low slope percentage values. Runoff volume and velocity increase along the slope and the steeper the slope the more erosion they may cause. An attempt was made to evaluate the topographic factor in some detail for extrapolation to the large area. Figure 31 shows a schematic cross section of the study area and Table 23 shows corrected LS and K along the slope.

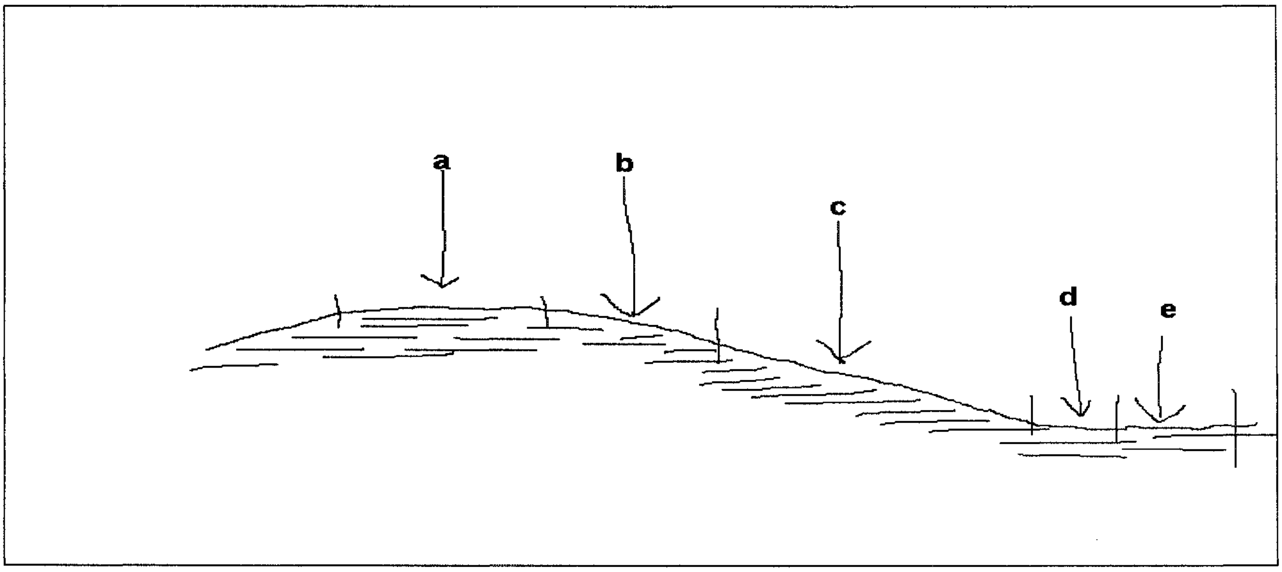

Figure 31: Schematic cross section through map unit Pu111.

Plate 5: Slightly dissected plateau showing vale with drainage channel.

Table 23: Slope with changes of soil erodibility in overland flow production.

Seg-ment	Gradient	Length	LS	Weighting factor	Corrected LS factor	K factor	Corrected KLS factor	Slope form
a	Flat interfluve			-	-	-	-	-
b	5	25	0.6	0.19	0.114	0.18	0.021	Convex
c	4	50	0.52	0.35	0.182	0.22	0.040	Straight
d	2	20	0.18	0.46	0.083	0.15	0.010	Straight – concave
e	Bottom land			-	-	-	-	-
Sum					0.379		0.071	

In flat interfluve (a) slope percentage is 0, in (b), (c) and (d) show slope forms and aggregated LS and K. It shows that overland flow production increase along the slope and weighting factor assigned is increasing downs the slope. Because of the flat bottom valley (e) before reaching the channel ways, it makes even little sediments detached along the slope to be deposited before reaching the channel. The data indicate that erosion increases along the slope which may suggest that, keeping other factors constant, the longer the slope the higher the erosion.

However it was not possible to carry out such details in all the mapping units due to shortage of time and cost which would be incurred to survey the whole catchment.

5.1.4 Land cover / use.

The cover and management factor C of the USLE equation gives the ratio of soil loss on a cropped plot to soil loss on a barefallow control of identical size, slope length, gradient and soil. Soil loss on the cropped plot is subject to changes over the year, which depend on crop growth and management. All in all the protection of the soil surface depends on the amount and quality of the coverage. Both are crop and management specific. However to establish soil loss ratios for different crops and management systems, field measurements are needed which are costly and time consuming.
In order to calculate soil loss for further crops and systems, Wischmeier (1975) proposed to divide the influence of the cropping system into subfactors. He defined sub-factors for:

1. the influence of the canopy cover**(c1)**
2. the influence of mulch or of vegetation close to the soil surface **(c2)**
3. tillage and residue effects of the former vegetation **(c3)**.

The **C** factor is calculated as the product of the three sub-factors: **C = <u>c1 * c2 * c3</u>**
According to Nill et al (1996), for tropical countries, the subfactor method is especially valuable because for many crops no experimentally determined data are available. The problem is further complicated by the fact that in Africa there exists a large variety of small holder system which are difficult to compare to the American standards (e.g hand tillage, mixed cropping, heaping, bedding, etc).

<u>Subfactor c1.</u>

The influence of canopy is calculated by Foster, (1982) as follows:
$C1 = 1 - CC_e * e^{-0.348He}$ (-)
With $CC_{e)}$ ----------- effective canopy cover
H_e ------------- effective height (m).
Subfactor c1 is calculated by using Appendix 1 after of Foster (1982) and Wischmeier (1975) and is presented in Table 24.

<u>Subfactor</u> c2.

The influence of mulch cover (c2) was calculated by (Yoder et al., 1992):

$$\mathbf{C2\ e^{-0.035 * MC}\ (-)}$$

This equation gives a conservative estimate of the mulch effect. Subfactor c2 gives the ratio of soil loss on a cover plot. It is determined from Appendix 2 influence of mulch on soil loss (Nill, 1993). Results are summarized in Table 24.

Subfactor c3.

Not much data are available to determine subfactor c3 for tropical agrosystems which accounts for the residue effect of the previous vegetation (Nill et al. 1996). He suggested an average c3 of 0.8 for the 1st year after forest fallow and 0.4 after grass fallow. A mean c3 of 0.67 for the first 2 years after grass fallow was estimated from data of Kilewa & Mbuvi (1987) by the ratio of erodibility during the first 2 years and erodibility of the 3rd to 5th year.
Nill et al. (1996) estimated an average c3 (residual effect) subfactor for forest, bush and grass vegetation. He suggested value of 0.8 for bush fallow and 0.4 for grass in the first year which can be determine by measuring the time until 10%, 20%, 40% and 60% canopy cover. From the fact that grass is dominating in almost every part in the study area; that value of 0.4 has been taken to be c3.
The obtained C – values were then checked and compared with previous studies (Kooiman, 1987) to see if there is unacceptable value from the field. The C – value for settlement and infrastructures were taken to be 1.

Table 24: Land cover (C-Factor).

S.N	SMU	Land cover / landuse type	Effective canopy cover %	Effective height (M)	Mulch cover %	Sub-factor c1	Sub – factor c2	C
1	Mo111	Forest	95					0.010
2	Pi111	Forest, maize, potatoes, pyrethrum,	90	15	20	0.9	0.2	0.072
3	Pi112	Forest, grazing, maize, pyrethrum, pasture.	90	4	4	0.70	0.83	0.210
4	Pi211	Grazing, maize	90	0.5	5	0.18	0.8	0.057
5	Pu111	Grazing, cereals, beans, trees.	90	0.5	5	0.18	0.8	0.054
6	Pu112	Pasture, maize, vegetables, potatoes, beans, peas	85	0.5	5	0.25	0.8	0.08
7	Pu113	Grazing, peas, potatoes, vegetables.	80	0.5	5	0.18	0.8	0.056
8	Pu114	Grazing, maize, beans, potatoes,	85	0.5	5	0.25	0.8	0.08
9	Pu115	Grazing, peas, potatoes, vegetables.	90	1	20	0.20	0.35	0.070
10	Pu121	Grazing, maize, peas, potatoes, wheat, flower,	85	0.5	5	0.25	0.8	0.08
11	Va111	Grazing, forest.	90	1	10	0.2	0.5	0.04
12	Va112	Bushed grassland, maize, peas.	80	3	2	0.60	0.9	0.22

Generally the land cover in the study is good / high (> 80%). Main land use is grazing (refer para 2.5) with perennial grass cover especially on the plateau. This makes the value of C to be very low (<0.1) in most of the mapping unit except in mapping unit Va112 and Pi 112. Mapping unit Va112 has the highest value of C factor of 0.22 because of the low mulch cover. The mapping unit Mo111 has the lowest estimated C value due to high / closely vegetation cover (forest tree) and mulching beneath the forest trees.

5.1.5 Land management – P.

By definition, the support practices factor (P) is the ratio of soil loss with a specific support practice to the corresponding loss with up-slope and down slope tillage (Renard and Foster 1983). These practices principally affect erosion by modifying the flow pattern, grade, or direction of surface runoff and by reducing the amount and rate of runoff. For cultivated land, the support practices considered include contouring (tillage and planting on or near the contour), stripcropping, terracing and subsurface drainage.

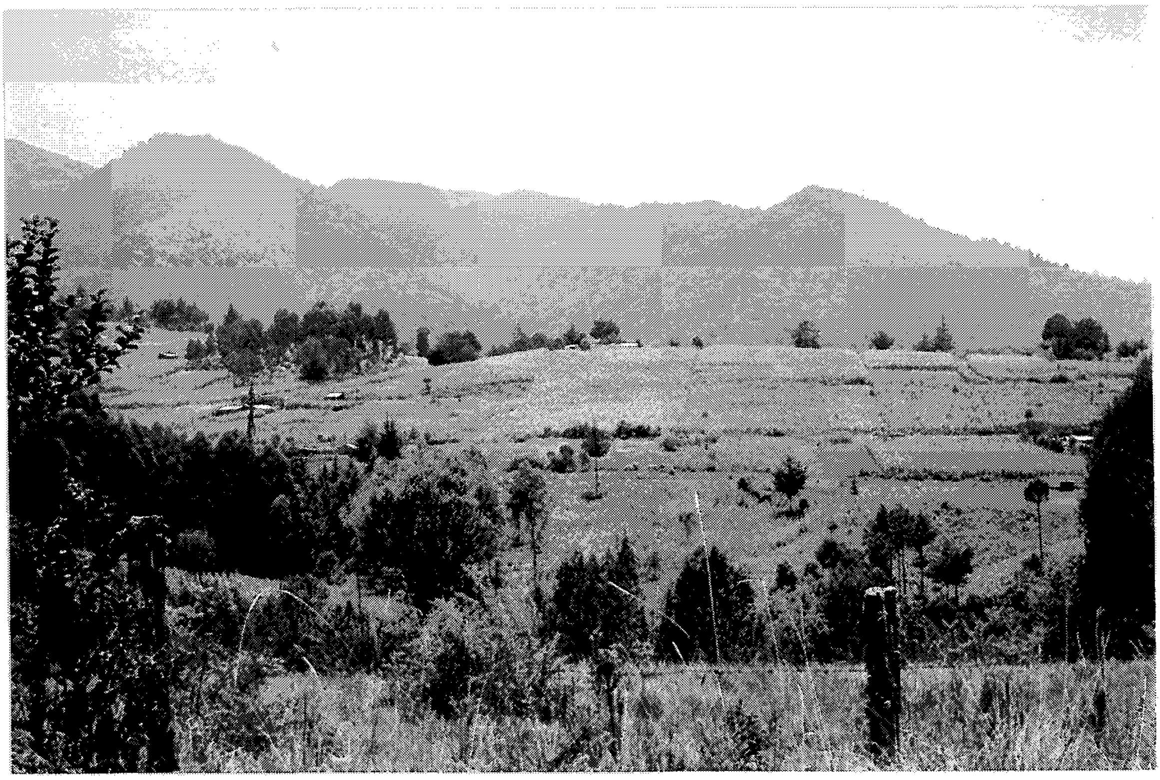

Plate 6: Lower Turasha catchment, dissected plateau with intensive rainfed cultivation even on steep slopes with anti-erosion measures. In the background the forested Kipipiri Hills.

The buffer strips of vegetation are established on the steep slopes in the northwest and in the piedmont landscape of the study area, in map unit Val12 and Pi111. They help to decrease runoff velocity thereby causing deposition of suspended sediment. According to Nill et al. (1996), the efficiency of bufferingstrips depends on the quality of the strip (strip widths, vegetation density), its age and position on the slope. The value of P is estimated from graphs of P factor for buffering of different widths (Schauder and Auerswald, 1992), whereby the width is taken to be 15m and gives the value of 0.56 for P. The rest of the study area there were no such practices so the value of 1 (one) is taken to represent P.
For the steep slopes (>15%), the contour interval should be reduced to 10m or even less than that in order to increase to increase the effectiveness of the contours.

5.2 Soil hazard and potential / susceptibility assessment.

5.2.1 Soil erosion hazard.

Soil erosion hazard or actual soil erosion under the present condition has been predicted by incorporating vegetation cover and conservation practices factors into the USLE equation to obtain the final erosion hazard map. For this purpose, the soil map where tables of the USLE factors are situated (Table 25), has been multiplied, while image slicing was carried out in ILWIS 2.2. The image slicing process produced the soil erosion hazard map (Figure 32) of the study area classified by Bergsma (1986) and is shown in Table 26.

Table 25: Attribute table of soil erosion factors of soil mapping unit.

S.N	SMU	R_1	R_2	K	LS	C	P	A_1	Factor	A_2 - t/ha/y
1	Mo111	427	251	0.19	1.2	0.01	1	0.572	2.24117	1.28
2	Pi111	427	251	0.14	1.58	0.072	0.56	4.048	2.24117	9.07
3	Pi112	427	251	0.23	0.30	0.210	1	4.116	2.24117	9.23
4	Pi211	427	251	0.20	0.27	0.057	1	0.773	2.24117	1.73
5	Pu111	427	251	0.24	0.26	0.054	1	1.500	2.24117	2.04
6	Pu112	427	251	0.21	0.60	0.080	1	2.500	2.24117	5.60
7	Pu113	325	191	0.22	0.42	0.056	1	1.970	2.24117	4.42
8	Pu114	325	191	0.18	0.71	0.080	1	1.950	2.24117	4.37
9	Pu115	325	191	0.15	1.69	0.070	1	4.200	2.24117	9.41
10	Pu121	427	251	0.20	0.70	0.080	1	2.810	2.24117	6.30
11	Va111	427	251	0.18	0.26	0.040	1	0.500	2.24117	1.12
12	Va112	325	191	0.17	1.60	0.220	0.56	6.400	2.24117	14.34

N.B: Units & conversion used:

R_1 = Newton / hour.
R_2 = US unit; 100 ft-ton/acre*inch/hour.
A_1 = US ton/acre / year.
A_2 = Ton/ha / year.
K = US customary units (Us tons/acre) per (100ft-tons/acre*inch/hour).
1US tons/acre/year = 2.24117 ton/ha/year.
1N/hr = 0.587349 100 ft-ton/acre*inch/hour.

Table 26: erosion hazard classes and their area coverage.

Class	Range of soil loss in t/ha/year	Area covered in ha	%
Very low	<5	44.125	70
Low	5 - 12	14.250	23
Medium	12 - 25	4.824	7
High	25 - 60	-	-
Very high	>60	-	-
Total		63.199	100

The study area covers 63,199 ha. Six map units are estimated to have very low erosion hazard (<5t/ha/y), which covers an area of 44.125ha (70% of the study area). 14.250ha are rated as low erosion hazard area (5-12t/ha/y), while 4.824ha are rated as moderate class to erosion hazard. Map unit Va111 and Mo111 have the lowest rate of erosion hazard of 1.28 and 1.12t/ha/y respectively. Map unit Va111 has lowest erosion hazard due to the low value of slope factor (0.28) and vegetation cover (0.04). Map unit Va112 has the highest rate of erosion hazard (14.35), which is contributed mainly by slope factor and relatively poor land cover which result into relatively high C factor. This area is in the western side, which receives relatively low rainfall compared to the east.

It is clear that landuse/vegetation cover and the conservation practices are the most important factor in soil erosion studies. Bergsma et al. (1996) and Moldenhauer and Foster (1981) concluded that, of all hazard factors, cover and management for conservation are the most important ones on the rain erosion hazard because of their great potential for reducing erosion and their influence on the soil cover.

With time, erosion hazard tend to change because of the influence of the vegetation cover, e.g land management and cultivation systems are variable and relative easy to change with respect to growing season, crop rotation etc. Therefore, the erosion hazard map should be reversed in a certain period. Currently the main landuse in the study area is mixed farming with emphasis on grazing by cattle and sheep. However the diversity of the crops in the area and variation in the areas under cultivation indicates that landuse may change with time.

The role of vegetation in surface soil erosion is determined by the effect of ground cover and canopy. Canopy cover reduces erosion by its effect on the amount and kinetic energy of rainfall that reaches the soil surface. With better management the grasslands can protect the soil surface from detaching power of raindrops. It prevents rain impact by intercepting it at very low height so that the kinetic energy accumulated over long travelling distance of the drops is confronted by the grass cover. The drops falling from the grass leaves therefore do not have the same detaching power as compared to the drops falling freely from the rain or from the forest canopy. Grasses slow down the overland flow by blocking its ways and also improve infiltration. The grass vegetation has intensive root system especially in the surface and subsurface soil layer than the trees. This enhances porosity and structural stability to a large extent. According to Bergsma (1993), the soil loss per hectare per year under good grass is similar to that under closed forest.

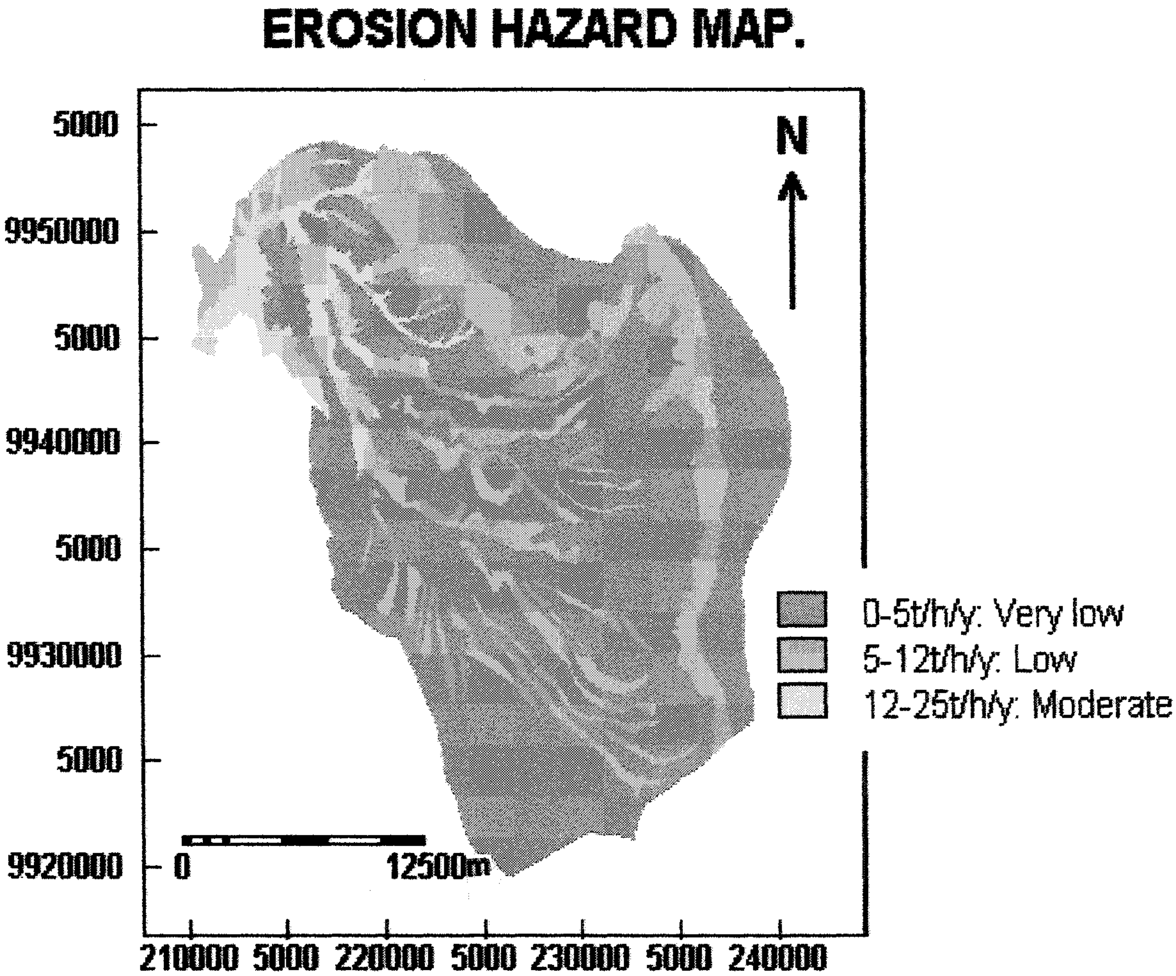

Figure 32: Soil erosion hazard map of the study area

The relative low values of erosion in Turasha catchment are caused by the land cover / use system which contributed to the better grass and forest cover.

5.2.2 Erosion susceptibility.

Erosion susceptibility is the loss expected under the influence of rainfall, relief, and soil properties in the absence of plant cover and control practices. Computing the product of the first four USLE parameters (R, K, L and S) has created soil erosion susceptibility or potential. Soil loss has been classified into the classes suggested by Bergsma (1986) in Table 28 which also shows the results of that classifications in the study area.

The erosion susceptibility map can be created by means of GIS-ILWIS where tables and columns of the USLE factors (R, K, L and S) have been multiplied and whereafter slicing carried was out into classes as suggested by Bergsma (1986) in Table 27. The result is also shown in the same table.

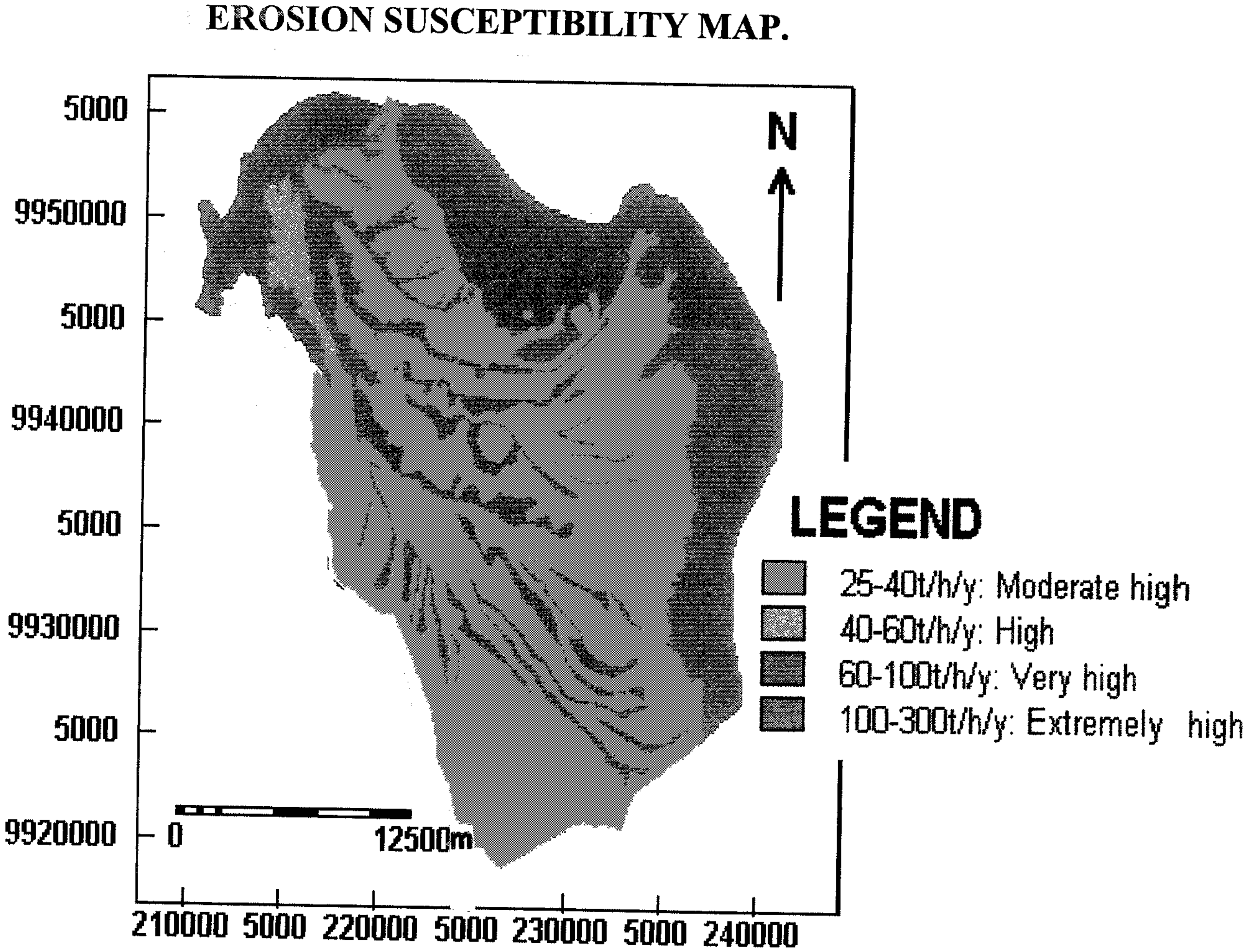

Figure 33: Erosion susceptibility of the study area.

The erosion susceptibility map (Figure 33) shows the potential soil loss due to water erosion without considering the protective effects of vegetation cover and conservation practices. As shown in the map and table, the erosion susceptibility generally is high to very high The high value is caused by application of the conventional parameters with respect to slope steepness and their length, high rainfall erosivity and to some extent by soil erodibility.

Compared to the soil erosion hazard map (Figure 30), the soil loss without vegetation cover is far higher rather than soil loss under vegetation cover. This suggests that the vegetation cover and conservation practices have been very effective and hence reduce the estimated soil loss.

Table 27: Soil erosion susceptibility of the Turasha catchment.

S.N	SMU	R_1	R_2	K	LS	A_1	A_2
1	Mo111	427	251	0.19	1.2	57.23	128
2	Pi111	427	251	0.14	1.58	56.22	126
3	Pi112	427	251	0.23	0.30	17.90	40
4	Pi211	427	251	0.20	0.27	13.55	30
5	Pu111	427	251	0.24	0.26	27.71	37
6	Pu112	427	251	0.21	0.60	31.63	71
7	Pu113	325	191	0.22	0.42	35.26	79
8	Pu114	325	191	0.18	0.71	24.41	55
9	Pu115	325	191	0.15	1.69	60.17	135
10	Pu121	427	251	0.20	0.70	35.14	79
11	Va111	427	251	0.18	0.26	12.65	28
12	Va112	325	191	0.17	1.60	51.95	116

Table 28: Distribution of soil erosion susceptibility in the Turasha catchment.

Class	Range of soil loss in t/ha/year	Area covered in ha	%
Very low	<5	-	
Low	5 - 12	-	
Medium	12 - 25	-	
Moderate high*	25 - 40	34902.00	55.23
High	40 - 60	1081.00	1.71
Very high	60 - 100	6587.30	10.42
Extremely high*	>100	20628.70	32.64
Total		63.199	100.00

***Classification by the outhor.**

5.2.4 Validity of the model and field evidence.

Validation of the model applied to determine the erosion hazard assessment was mainly based on field observations of erosion features, such as sheet and rill erosion, gullies, landslides and truncated profile (loss of topsoil) exposure of subsoil. A field indication of sheet erosion and rill erosion are the exposure of tree roots, clear runoff on the ground, pedestals, deposition of material in local depressions, surface stones and rock outcrop.

Base on the field observations, it was noted that erosion features were very few in the study area. This is because of the land use, which is a mainly grazing and forest reserve area. On the steep slopes, conservation measurements (contours) were constructed across the slope to counteract any runoff. Only in a very few cases erosion feature was observed, which occurred in fields with some annual crop, such as in sloping cultivated land with poor land management. Also the roadside gully erosion was the main feature of erosion in the study area (Plate 7).

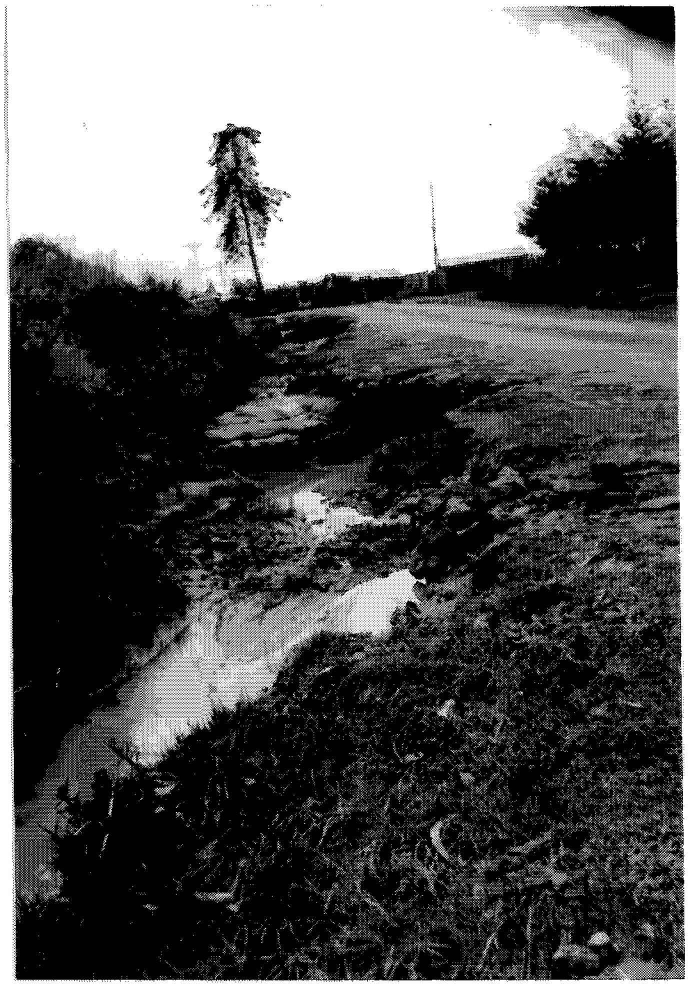

Plate 7: Roadside gully erosion caused by inadequate construction of the road drainage.

Field observations and the calculated soil loss under the current land use therefore support each other. In map unit Va112 where the erosion hazard is moderate, only few signs of erosion can be observed such as splash erosion. In order to lower the value of erosion hazard, the conservation measures which have been undertaken should be rehabilitated in such away that the contour intervals are reduced from the current one which is about 15m, to 10m apart.

5.2.5 Soil loss tolerance.

The determination of the soil loss tolerance is intended to compare the expected soil loss with the loss tolerance. If the soil loss is less than or equal to soil loss tolerance, the soil loss can be still accepted. But if the soil loss is more than soil loss tolerance, measurement to reduce soil erosion should be taken into consideration until the level of equal or less than the soil loss tolerance has been reached. Recommended soil loss tolerance for tropics is 25t/ha/y (Arsyad, 1981) but the common used one according to Crosson (1985) and Lal (1985) is 5 – 12 t/ha/y. Due to the importance of the catchment in supplying water to Lake Naivasha, soil loss tolerance in the study was considered based on both onsite and off-site effects. For this matter soil loss tolerant limits of 5 – 12 t/ha/y will be taken in the study area because they are relative low. This will be relatively sensitive to check erosion and to allow necessary measurements to be taken in time.

Although mapping unit Val12 show relatively high erosion severity to call for measurement to take place, but still there is no many signs of soil erosion to rise any suspicious about the erosion hazard problems. Good soil structure of soil allows infiltration of rainfall water, which discourages runoff hence, no erosion. This suggests that based on the situations, the predicted soil erosion hazard can still be accepted.

In other mapping units soil loss is too little to call for any conservation practises aiming at erosion control. Current land use in the study area is the main factor for low erosion hazard which apart from cover properly the land to give low value of C – factor, is also reducing the overland flow production which then results into relatively low LS – factor.

5.3 Sediment yields of the Turasha River in relation to soil erosion assessment (validation).

To verify the validity of the model applied for erosion hazard assessment, observations on erosion features in the field have been made and the assessment of sediment conducted by using previous findings. According to Hamududu (1998), the mean and the standard deviation of the suspended sediment load (ppm) for each season is summarized in the following Table.

Table 29: Suspended sediment load (ppm) from Rivers Turasha and Malewa.

	TURASHA RIVER		MALEWA RIVER	
Season	Mean	Std	Mean	Std
Long rainy	72	81	199	135
Short rainy	26	16	25	35
Dry period	41	68	208	93
First rains	57	62	110	204

Source: Hamududu (1998).

The mean sediment yield for first rains in River Turasha is higher compared to the short rains because the vegetation at that time is very low. During the short rainy season, the vegetation quickly rejuvenates as the rain continues unlike during the dry season when rainfall is sporadic on the poor land cover. In the long rainy season most storms are quite erosive resulting a high mean. Therefore at the beginning of the rainfall a substantial amount of sediments reaches the river. Dune (1979) concluded that land use is the main controlling factor in determining the amount of sediment yield of any catchment. He produced graphs showing different sediment yield with land use; i.e. forest, agriculture and grazing land. Through a thorough investigation in the Turasha catchment, not only land use can be a determined factor of the amount of sediment yield, but also land topography especially the shape and steepness of the slope plays a major role. As it is shown in Figure 31, the Turasha catchment contains bottomlands at the end of many slopes before reaching to drainage ways. This may cause sediments produced along the slope to be trapped in the bottomlands, which therefore fail to reach the waterways and have no influence at the point of outflow of the river where the suspended load is measured.

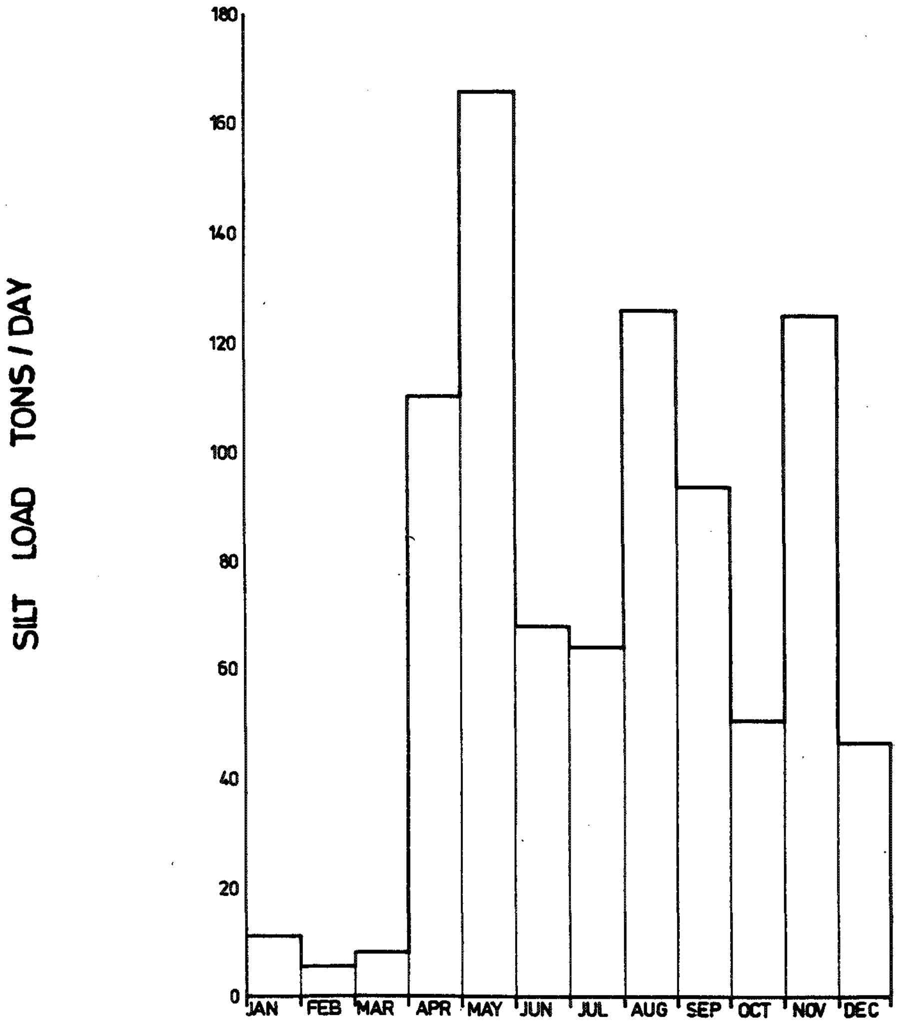

Figure 34: Mean monthly silt load of Malewa River RGS 2GBI.
Source: Naivasha Water Supply Project (1992).

Generally the sediment yield from Turasha catchment is very low also in relation to the Malewa River (see Table 29 and Figure 34). According to Hamududu (1998), River Malewa produces only 142 tons of sediments per year with the ability to raise the Lake Naivasha bottom by just 1mm. Because River Turasha is the main contributor of water to Malewa River it shows that its sediment yield contribution is very little. Highest amount of sediment are obtained in May; followed by quite substantial amount in April, August and November. Lower amounts are obtained in January, February and March.

There is a positive correlation between estimated soil loss yield and sediment yields i.e. both estimated soil loss and sediment yields are relatively low. There are very few erosion features observed in the field as per para 5.2.3. By using the sediment yield assessment results from the catchment and erosion feature observations, USLE model has to a great extent proved successful in its application to the Turasha catchment.

5.4 Scenarios:

5.4.1 Current land use and calculated soil erosion hazard.

Mixed farming of arable crops and livestock production (dairy cattle and sheep wool) are the main land use in the study area especially on the plateau. In the mountainous (Kipipiri and Aberdares) the area is planted with trees for the purpose of research or reserve. Due to proper land cover which is mainly influenced by the land use type, C factor is very low in such a way that in many mapping units are less than 0.1 which make it to be very effective in soil erosion control. The erosion hazard in this area is very low (<5 tons/ha/year).

5.4.2 Soil loss under alternative land use.

Current land use is the reason of low erosion hazard in the study area. Erosion susceptibility is very high as discussed under para 5.2.2. So in case of any land use changes which will influence land cover depletion and temper with conservation structures, then erosion hazard will increase. If they destroy soil conservation structures then the soil loss will almost double in mapping unit Va112 and Pi111. The history has shown that the land use apart from being determined by soils and climatic condition, is also determined by the land tenure and marketing. The small holders who have secured legal rights of owning the land after independence, have shown the tendency of trying to maximize profit in the allocated piece of land. With time this might bring some negative effects to the current calculated erosion hazard.

If vegetation cover decrease by half, the equilibrium will change in such a way, C factor will increase and slope factor (LS) will also increase due to the increase of the slope length. Erosion features such as rill and interills may be obvious. In the concentrated land flow, gull erosion may result. In the arable land as on site effect, this will interfere with agriculture activities and lower ground water table. Sediment yield may increase and cause problems of sedimentation and silting of reservoirs, lakes, flooding and destruction of settlement areas, roads and other infrastructures.

CHAPTER 6.

6. CONCLUSION AND RECOMMENDATIONS.

On the basis of foregoing results and discussions, the following conclusions and recommendations can be drawn:

6.1 Conclusions.

The results show that, the erosion hazard in the study area is generally low. Most of the area lies in the range very low (0-5t/ha/y) to low (5-12t/ha/y), which covers 93% of the study area. According to the selected soil loss tolerance of 5-12t/ha/y, the results conclude that 93% (50.000 ha) are not in the need of soil erosion conservation measures. When erosion susceptibility and erosion hazard maps are compared, the erosion susceptibility are generally high (25-60t/ha/y) to very high (>60t/ha/y) according to Bergsma (1980) classifications. These results conclude that, the current land use is the main factor of the low erosion hazard in the study area. Vegetation as landcover intercepts the raindrops so that their kinetic energy is dissipated by the plants rather than imparted to the soil. The largest area (the Plateau) is well covered with grass, which is used for grazing. In the Mountains, most area is well covered by forest and beneath the trees there is mulch which further control the erosion even more efficiently.

The topography contribute also to low erosion hazard where, 60% of the study area occurs in the slope range of 0-5% (gentle undulating). Even on the relatively steep slope (>10%), the vegetative cover and / or drainage waterways shorten slope length and results into low value of topographic factor (LS) of USLE.

Based on Wischmeier and Smith (1978) nomography, soil erodibility is relatively low, classified as low to moderate. Relative high clay content and organic matter is the cause of this (low erodiblilty). Both clay and organic matter are binding agents, which enable soils to withstand detachability by raindrops.

Major soils in the study area include Dystric Planosols which covers an area of 31.280 ha which is about 50% of the study area. This conclude that large part of the study area have soils which are relatively imperfect to poor drained especially when it considered the texture of many other soils are of clayey. Poor infiltration has great influence on accelerate overlandflow (runoff) and in turn increase surface erosion especially on the bare land. In other cases this is controlled by vegetation cover.

Analysis of the rainfall characteristics especially in the eastern part of the study area showed >50mm in all months of the year, which ensures the presence of vegetation throughout the year, hence low / no soil sediments are available for erosion even in heavy storms. Actually soil erosion occurs when there are erodible materials. In the western part there is dry spell, which indicates that high erosion can be expected during the first rain because there is much loose dry soil material available at that time on the land surface which can be washed away.

Owing to the importance of controlling soil erosion in the study area based on the on-site and off-site effects, low soil loss tolerance of 5-10t/ha/y is more appropriate instead of 25t/ha/y generally recommended for Tropical environments. Based on the selected soil tolerance, map unit Va112 soil erosion severity is relative high (14.34t/ha/y) requires conservation measures to be taken.

It has been concluded that both estimated soil loss and sediment yields are generally low. There are very few erosion features observed in the field. By using the sediment yield assessments and erosion feature observations, USLE model has to a great extent proved successful in its application to the Turasha catchment, which was prior divided into terrain map unit.

6.2 RECOMMENDATION.

The erosion hazard map has to be revised when the land use and management systems change in time and space. Observed diversity of the crops in the area and variation of the areas under various crops from year to year, through which the farmers try to secure successful harvest and profit, may one day lead to significant changes in the current land use.

Although the erosion hazard under current land use is low, it is recommended to educate / create awareness about the effects of soil erosion to all stakeholders. In order to analyse the situation more accurately, stakeholders should be divided into parts such as; ***on-site versus off-site victims of the effect of soil erosion* and / or *direct versus in-direct victims of the effects of soil erosion*.** The effects of erosion should be clearly stipulated and through a participatory approach be brought under discussion, in order to come out with the sustainable land management. The Lake Naivasha Raparian Association Owners (LNRAO) play a vital role in such a programme.

The current conservation practices by farmers should be maintained, and any change in cropping pattern must be accompanied by suitable land conservation techniques. In mapping unit Va112, contour strip / bund interval (VI) should be reduced to about 10m. The recommended formulae for determining spacing of terrace (VI) recommended for Kenya can be used:

Kenya VI (m) = 0.3(S+2)/4

Kenya (fanya juu) VI (m) = aS + b

In which a = 0.075
b = 0.6 and
S = slope percent.

Agroforesry practices could be applied not only to increase the quality of the vegetation buffer strips of the contour for effective soil erosion control, but also to be used as fodder, to increase soil fertility, and as a source of fuel wood and building materials are recommended. Fast growing trees / shrubs such as Lucaena, Sesbania, Granville, and *Acacia albida* on the steep slope of western part of the study area where soils are relatively well drained and hotter. On the eastern part on the poorly drained soils, Eucalyptus are suitable, while on the relatively well drained areas, pines are recommended.

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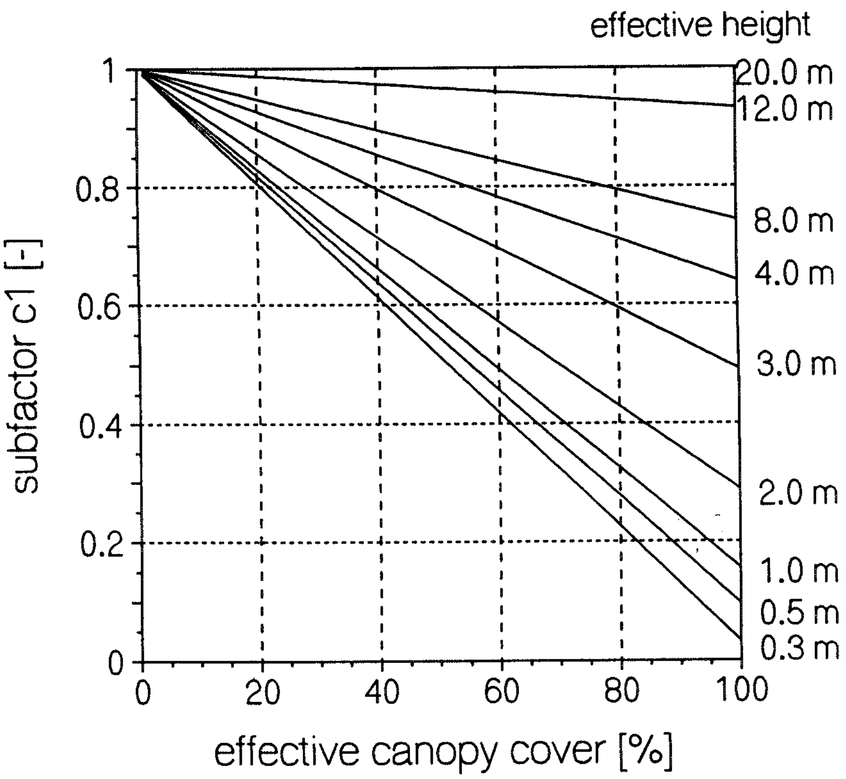
DETERMINATION OF C – FACTORS.

APPENDIX 1.

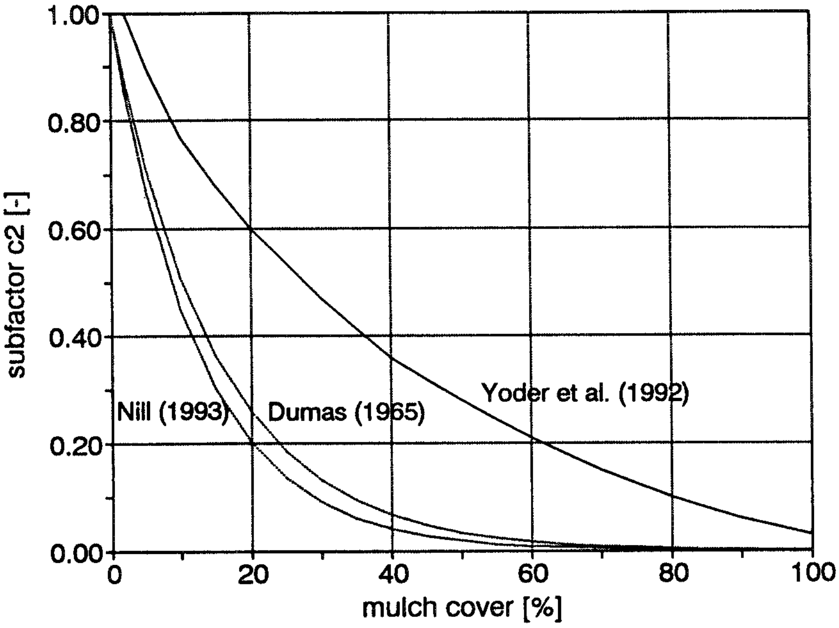
Subfactor c1 as influenced by effective canopy cover and crop height.



Source: Foster (1982) and Wischmeier (1975)

APPENDIX 2.

Subfactor c2 gives the ratio of soil loss on a covered plot uncovered plot.



Source: Nill (1993); Dumas (1965) and Yoder et al. (1992).

APPENDIX – 3

DESCRIPTION OF THE REPRESENTATIVE SOIL PROFILES.

(Source: Soil conditions in the Kinangop area).

Map unit MO111.

Soil classification	: Mollic Andosol.
Geological formation	: Olivine basalt.
Physiograpy	: Mountain.
Relief – macro	: Mountains >30% slope
Vegetation/Land use	: Forest
Erosion	: Not observed.
Surface stoniness	: Nil
Slope gradient	: 30%
Slinity / alkalinity	: Nil
Drainage class	: Well drained

Profile description:

A1 0-13cm Reddish grey (5YR 5/2, moist); loam to clay loam; weak, very fine and fine crumb structure; friable when moist, slightly sticky and plastic when wet; common, very fine and fine roots, few to common, medium roots; clear and smooth transition to:

AB 13 – 27cm Dusky red (2.5YR 3/2, moist) clay; moderate, fine and medium subangular blocky structure; friable when moist, sticky and plastic when wet; common, very fine and fine pores, few to common, medium pores; very few manganese concretions (5mm in size); few, very fine roots; gradual and smooth transition to:

Bw1 27 – 72cm Dusky red brown (2.5YR3/4, moist); clay, moderate, fine, medium and coarse angular blocky structure; friable when moist, sticky and plastic when wet; common very fine, fine and medium pores; few very fine pores, common, fine and medium roots, very few, coarse roots; clear and smooth transition to:

Bw2 72 – 120cm Dark reddish brown (5YR3/4, moist), black mottles; gravely clay; moderate very fine, fine and medium angular blocky structure with a tendency to prismatic structure; friable when moist, sticky and plastic when wet; few weak clay cutans; common, very fine, fine and medium pores, common manganese concretions (10 – 20mm in size); few fine roots, very few medium roots; clear and wavy transition to:

C 120+ cm weathering parent material.

Map unit Pi111.

Soil classification	: Ando-ferric Acrisol.
Geological formation	: Vesicular olivane basalt
Local petrography	: Colluvium
Physiography	: Footslpoe of the mountain
Relief – macro	: Rolling, convex-linear, uniform.
Vegetation/Land use	: Maize, potatoes and forest.
Erosion	: Nil
Surface stoniness	: Nil
Slope gradient	: 13%
Salinity / alkalinity	: Nil
Drainage class	: Well drained.

Profile description:

Ap 0 -18cm Dark reddish brown (5YR 3/3 moist, 5YR 4/3 dry); clay loam to clay; moderate, fine and medium, angular blocky structure; slightly hard when dry, friable when moist, slightly sticky and slightly plastic when wet; common, fine and very fine roots, few to common medium roots; clear and smooth transition to:

Bt1 18 – 55cm Dusky red (2.5YR ¾ moist); clay; weak, fine and very fine subangular blocky structure; slightly hard when dry, friable when moist, sticky and plastic when wet; many, very fine and fine pores, common medium pores; few, very fine roots, very few medium roots; clear and smooth transition to:

Bt2cn 55 – 104cm Dusky red (2.5YR ¾ moist); gravely clay; weak, fine and medium subangular blocky structure; slightly hard when dry, friable when moist, sticky and plastic when wet; few, faint, clay cutans; many very fine pores and few coarse pores; few iron-manganese concretions (2-20mm in size); very few, very fine roots; gradual and smooth transition to:

C 104 – 150cm weathering parent material

R 150+cm Rock

Map unit Pi112.

Soil classification	: Orthic Luvisol
Geological formation	: Pyroclastic rocks with intercalated Laikipian type Basalt.
Local petrography	: Pyroclastic rocks with intercalated Laikipian type Basalt.
Physiography	: Gently undulating to undulating
Vegetation/Land use	: Maize, carrots, potatoes, forest trees.
Erosion	: Nil
Surface stoniness	: Nil
Slope gradient	: 3%
Salinity / alkalinity	: Nil
Drainage class	: poorly drained

Profile description:

Ap 0 -25cm Black (5YR 2.5/1 moist, 10YR 4/2 dry); silt loam; weak, fine subangular blocky structure with a tendency to weak, very fine and fine crumb structure; loose when dry, very friable when moist, slightly sticky and plastic when wet; many, very fine pores, common, fine and medium pores, few coarse pores; small shiny mica-like minerals; many fine roots; common, fine roots; gradual and smooth transition to:

A12 25 – 42cm Black (10YR 4/2 dry, 5YR 2.5/1 moist); clay loam; moderate fine, medium and coarse subangular blocky structure falling apart to very fine and fine crumb structure; loose when dry, very friable when moist, slightly sticky and plastic when wet; many, very fine and fine pores, common medium pores, few, coarse pores; small shiny mica-like minerals; common, very fine and fine roots; clear and smooth transition to:

Bt1 42 – 60cm Dark reddish brown (10YR 3/2 dry, 5YR 3/3 moist); clay loam; weak, fine, medium and coarse subangular blocky structure; loose when dry, very friable when moist, sticky and plastic when wet; few, very thin clay cutans; many, very fine and fine pores, common medium pores, few, coarse pores; few, very fine roots; gradual and smooth transition to:

Bt2 60 – 115cm Dark reddish brown (2.5YR ¾ moist, 5YR 4/4 dry) few, distinct dark reddish brown mottles (10R 3/6) and 5mm in size; clay; moderate, fine, medium and coarse angular blocky structure; slightly hard when dry, friable when moist, sticky and plastic when wet,; common, moderately thick clay cutans; many, very fine, and fine pores, common medium and coarse pores; Krotovinas and other animal channels; few fine rots; gradual and wavy transition to:

115 – 135+cm Reddish brown (5YR 4/4, moist) weathering rock admixed with soil.

Map unit Pu113.

Soil classification	: Dystric Planosol
Geological formation	: Pyroclastic rocks
Local petrography	: Tuff
Physiography	: Plateau
Relief – macro	: Termite mounds
Vegetation/Land use	: Natural grazing for cattle and sheep
Erosion	: Nil
Surface stoniness	: Nil
Slope gradient	: 1%, top part of slope
Salinity / alkalinity	: Nil
Drainage class	: Poorly drained

Profile description:

AP 0-20cm Very dark greyish brown (10YR3/2 moist, 10YR 6/2 dry); few fine, faint, strong brown mottles; silty clay loam; moderate medium, subangular structure; hard when dry, very friable when moist, non-sticky and non-plastic when wet; many, very fine and common, fine pores; many, fine roots; gradual and smooth transition to:

E 20 – 32cm Very dark greyish brown (10YR 3/2 moist, 10YR 6/2 dry), many, medium, distinct, strong brown mottles; silty clay loam; massive structure; hard when dry, very firm when moist, non sticky and when wet, many, very fine and common fine pores; many very fine roots; abrupt and smooth transition to:

Bt 32 – 43cm Very dark grey (10YR 3/1 dry, 10YR 3/1 moist); many, medium distinct, strong brown mottles; silty clay; moderate medium, prismatic structure; very hard when dry, very firm when moist, sticky and plastic when wet; very few manganese concretions, 2mm in size; very fine roots on structural peds only; gradual and smooth transition to:

Bt1g 43 – 65cm Very dark grey (10YR 2.5/1 dry, 10YR 3/1 moist); many coarse prominent, strong brown mottles; clay; strong fine and medium angular blocky structure; very hard when dry, very firm when moist, sticky and plastic when wet; abundant, moderate to thick clay cutans; few, very fine pores; few, very fine roots; distinct and wavy transition to:

Bt2g 65 – 100cm very dark grey (10YR 3/1 moist); few, very fine, district mottles; clay; strong, medium, angular blocky structure; very hard when dry, very firm when moist, sticky and plastic when wet; abundant; moderate and thick clay cutans; common, slickensides; few, very fine pores, diffuse and irregular transition to:

BC 100 – 140cm very dark grey (10YR 3/1 moist); many medium, distinct, strong brown mottles, clay with patches of weathered rock; moderate fine to coarse, angular blocky structure; very hard when dry, very firm when moist, sticky and plastic when wet; abundant, moderate clay cutans; few, very fine pores; gradual and irregular transition to:

140+cm Dark yellowish brown (10YR 4/6 moist), weathered rock.

Map unit Pu115.

Soil classification	: Calcic Luvisol
Geological formation	: Pyroclastic rocks
Local petrography	: Tuff
Physiography	: Plateau
Relief – macro	: Undulating to rolling
Vegetation/Land use	: Bushed grassland; locally cultivation of maize, peas and beans; ranching
Surface stoniness	: In places rock outcrops
Slope gradient	: 8%, top part of slope
Salinity / alkalinity	: Nil
Drainage class	: Moderately well drained

Profile description:

A1 0-10cm Dark brown (10YR3/3 moist, 10YR 4/2 dry); clay moderate to strong very fine and fine subangular blocky structure; hard when dry, firm when moist, sticky and plastic when wet; common fine; clear and smooth transition to:

AB 10-25cm Dark brown (10YR 3/2 dry, 7.5 3/2 moist); clay; strong very fine, fine and medium prismatic structure falling apart to strong, very fine and fine angular blocky structure hard when dry, firm when moist, sticky and plastic when wet; few fine roots and very few, medium roots; gravely and wavy transition to:

Bt 25-48cm Dark brown (7.5YR 3/2 dry, 7.5YR 3/2 moist); gravelly clay; strong very fine and fine, prismatic structure falling apart to angular blocky structure; hard when dry, firm when moist, sticky and plastic when wet; few calcium carbonate concretions; abrupt and smooth transition to:

C 48-110+ cm weathering rock dark greyish brown (2.5Y 6/4 dry, 2.5Y 4/2 moist).

Map unit Pu121.

Soil classification	: Humic Andosol
Geological formation	: Pyroclastic rocks
Local petrography	: Tuff
Physiography	: Plateau
Relief – macro	: Flat to gentle undulating.
Vegetation/Land use	: Cultivation area (maize), cattle and sheep
Erosion	: Nil
Surface stoniness	: Boulders
Slope gradient	: 3%, upper slope
Salinity / alkalinity	: Nil
Drainage class	: Well drained

Profile description:

Ap 0 - 20cm Dark brown (10YR 3/3, moist); clay loam; weak fine and medium coarse subangular blocky structure falling apart to weak, fine and medium, crumb structure; slightly hard when dry, friable when moist, slightly sticky and plastic when wet; common, very fine and fine pores; small shiny mica-like minerals; many, very fine roots, common fine roots, few, medium roots, gradual and smooth transition to:

AB 20 - 35cm Very dark greyish brown (10YR 3/2 moist); clay loam to clay; weak to moderate, fine, medium and coarse, angular blocky, soft when dry, very friable to friable when moist, slightly sticky and plastic when wet; animal activity; many very fine pores, common, fine roots, very few, medium roots; gradual and smooth transition to:

Bwl 35 - 60cm Dark brown (7.5YR 4/4 moist); clay; strong loam; weak coarse sub-angular block structure falling apart to weak, very fine and fine, angular blocky; soft when dry, very friable to friable to friable when moist, slightly sticky and plastic when wet; animal activity; many, very fine pores, common, fine and medium pores; few, very fine roots, common, fine roots, very few, medium roots; gradual and smooth transition to:

Bw2 60 - 85cm Dark brown (7.5 4/4 moist); clay loam; weak, fine and medium angular blocky structure; soft when dry, very friable to friable when moist, slightly sticky and plastic when wet; common, fine pores, few medium pores; very few, very fine roots, few, fine roots, very few; gradual and smooth transition to:

Bwca 85 - 115cm Dark yellowish brown (10YR 3/6 moist); loam to clay loam; weak medium and coarse, angular blocky structure falling apart to weak, fine and medium subangular blocky structure soft when dry, very friable to friable when moist, slightly sticky and plastic when wet; strongly calcareous, very fine pores, common to many, fine pores, common medium pores;

C 115-140cm Plinthite.

Map unit Pu114.

Soil classification	: Calcaro-pellic Vertisol
Geological formation	: Pyroclastic rocks
Local petrography	: Tuff
Physiography	: Plateau
Relief – macro	: Flat to very gentle undulating, 200m long, convex to linear, uniform slope.
Vegetation/Land use	: Cultivation (wheat).
Erosion	: Nil
Surface stoniness	: Nil
Slope gradient	: 1%
Salinity / alkalinity	: Nil
Drainage class	: Imperfectly drained

Profile description:

Ap 0- 22cm Black (10YR2/1 dry, 10YR2/1 moist); clay; strong fine medium and coarse subangular block structure; hard when dry, firm when moist, sticky and plastic when wet; shiny mica-like minerals; (sub) rounded gravels (size 2-5mm); common, very fine and fine roots, few, very fine and fine roots; clear and smooth transition to:

Bwl 22-80cm Black (10YR 2/1) moist; clay; strong, medium and coarse prismatic structure falling apart to strong, fine and medium angular blocky structure; hard when dry, firm when moist, sticky and plastic when wet; many slickensides; very few calcium carbonate concretions (2-8mm in size); very few manganese concretions (5mm in size), common, (sub) rounded graves (2-5mm in size); few, very fine and fine roots clear and smooth transition to:

Bw2 80-130+cm Dark brown (7.5YR 4/4 moist); clay; strong loam; weak coarse sub-angular block structure falling apart to weak, very fine and fine, angular block; soft when dry, very friable to friable to friable when moist, slightly sticky and plastic when wet; animal activity; many, very fine pores, common, fine and medium pores; few, very fine roots, very few, fine dying roots.

Map unit Pu111.

Soil classification	: Dystric Planosol
Geological formation	: Pyroclastic rocks and sediments.
Local petrography	: Tuffs
Physiography	: Plateau
Relief – macro	: Flat.
Vegetation/Land use	: Cultivation (wheat) pasture – cattle and sheep.
Erosion	: Nil
Surface stoniness	: Nil
Slope gradient	: 1%
Salinity / alkalinity	: Nil
Drainage class	: Imperfectly drained to poorly drained.

Profile description:

Ap 0- 25cm Dark grey (10YR4/1 moist); silt clay loam; moderate, fine and medium, angular blocky structure; friable when moist, slightly sticky and plastic when wet; common, very fine and fine pores, few medium pores; common, very fine roots, very few, medium roots; gradual and smooth transition to:

E 25-40cm Greyish brown (10YR 5/2 moist); common reddish brown mottles (5YR 4/4), 5mm in size; silty clay loam; moderate, fine and medium, subangular blocky structure; friable when wet; many, very fine pores, common to many, fine pores and common, medium pores; very few, fine roots, few, fine roots; abrupt and smooth transition to:

Btcn 40 - 65cm Very dark brown (10YR 2/2 moist); black mottles; clay; moderate to strong, fine medium and coarse prismatic structure falling apart to moderate to strong, fine and medium angular blocky structure; firm when moist, sticky and plastic when wet; common, moderately thick, clay cutans, few slickensides; common, fine pores, few to common, medium pores; few iron-manganese concretions (5-10mm in size), few (sub) rounded gravels (5mm in size); very few, fine rots; gradual and smooth transition to:

Bt1 65 - 85cm Very weak dark greyish brown (10YR 3/2, moist); clay strong fine medium and coarse angular blocky structure; firm when moist, sticky and plastic when wet; few faint clay cutans, few slikensides; common fine pores, few to common, medium pores; few subrounded gravels; dead roots; clear and smooth transition to:

Bt2cn 85–107cm Brown to dark brown (10YR 4/3 moist), few to common yellowish red mottles (5YR 5/8), 5mm in size, and black mottles; gravely clay; strong, fine and medium subangular blocky structure falling apart to fine angular blocky structure; firm when moist, sticky and plastic when wet; few, fine pores; few manganese concretions (5mm in size); clear and smooth transition to:

Bt3 107 – 150cm Dark yellowish brown (10YR 4/4 moist), black mottles; clay; moderate, prismatic structure falling apart to moderate, fine and medium angular blocky structure; very friable when moist, sticky and plastic when wet; common slickensides.

Unit Map V111,

Soil classification	Eutric Gleysol
Observation	Nyandarua District, E3.7, & N20.0;
Geological formation	Alluvium
Local petrography	Alluvium deposits
Relief-macro	Very gentle undulating to undulating.
Vegetation/landuse	Swamp grassland – grazing by cattle and sheep
Erosion	Nil
Flooding	Frequent (seasonal).
Slope gradient	Nil.
Salinity / alikalinity	Nil
Drainage class	Poorly drained.

Profile descriptions

A1 0 - 12cm Very dark greyish brown (10YR 3/2 moist), common, distinct yellowish red mottles (5YR 4/6) 5mm in size; silty clay loam; moderate to strong fine and medium subangular blocky structure; firm when moist, sticky and plastic when wet; common, very fine roots, very few, medium roots; gradual and smooth transition to:

AB 12 – 28cm Very dark greyish brown (10YR 3/2 moist), many, distinct black (7.5YR NS) and reddish brown (5YR 4/4) mottles 10mm in size; clay; strong, fine and medium prismatic structure falling apart to very fine and fine angular blocky structure; firm when moist, sticky and plasic when wet; many very fine and fine pores, common medium pores, few coarse pores; few fine roots; clear and smooth transition to:

Bwg1 28 – 52cm Dark greyish brown (10YR 6/3 dry, 10YR N/2 moist), many distinct black mottles (7.5YR N/2 20mm in size; clay; strong, fine, medium and coarse prismatic structure; firm when moist, sticky and plastic when wet; common, very fine and fine pores, few to common, medium pores; manganese concretion, few (sub) rounded gravels; few, roots; clear and smooth transition to:

Bwg2 52 – 80cm very dark greyish brown (10YR 3/2 moist), many distinct black mottles (7.5YR N/2) 20mm in size and many, distinct yellowish red mottles (5YR 5/8) 10mm in size; clay; strong, fine, medium and coarse angular blocky structure; firm when moist, sticky and plastic when wet; many, very fine pores, common, fine and medium pores; very few manganese concretions, 5mm in size, subrounded gravels; very few fine roots; clear and smooth transition to:

Bwg3 80 – 125cm very dark brown (10YR 3/2 moist), many distinct, black mottles (7.5YR N/) 20mm in size and many, distinct, yellowish red mottles (5YR 5/8) 10mm in size; clay; strong, fine, medium and coarse angular blocky structure; firm when moist, sticky and plastic when wet; many very fine pores, common, fine and medium pores; very few manganese concretions, 5mm in size, subrounded gravels; very few fine roots; clear and smooth transition to:

C 125+cm Weathering parent rock.

Soils of the Valleys V112.

The unit consists of valleys, which are deeply incised with steep sides (=>10%). The majority of the unit is found to the North of the survey area where the plateau is very much dissected. The underlying geology of the area is pyroclastic rocks. The nature of the slopes is such that the relief of the whole unit is undulating to hilly (5 – 30%). The natural vegetation type is bushed grassland.
The unit consists of a complex of soils which are well drained, shallow mainly on the slopes and moderately deep in the valley bottoms. In places there are inclusions of deep soils. The topsoil colour range from very dark greyish brown (10YR 3/2, moist) to black (10YR 2/1 moist) and that of the subsoil is dark brown 10YR 4/2, moist) to very dark brown (10YR 2/2, moist). The texture of the A-horizon is gravely clay loam to clay loam and that of the subsoil is ranging from clay loam to clay. The consistence is friable.
The very steep parts are mainly under grass and are used for cattle and sheep grazing. Areas with moderately deep soils with inclusions of deep soils are used for cultivation of maize and peas.