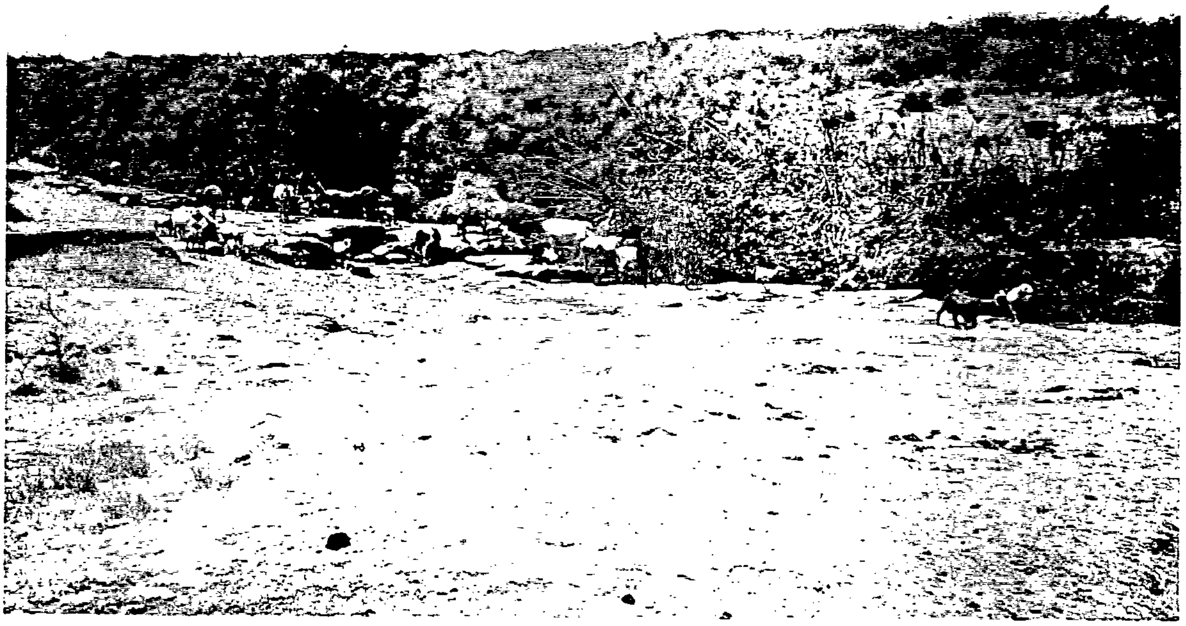
# Erosion stratification in the Kiambu area in Kenya:

a methodological study to get quick insights in the distribution of erosion conditions, using aerial photographs and field observations

by Reinoud van der Linden



Wageningen Agricultural University
Department of Soil and Water Conservation
Supervisor: Leo Eppink
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## Abstract

This study provides a method to stratify the Kiambu area in Central Province, Kenya, into meaningful erosion units. This way insights in the distribution and intensities of mainly sheet erosion are obtained. Aerial photographs scaled 1:50,000 and 1:25,000 are interpretated and field observations are made with the Clark method. This method provides simple observation techniques on Soil Surface Factors, to come to a numeric erosion condition assessment.

An object oriented and data driven approach is used. Parameters, believed to be highly correlated with the erosion process are used as indicators. These are referred to as key data. Like erosion features these indicators have characteristics which are expressed in the grey tone and pattern of aerial photographs. In this study the drainage density and drainage pattern are used as indicators representing landform. Based on these indicators different broad landforms are delineated: sloping vs. level lands with a dendritic vs. parallel drainage pattern. Broad land use forms a third indicator, delineating areas with large scale tea and coffee, areas of small scale farming and range lands.

Field observations are used to validate the Aerial Photo Interpretations and to collect detailed information on the distribution of erosion types and intensities. Statistical analyses on the detailed field observations prove that the delineated erosion units differ significantly in erosion conditions. A statistical model is generated in which erosion condition is expressed in slope and cover conditions in an area. For different sample areas the correlation coefficients read 77%, 61% and 59%. This model still needs to be tested with detailed field observations to determine its predictive qualities.

For the Kiambu area it is concluded that the land use is of more importance in determining the erosion condition, than the landform. Large scale tea provides the best cover conditions to limit water erosion. Areas used for small scale farming and ranging are most vulnerable for erosion. In the range lands intensified grazing and cultivation will accelerate the erosion considerable.

## Acknowledgements

In March 1993 Mr Peter Okoth has started a PhD research which concentrates on the relation between landform and land use systems and its combined effect on soil erosion. Special use will be made of areal photographs and satellite imagery. The study area of this research is formed by the upper ridges of the Athi-Galana-Sabaki catchment, concentrated in Kiambu District. Mr Okoth is employed at Kenya Soil Survey, part of the National Agricultural Research Laboratories (NARL) of the Kenya Agricultural Research Institute (KARI).

Beginning 1993, I came into contact with Mr Eric Smaling, of the Winand Staring Institute in Wageningen, who offered me the opportunity to assist Mr Okoth in his research. From June 1993 to October I paid a 4 months visit to the Kenya Soil Survey. During this time I assisted Mr Okoth in the preparations for his research which resulted in this paper.

This paper is presented as a research thesis, as part of my study at the Department of Soil and Water Conservation of the Wageningen Agricultural University. My supervisor of this study is Mr Leo Eppink .

I would like to thank Mr Eric Smaling for his technical, moral and financial support. I thank Mr Okoth for his friendship and support with regard to the content of this paper. All the people of Kenya Soil Survey I would like to thank for their hospitality. Without their help and willingness to assist me, I could not have performed this study. I want to thank Mr Leo Eppink, for his advise and critical eye. Finally, I would like to thank the family Linden for their hospitality. They offered me a warm home and insights in the ins and outs of Kenya.

CONTENT

# CHAPTER 1: PROBLEM DESCRIPTION

Kenya, with a population of 25 million people, is covering an area of 583,000 $km^2$. If one wants to understand the problems that Kenya is facing a helpful phrase to think of is that in Kenya approximately 80% of the population lives and eats on only 18% of the land. The remaining 82% of the land surface can be qualified as marginal lands.

Together with an ever increasing population of 3.6 per cent per annum (World Bank, 1992), this limited supply of arable land indicates, and even sometimes can explain, a range of environmental problems. What these problems all have in common is their spatial character. Many environmental problems start at the level of the small holder and have their aggregated effects on a regional scale. The fact that people on one site are using their land in a certain way, not only has on-site effects but also influences the potential land uses on sites at much larger distance. This is just the case with erosion processes, especially when they are human induced and leading to soil degradation.

In Kenya the vast majority of the rural land users is still adopting traditional farming techniques despite the growing population. This has resulted in the replacement of shifting cultivation techniques by more permanent forms of cultivation. By clearing forest and other natural vegetation new often fragile marginal lands are opened up for agriculture. Sustainable agriculture in these areas is questionable, accelerated erosion a fact (Dunne 1974, Lewis 1985, Biamah 1986). Soil erosion in Kenya is furthermore accelerated by poor road constructing techniques, overstocking and overgrazing of rangelands and by land tenure systems which do not promote soil conservation activities for communally owned lands (Linden, 1993).

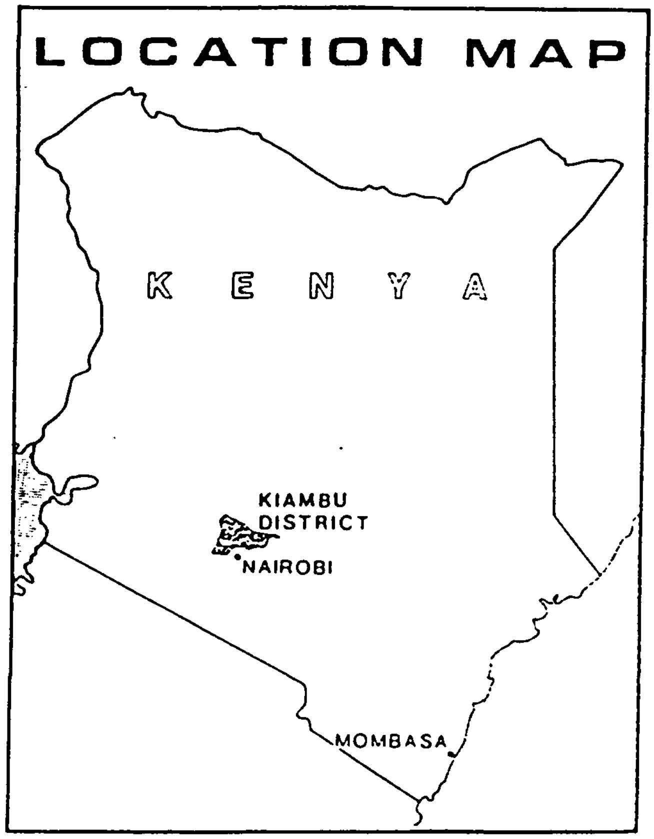
The Kiambu District, inhabited by more than 1.1 million people, covering 2573 $km^2$, is located in Central Province, 30 km north of Nairobi. It is situated in the upper reaches of the Athi-Galana-Sabaki catchment, originating from the footslopes of the Aberdare mountains. The highest, western part of the area is an intensely cultivated, high productive, agricultural area where a variety of landforms and land uses can be found. The slopes can be as steep as 60%, with relief energies up to 50 metres. Varying with the altitude the annual precipitation in the sloping land is averagely 1200 mm. The rain falls in two seasons from March to June and from October to December. In the study area the minimum temperatures vary between 1°C and 4°C. Mean annual temperatures range between 14°C and 19°C. (Jaetzold and Schmidt, 1983).

Large scale deforestation started in the 30's when european settlers developed coffee, tea and sisal plantations. After independence in 1963 some of the tea and coffee plantations were divided and redistributed among small scale farmers who were lacking the resources to maintain or develop soil

conservation practices.
Nowadays land pressure has reached its limits and diminishing landownership per capita is causing farmers subsistence problems. A number of large scale coffee and tea plantations can be found. The major crop in small scale farming is maize. Because of the low coffee price small scale farmers in the area have neglected their coffee trees for many years. The trees are usually intercropped with maize or beans. Soil conservation structures like fanya juu's (earth benches), are neglected as well. Only recently the coffee crop has become more profitable for small scale farmers. Irrigated horticultural crops like tomatoes, onions and cabbages are cultivated on the more level parts on top of the ridges. Going down the slope coffee, maize and bananas are cultivated. Traditionally, on the steepest parts of the slope near the gully bed, trees are planted for fuelwood and timber. More and more farmers are forced to replace them by annual subsistence crops.

Due to this intensified cultivation soil erosion is increasing and on-site soil degradation is threatening agricultural production. The erosion in the upper catchments causes massive sedimentation downstream the river basin. This sedimentation reduces the quality of water and increases the risk of flooding and sporadic drying. Near the mouth of the Sabaki river at Malindi for instance, the muddy sea and beaches reduce earnings in the tourist sector, one of Kenya's main hard currency generating activities.

The south eastern part of the area, south of the Thika, has a semi-arid climate with 800 mm precipitation. Until the 1970's the land was mainly used for irrigated sisal plantations. Since then, artificial vessel production made the sisal production a non paying enterprise. Most plantations were abandoned. Since 1985 plantations are redistributed among farmers forced to move from the high potential high lands. Ranging, with cattle, sheep and goat, is the main land use nowadays. Since more and more people are settling in the area, already signs of overgrazing are evident. The cultivated area is increasing. River sides are cleared and illegal charcoal burning is a normal practice. These developments contribute to accelerated erosion and may endanger future agricultural production. Due to the open character of the vegetation, wind erosion is an important source of soil loss.



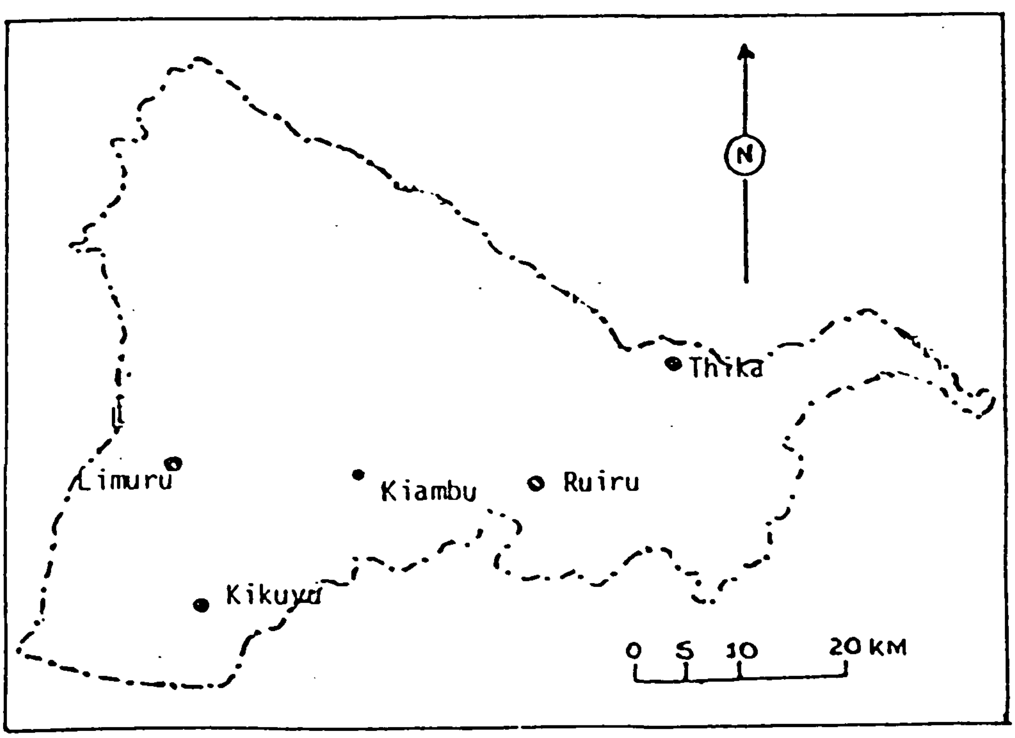




Figure 1. Location of Kiambu District.

# CHAPTER 2: OBJECTIVES

The main objective of this study is to look for a method, to get information on the spatial distribution of erosion intensities over a larger area. An evaluation of the role and possibilities of Aerial Photograph Interpretation (API) and field observations is given. In erosion mapping, API is considered a very useful tool. Depending on scale, API can give quick and detailed information. A fieldcheck will always be necessary to validate the interpretated photocharacteristics.

Although limited quantitative data exists on the spatial relation between erosion intensities and loss of agricultural production, accelerated erosion reduces the availability of nutrients in the top soil, for crop production. Insights in the spatial distribution of types, intensities and hazards of erosion can contribute to sustainable agriculture.

By mapping erosion, areas of increasing erosion rates and high erosion hazard can be differentiated. Priority for the implementation of soil conservation measures should be given to such areas. This way the generally limited farmers resources will be used most efficiently. Without these measures land degradation will occur first, in areas with the highest erosion rates.

Main research objective:

How can aerial photographs and fieldobservations be used to give insights in the distribution of erosion conditions in the Kiambu area.

The following questions need to be answered:

* What are the interpretated erosion features, differentiated to types and intensities of the 1978 aerial photographs?
* What is the actual 1993 erosion condition in different parts of the Kiambu area?
* How do the aerial photograph interpretations compare to the actual field condition, concerning erosion features and land use?
* What are the cover and slope conditions in different parts of the Kiambu area?
* How do slope and cover conditions relate to the distribution of erosion conditions?
* Can landform and land use be used as indicators to stratify the Kiambu area in logic erosion units?
* How are these criteria represented on the APs of 1967 and 1978?

# CHAPTER 3: METHODOLOGY

There are different ways of mapping erosion depending on the purpose they will be used for. Erosion maps can roughly be divided in three different classes:

1- Maps that represent the erosion status at one time in a certain area. These maps give information on the place of occurrence, intensities and types of erosion features also incorporating sedimentation patterns

2- Erosion trend maps which indicate areas of increasing or decreasing erosion rates. They are elaborated based on different time series of erosion data and offer the possibility of erosion trend analysis.

3- Erosion hazard maps. These maps are considered most detailed. They generally do not give information on the erosion rates but describe topographic, climatic, soil and land use factors that determine the erosion risk in a mapping unit.

The relative importance of the API is highest in the first mapping procedures. Mapping erosion features and their intensities is largely based on API especially when information is needed of past erosion. A fieldcheck will always be necessary to validate the interpretation. In erosion hazard mapping, field observations are more important compared to the API. Detailed information is necessary to determine the factors influencing erosion. Sometimes even quantitative estimates of soil losses are provided when by erosion affected soil depths are compared with undisturbed soil depths. Also quantative estimates can be obtained if, by using runoff plots, factors of the USLE* equation can be determined.

An estimation of USLE factors calls for detailed runoff observation over several seasons. Still the estimates remain site specific covering only one land use under fixed conditions. In other words they cannot be extrapolated to larger areas without losing their significance. Most data should be treated as point data representing a limited area. This gap between the scale of observations and the desired scale of presentation is further discussed in §4.2. To overcome this type of scaling problems in this study an object oriented and data driven approach is used.

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* In the Kiambu area some estimates of the soil loss by runoff, vary from 20 t/ha/season on cultivated land to 70 t/ha/saeson on bare soils. The USLE crop-factor varies between 0.02 for (irrigated) coffee and 0.49 for maize (Lewis, 1985). The C-factor for large scale tea is not investigated.

Object oriented in this context means for the description of erosion, representative mapping units will be chosen. The units have geometric characteristics and a uniform thematic content. The thematic content will represent an erosion condition class. The mapping units are the objects looked for.

Data driven here means the objects or mapping units are not known on forehand but will be delineated according to key data. This key data will contain information on factors presumed to be highly correlated with the distribution of erosion intensities.

In our case the key data and interpretation keys will be :

- the photocharacteristics of erosion features
- the photocharacteristics of land uses
- other image appearances that can be used as indicators e.g. slope, type of slope, cattle trails, drainage pattern.
- field information on erosion conditions, land use and slope.

From the many image characteristics (grey tone, texture, spatial pattern) mutually discernable mapping units have to be distilled. This presumes knowledge of the possible occurrence of object characteristics in a certain context, as well as knowledge of the image appearances of possible objects. Some image appearances may not be recognized correctly and need validation by a fieldcheck. All this information is referred to as expert knowledge. It is often applied in an informal way, making the interpretation process iterative. It means the stratification is an iterative process of recognition, validation and delineation.

The main interest of this study is erosion. It is important that the rules or expert knowledge, according to which the area is stratified, are made explicit. It allows for a better understanding of which factors are considered important, in determining the distribution of erosion, and which factors are regarded less relevant. This way an evaluation of the interpretation results is possible which allows adjustments. It also offers a method for future use.

As stated before this study is part of a more extensive PhD research for which a GIS will be developed. By using an object oriented and data driven approach the mapping units will link up with the basic mapping units used in this GIS. These units will form the basic units of analysis to relate to all other variables.

First an interpretation is made of a time series of APs of 1967. Areas affected by sheet erosion are discerned, as well as the drainage pattern. Also boundaries of broad land use zones are recognised. This API is used to make the stratification of the study area. The stratification is used to select three sample area each representing a stratified unit. With an optical pantograph the photo interpretation is transformed to a topographic map (scale 1:50,000, 1968) to create a base map.

Based on detailed fieldobservations and the API of 1978 (1:25,000) three erosion maps are made of the different sample areas each representing a larger area. The map represents erosion condition classes for the 1978 situation. Erosion features and land uses are interpretated and related to the present landuse. The interpretation result is compared with the 1967 API. The influence in scale as well as possible land use changes are discussed. A description is given of erosion trends and its relation with changing land use. A satellite image of 1986 (Thematic Mapper (TM) image, band 3,4,7) is used for overview. This image is scaled 1:50,000 and is covering the whole study area.

The detailed data on soil surface factors are statistically analyzed in SPSS. First all possible T-tests are performed, to examine whether the erosion conditions in the stratified units differ significantly. The variable slope is used to check differences between the sample areas. The variable cover is used to check the differences between different land uses. Finally linear regression analyses are performed to examine the correlations between slope, cover and erosion conditions.

Tabel 3.1 Overview of activities

| chronological overview of activities | -source of information |
|---|---|
| stratification of broad landforms and land use zones | -API of 1967<br>-topographic map<br>-additional field observations |
| ↓ | |
| base map | |
| ↓ | |
| selecting sample areas | -base map<br>-API of 1978<br>-additional field observations |
| ↓ | |
| erosion stratification | -API of 1978<br>-TM image<br>-detailed field observations |
| ↓ | |
| statistical analyses in SPSS | -detailed field observations on slope, cover and Soil Surface Factors |

Table 3.1 gives an overview of the different activities and their information sources. The APIs are generated as part of the activity where they are first mentioned. Since the interpretation process is iterative they are adjusted whenever this is required by new information.

# CHAPTER 4: STRATIFICATION

## §4.1 Introduction

When stratifying an area the purpose of the stratification has to be clear. In this case mapping units are looked for, which can be classified as logic erosion entities. The criteria according to which the mapping units are delineated need to be described in order to understand the erosion processes taking place.

In understanding the occurrence, types and intensities of erosion it is very useful to look at the factors that are closely related to erosion. According to Bergsma (1982) the API as for soil surveys can be best used to determine the basic mapping units in erosion mapping. Erosion features are often closely related to factors that determine soil differences: e.g. geology, relief, landform, vegetation, landuse. Subdivisions can be made incorporating slope, slope length, erosion density and conservation practices.

It can also be argued that geomorphology provides the best basis for classifying terrain because landforms are often clearly displayed on APs and in the field. They can be classified hierarchically from smallest to largest. They also cover the terrain continuously in space and time and many soil related processes, like erosion, are closely related to landforms (Cooke & Doornkamp, 1990).

The approach chosen for in this study is based on the assumption that factors influencing erosion processes should be used to delineate the mapping units. Soil erosion by water is influenced by land use, topography, soil erodibility and climatic conditions. The most important factors influencing the distribution of erosion intensities is believed to be land use and landform. Soil conditions and climate have a lower spatial variation than land use and landform. On a semi-detailed scale they will have less influence on the large variation of erosion intensities. Despite this spatial variation landform is regarded as a relatively stable terrain feature in time.

Land use in agriculture is defined as the vegetation covering a soil and the level of inputs applied. Under the same topography, soil conditions and climate the only factor influencing the erosion changes is landcover. By varying landcover the erosion intensity will also vary. If the surface cover condition are minimal, slope degree plays an important role in determining the amount of erosion in an area. Steep areas, with little cover, will develop the highest soil loss rates. Gentle sloping lands, with higher cover, will provide the best protection against soil loss. When the cover is higher than 70% (Cooke & Doornkamp, 1990), the erosion intensities are stabilised. In areas with the same soil and climatic conditions the spatial relation, between landform and landcover, will determine the distribution of erosion intensities.

## §4.2 The scale factor

When mapping erosion features, one of the difficulties is, to determine the scale of the working map and the scale of the final map for presentation. The working map, also called base map, represents the APIs. The final map should generalise the information, according to the purpose of the mapping procedure. The final map is of the same or a smaller scale than the working map. A final map of a larger scale, suggests a higher accuracy then can be verified and should be rejected.

In this study, one of the scale conditions is made by the possibility to differentiate erosion features by type, occurrence and intensity. A limited availability of APs is also a restriction. A last condition is formed by the demand that the results can be used in an extended study of the Kiambu District. How are these conditions translated in scale requirements?

In differentiating erosion features three levels of survey are recognised according to Bergsma (1982):

1- farm survey
2- catchment survey
3- (national) erosion inventory survey

**ad 1)** The farm survey is used for *detailed* erosion studies for implementing conservation measures on farm level. At least five classes of erosion types and intensities can be made, not including sedimentation, badlands and flooding areas. The scale of the APs to be used and the final map range between 1:1,000 and 1:10,000. Field investigations are more important compared to the use of APs.
**ad 2)** The *semi-detailed* catchment survey requires APs scaled 1:10,000 to 1:40,000 to generate a final map of 1:25,000 to 1:100,000. Different types of erosion features are still visible on these APs but the intensity classes are limited to three (light, moderate and severe). Slope forms, parts of landform and faces of groups of fields can be recognised. A full API is considered essential in this type of survey. Still field investigations are needed. Also satellite images can be of limited use.
**ad 3)** In the erosion inventory survey the purpose of mapping is to assist in *regional* or *national* environmental planning. The degree in which erosion threatens the national resource agriculture is an important factor in planning in the long run. Broad classes of erosion types are distinguished e.g surface erosion and gully erosion. Erosion intensities are considered less important because the main objective is to select priority areas for soil conservation planning. This also explains why field observation are not very detailed. The scales of APs used range from 1:40,000 to 1:100,000 to come to a final map of scale 1:200,000 to 1:1,000,000.

From the above types of surveys the *semi-detailed* catchment survey seems most suited for the Kiambu area. Although the differentiation in intensities is limited, still individual erosion features are interpretated. The available APs of 1967 are scaled 1:50,000. These will be used for the stratification of the Kiambu area. The final map used for the presentation is scaled 1:100,000. The 1978 APs are scaled 1:25,000 and are used for detailed interpretation. It will be too time consuming to interpret the whole study area completely. Therefore sample areas will have to be selected.

### §4.3 Levels of stratification; broad landforms

A delineation according to broad landforms is chosen as a first stratification level. In combination with a TM image of 1986, the API of the 1967 APs is used for this stratification. In the area a distinction is made between level land and sloping land. These units are classified as dissected plains and sloping land dominated by ridges, respectively. This classification is based on Remmelzwaai (1991) who gives a hierarchy of landforms.

Figure 4.1 Sloping land with approximately 40% slope degree

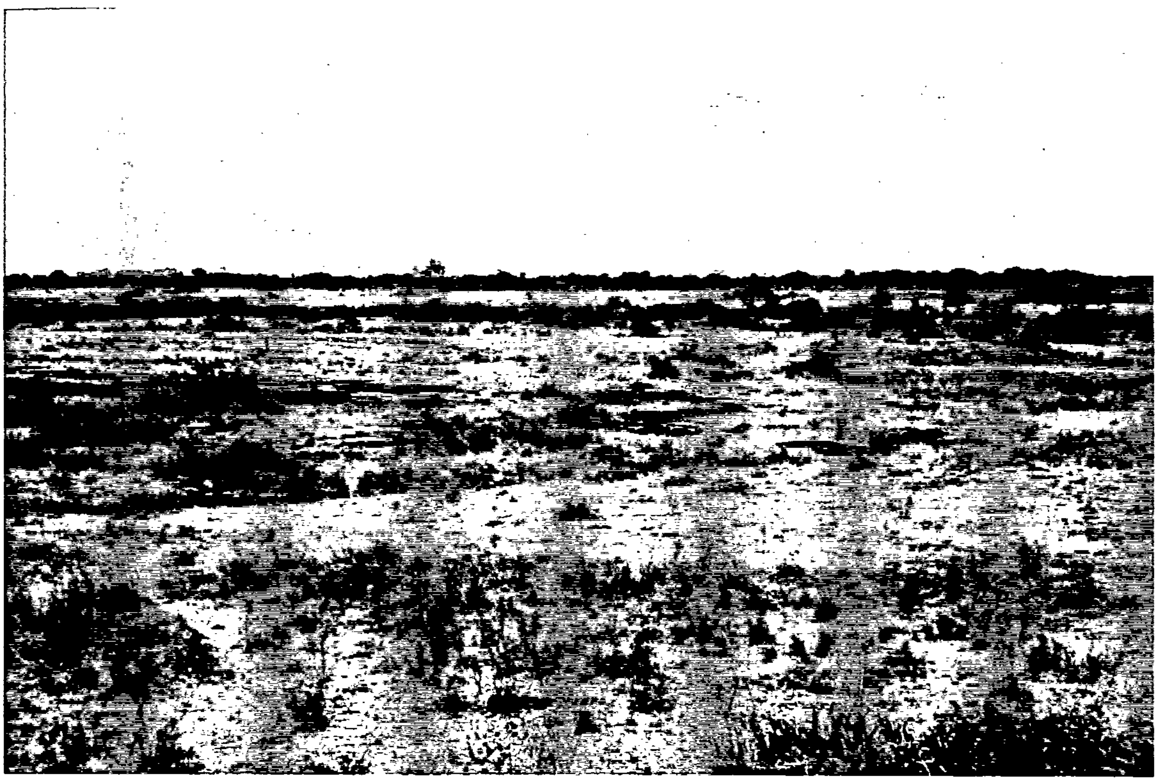

Figure 4.2 Level land with ranging as dominant land use

On the TM the resolution of landcovers clearly reveals this boundary. The boundary is highly correlated with the irrigated large scale coffee zone. Likely it also indicates the transition of agroclimatic zones. The plains are much drier than the sloping lands. This is indicated by a blue reflection on the TM image. A blue reflection indicates dry, scarcely vegetated surface. Because the TM image is covering the whole study area a good overview is obtained.

The APs, with the same scale (1:50,000) as the TM image, are used for detailed delineation of the boundary. The stereo images make a clear differentiation possible. The change in gully density denotes a break in the landform. This is interpreted as a sudden decrease in overall slope steepness. In the level area the stream density is lower and the area in between is flat. The boundary is delineated including the points where streams or gullies join.

The resulting units however are still too large to be used as meaningful erosion entities. This is why a second stratification criterium is needed. Since soil conditions are not considered a suited criterium, the drainage pattern is used. Drainage pattern of course is a result of erosion processes, although it does not necessarily reveals signs of recent erosion.

In the Kiambu case a remarkable differentiation is possible especially in the sloping area. Three different types of drainage patterns can be recognised.

In the north western part of the study area the drainage pattern is dendritic. On the TM image the gullies and streams are easily recognised by the linear red reflection of dense vegetation. The gully beds and sides are relatively moist allowing this vegetation. The density of gullies per surface area is high.

In the more downstream part of the sloping land the pattern of the gullies is remarkably different. Here the gullies occur less frequent. Their orientation changes to an overall northwest-southeast direction. The pattern changes from dendritic to parallel with less and much shorter, often rectangular, branches. In the southern part of the sloping area the pattern shows no clear characteristic and is classified as mixed.

In the dissected plains the orientation of the streams is generally the same. The only differentiation that can be made with help of the drainage pattern, concerns the drainage density. Three different zones, decreasing in drainage density from northwest to southeast, are recognised. Again the APs are used for the detailed delineation of the boundaries. The boundaries include, as much as possible, natural features like streams and points where streams join. Due too the lack of streams for orientation the most south eastern boundary is drawn according to the 1500m altitude.

The clear difference in drainage pattern in the sloping land can be explained by the occurrence of andosols in the north eastern part of the area. This part has the highest altitude and is situated on the footslopes of the Aberdare mountains. These mountains are of volcanic origin. The lithology consists of consolidated basalt. This is more resistant to the scouring of runoff water than the periclasts and soft ashes or tuffs which can be found in the southwestern part of the sloping land.

## §4.4 Land use as third level stratification

At the third stratification level land use is used. Here the delineated broad landforms are subdivided according to broad land use zones. A differentiation is made according to small scale and large scale farming. It is expected that small scale cultivation, which is dominated by annual crops, generates more soil loss than large scale cultivation. Large scale tea and coffee plantations provide year round cover of the soil. In most cases the surface litter is left on the fields to regenerate nutrients. This increases surface roughness and decreases the runoff impact on the soil.

Also small scale farmers grow coffee trees. Contrary to large scale farmers they have to sell the berries through middlemen and hardly make any profit. Since it is forbidden by law to cut the trees, most small scale coffee trees are neglected and intercropped with maize and beans. The dominating crops in small scale farming are subsistence crops which are harvested every season. This means parts of the year the soil is left without canopy. Usually soils are left bare just before the rain is starting. This way the soils are easily saturated with water for the seeds of the next crop but it also makes the soil very vulnerable for splash and subsequent sheet erosion. Except for the harvested crop often also the crop residues are removed to be used as fuel or fodder. This way no surface litter, to increase the surface roughness and limit the impact of runoff, is left.

In the large scale farming area a subdivision is made between the coffee and tea zone. In tea plantations the soil loss due to runoff is expected to be less than in coffee. In mature tea the canopy can reach a 100% cover. The coffee trees are spaced in squares of 3*3 m leaving open spaces. In the small scale area the scale of the photographs did not allow for a more detailed differentiation between land uses.

On the 1967 APs the boundary of between large scale and small scale farming is clearly visible. It is more difficult to make a distinction between tea and coffee zones. In some cases it is possible to recognise coffee by its shadows trees. Tea does not grow well under trees while coffee does. However not all coffee plantations have shadow trees. On the APs the faces of plantations can be recognised but not the distinction between tea and coffee. At this point the TM image proved to be useful. The resolutions of tea and coffee differ. Tea has an almost pink colour while coffee appears fully red, especially when irrigated.

Figure 4.3 Differentiating between large scale tea and small scale farming

## §4.5 Selecting sample areas

Because of the size of the total study area (2573 $km^2$) it would be too time consuming to make a full interpretation. For this reason sample areas are selected. Within these sample areas the smallest erosion units will be delineated. For this delineation, the 1978 APs are used. Together with detailed observations of the soil surface, the API is used to classify the erosion mapping units in representative erosion condition classes.

Because erosion by water is conditioned by hydrological processes, often socalled hydrological units are used as the elementary geographical units; e.g (sub-)catchments. These units represent the erosion processes and subsequent runoff, taking place in that area. The boundaries are profound, to prevent runoff water other than originating from precipitation on the represented surface from entering the unit. However, the size of the catchments to be used is difficult to chose. Also the erosion conditions within one (sub-)catchment are not constant. On APs of scale 1:25,000 detailed data concerning slope, land use and erosion features can be distilled. This will be lost when subcatchments are used to represent the information. The catchment boundaries do not necessarily have to overlap with the broad landform and land use boundaries nor do the erosion condition classes.

For the selection of sample areas other criteria have to be looked for. The intensities of erosion processes will vary according to landcover and slope. The sample areas therefore must offer a variation in these factors. In the sloping area, dominated by ridges, the landcover varies in different sites along a slope. This is why the different sample areas are chosen perpendicular to the direction of a stream or gully. They will cover at least one ridge in between two streams and slopes on both sides of one stream. To discriminate between the broad land use zones the sample areas will at least cover small scale and large scale farming systems.

Of course there are also less controllable factors influencing the selection of sample areas. These are time, accessibility of the areas and the availability of the APs. Time means, the sample areas must have a limited size, to be able to interpret them. The areas chosen, measure 1*2 $km^2$. For logistic reasons their size is rectangular. Accessible means, the areas can be reached from a central camping place within reasonable time. There must be roads, although too much infrastructure should be avoided. This may affect its representation for a larger area. The overall land use in a sample area, should be agricultural production. Inevitably houses will occur but it must not be a residential area.

The most limiting factor in the selection procedure is the dependence on available photographs. Initially the area was believed to be covered by three time series of photographs, also using APs of 1948. Due to logistical problems only two time series were available. Some selected areas were rejected because of a low printing quality of APs. These photographs were printed by manual exposure of light, making the grey tones within one photograph too variable to correctly discriminate for instance sheet eroded sites. Also one selected area was, on the APs, obscured by clouds.

Finally three different sample areas were selected, each believed to be representative for the broad landform and land use zones they cover. Two of them are situated in the sloping lands, covering large scale tea, large scale coffee with and without shadowtrees and small scale farming. The altitude between the two areas differs 200 m. In the range lands the sample area is larger of size, only covering one slope side of a stream, because the land use in these plains is more uniform.

# CHAPTER 5: AERIAL PHOTOGRAPH INTERPRETATION

## §5.1 Introduction

Aerial photographs are useful tools in mapping erosion features. Many erosion features have a size, pattern or grey tone that can be recognized on AP. Some features like large rills and gullies, are directly visible, others like sheet erosion may be inferred using indications concerning grey tones, vegetation and field position. Recent erosion features are easier to recognize then older ones. When using aerial photographs the scale, reprint quality and season and frequency of flight are of great importance for mapping these erosion features.

In the interpretation of APs the geometric or spatial resolution plays an important role. The geometric resolution is the visual detection of a contour on the APs. These contours are the product of a change in granular density, tone and pattern on the APs and the imagination or expectation of the interpreter (Loedeman in 'Remote sensing: theorie en praktijk', p.98-99).

## §5.2 Erosion appearances

Sheet erosion is believed to be the largest contributor to soil loss (Bergsma, 1986). In the Kiambu area, all of the sloping land is affected by sheet erosion. The erosion intensities however, differ considerable. The scale and quality of the APs determine to what extend a discrimination between different intensities can be made. Sheet erosion is difficult to detect, before it reaches a pronounced stage. It can only be recognised when it has caused a change in the colour of the surface soil or in vegetation. The subsoil, with different colour, may show up on the AP after sheet erosion has washed out the overlying material. Then a different grey tone is visible. Course material, accumulated at the soils surface by the washing out of finer materials, shows up light on the AP. Also a greater amount of light is reflected by course particles.

If part of the top soil is removed, the moisture holding capacity, depth of the profile and fertility decrease. The soil dries out quicker than non-affected areas and vegetation is shorter and more openly spaced. These differences will be reflected in the tone and pattern of the AP and can be indicators of sheet erosion. Dryness is reflected by a light grey tone.

But grey tones on APs are also influenced by other factors, irrespective of sheet erosion:

- position of the feature in the terrain (slope degree)
- surface roughness of the fields (shadow effects)
- position of the sun (summer/winter observation); in the Kiambu case, situated slightly South of the equator at 0°25", this is of no influence.
- hot-spot effect in the centre of the picture (light reflection)
- light reflection of salt crusts
- absence of vegetation (light reflection)
- relative moist conditions of freshly ploughed land (dark reflection)
- overall dark colour of the (top-)soil

Summarizing one can say that light tones may indicate moderate or severe sheet erosion via indications like dryness, coarse material and poor plant growth and cover. But in some cases sheet erosion appears as a dark tone (see §7.3) or light tones are caused by other effects. Generally the mottled faces of contrasting grey tones appear non-directional and can have natural or land use boundaries. Except for grey tones and vegetation patterns also the position of the features in the field can be used as an indication. Shoulders of valleys, convex slopes, drinking places and trails in grazing lands are positions vulnerable to sheet erosion.

The more contrasting the grey tones and granular pattern are, the easier contours of faces can be detected. In more homogenous conditions changing tones and pattern will be easier to detect. This means that in the Kiambu area more faces of different tone and texture are detected in the large scale coffee and tea plantations compared to the heterogenous scattered small scale farming area.

For rill erosion generally the same accounts as for sheet erosion. Depending on the scale of the APs, rills will be visible by their mottled linear exposure on the APs. They normally cross the contour lines. According to Bergsma they will be visible on the 1:25,000 APs. Their representation on the 1:50,000 APs is uncertain.

Gully erosion is detected more easily, especially when using stereoscopy. Depending on the shadow effects active gullies on APs can be separated from stabilised ones. Also stabilized and incipient gullies may have some vegetation where young and active gullies are bare.

The advantage of API compared to the use of satelite images for the mapping of erosion features is the detailed scale in combination with the stereo image that can be obtained. For erosion studies the relief is very important. Not only can it be used as an orientation, relief also forms an important factor in the occurrence and intensity of the erosion features. The TM image used gives an overview of the area revealing different vegetation.

## §5.3 The APIs of 1967 and 1978

Gullies or streams are clearly recognised on the small scale APs. Different drainage pattern are discriminated. Besides the difference in pattern, the gullies can also be differentiated by their form. In the upper sloping region the gullies are narrow, deeply intersected and V-shaped, while in the south eastern part the parallel gullies are much broader. They are U-shaped and the broad stream valleys are in some cases cultivated.

In the sloping area no evidence is found for active gully erosion. The stream sides are covered with vegetation. Incidently bare sites are identified in the small scale farming areas. These sites are interpretated as harvested fields. Only in the level range lands some small active gullies, branches of the main streams, are discriminated.

The convex ridge crests, more or less marking the beginning of a slope, are significantly affected by sheet erosion. Even on the 1967 APs this is clearly visible. Faces of contrasting light tones appear along the contour.

Slopes, even uniform ones, can show typical bands of light and dark grey tones, rectangular to the slope direction. This is recognised on both APIs. The ridge crests are light, followed by an accumulation zone where there is no clear sign of sheet erosion (probably the input and output of soil material is equal). This zone has a darker grey tone. Downstream where the slope reaches the valley or gully again a lighter zone can be recognized. This might be the combined effect sheet and rill erosion.

The areas being affected by sheet erosion are for a larger part situated in the small scale farming systems. The rationale being that these areas are dominated by annual crops like beans and maize. Since they are harvested every season the soil is not covered part of the year. This results in a higher vulnerability for splash and subsequent sheet and rill erosion. The small scale API mainly concentrates on sheet eroded areas, although it is likely that sheet and rill erosion will go hand in hand; the ridge crests of slopes are dominated by sheet erosion while, down slope depending on slope form and steepness, on $^1/_3$ of the slope length rill erosion is likely to occur. Overall the scale is too small to recognise these linear features.

Rills are not recognised in the API of the 1:50,000 and 1:25,000 APs. In the small scale land use zones rills probably do occur but they can be obscured by the frequent land preparation practices.An exception are some incidental sites in the level plains in the south-eastern part of the area. Here sheet erosion occurs in combination with visible rill erosion. Rill erosion appears as linear faces of mottled light tones in a radial pattern. Although the inclination is much smaller, which makes the area less vulnerable to rill erosion, the much smaller intersection with gullies and more uniform land use and grey tone, probably cause the rills to be so perceptible.

Since differences in grey tone can result due to factors irrespective of sheet erosion -see §5.2- it is impossible to give a uniform absolute index of grey tones, representing the intensity or severity of sheet erosion. On the small scale API the areas marked as affected by sheet erosion merely have a significant lighter grey tone than the surrounding areas. It means the marked areas display a range of sheet erosion intensities. In the more detailed API of 1978 several intensity classes can be identified.

It is important to note that in large scale farming areas faces of sheet erosion are more easily recognised because of the higher contrast with the homogenous grey tone of surrounding areas. In the more scattered small scale farming systems a larger variation of grey tones occurs. Due to a limited contrast contours are less clear. For that reason the recognition of areas affected by sheet erosion is more difficult. Compared to small scale farming systems the intensity of sheet erosion in the large scale farming area will be less.

Compared to the 1967 situation on the API of 1978 less areas are covered by natural or secondary forest and shrubs. Most of these areas are situated near the streambed on the steepest parts of the slope.

In the range lands differences between land formerly used a sisal plantation and non-cultivated lands is clearly visible. In the non-cultivated land erosion is more intense. While on the 1967 API the sisal plantations are operational, on the 1978 API field boundaries are less clear. Probably at this time people started to abandon the plantations.

# CHAPTER 6: FIELD OBSERVATIONS

## §6.1 Introduction

To evaluate the stratification based on the APs, additional field observations are necessary. In this study the field investigations are made for different reasons. The function of the observations differ for the different scales of the API.

First the investigations should serve as a fieldcheck for the 1967 API of 1:50,000. Since in this API a limited amount of erosion types is interpretated and no differentiation into different intensities can be made the field investigation do not need to be very detailed. They should give answer to wether or not the drainage pattern and land uses are qualified according to the field situation. If this is not the case it does not necessarily mean the interpretation has been wrong.

In the 26 years time since the photo observations the field situation has changed. It is believed the drainage pattern has not changed but land use changes did occur. Some faces in the large scale farming, interpretated as areas of semi-natural condition used for grazing or timber, actually are coffee plantations. The area used for small scale farming compared to large scale farming has not changed. In the tea plantations billboards were placed inside the tea fields indicating areal, tea species and date of planting. All tea fields were planted before 1967. Some fields were renewed. Small additional areas were planted at a later date.

Secondly the field observations should give additional information on areas which could not be clearly identified on the photographs of 1967. After the fieldcheck for instance some amazing white linear features surrounded by trees proved to be golfcourses. Areas recognised on the photographs as secondary forest showed up to be coffee plantations with shadow trees.

A third function of the fieldinvestigations is to give additional information to the 1967 API, for the selection of sample areas. It should be verified wether the variation of slope is according to the photo impressions. Also the variation of land use, in the small scale area, needed to be checked.

Detailed field observations are performed in these sample areas. The detailed field observations concern canopy, surface litter, slope and soil surface factors as indicators of soil erosion. In this phase first the actual erosion status of the sample areas is assessed. The 1978 APs are interpretated. Not only erosion features concerning rill, sheet and gully erosion are recognised. Faces of different land use are interpretated. Also a discrimination of steep (> 10%) slopes is made. The observations are used as a field check for the occurrence, types and intensities of gully, rill and sheet erosion as well as a validation of the delineated land use and slope units. Sheet erosion is believed to contribute most to the soil erosion. These features appeared most active in the field. It is only in the range land where active gully and rill erosion was recognised.

Because the API is of a larger scale (1:25,000) more detailed information is generated. This means more changes are identified compared to the 1993 fieldsituation. These changes concern landuse. Especially the third sample area shows a different land use and more erosion than could be expected from the 1978 APs. This is the main function of the field investigations supporting the 1978 API. To analyze the spatial relation between land use, slope and erosion conditions and discover their influence on erosion trends.

## §6.2 The method for field investigations

Field investigations concerning erosion conditions, are often made to determine the different factors of the USLE equation, developed by Wischmeier. This requires intensive field measurements. They involve detailed year round observations of soil and soil depth, precipitation intensities and amounts of soil loss of runoff plots. This study aims to provide a method, to asses the erosion conditions of a large and stratified area, in a limited time span. Observations concerning erosion factors, as they are defined in the USLE equation, will be too incidental and too time consuming. Therefore a different approach is followed.

In erosion studies most 'quick and dirty' erosion assessments are qualitative statements. They can be nominal or at best ordinal. They enclose ad random observations, interviews and transects observations. To be able to analyze the spatial relation between slope, landcover and erosion conditions statistically, rational data is needed.

A classification used by Clark (1978) provides quantitative assessment of erosion conditions in different areas. The advantage of this classification is the possibility to compare assessments of erosion conditions of different areas, as long as the observations are undertaken consequently. The data are rational, allowing for statistical regression analysis.

The method is elaborated by the bureau of land management in Denver U.S.A. in 1970 as an erosion inventory procedure to be applied to 160 million acres of public lands. It has been used for 135 million acres of arid and semi-arid soils from 1971 to 1978 in the state of Colorado. In 1978 Clark presented a technical note for a revised system, to classify the degree of accelerated erosion condition and to give guidance on the field method for measuring the erosion condition in a sample area. Clark states that the method will not be used for the evaluation for areas in which wind is the dominant erosional agent. No mention is made about the size of the sample areas.

The erosion condition is represented by field observations made on seven surface features that are visually affected by current wind and water erosion activity. These seven Soil Surface Factors (SSF) are: soil movement, surface litter, surface rock fragments, pedestalling, flow patterns, rills and gullies. In this observation method sheet erosion is represented by five of the seven factors. Since in the Kiambu area sheet erosion is believed to contribute most to the soil erosion this is considered another advantage of the Clark method.

Each of the SSF is assigned a value in accordance with the degree of erosion as is manifested by the SSF. The values range from 0 to 14 for all features except for the flow pattern and gully SSF. This way the maximum score for the erosion condition in an observation point is 100.

| SSF | weighted value |
|---|---|
| soil movement | 14 |
| surface litter | 14 |
| surface rock fragments | 14 |
| pedestalling | 14 |
| flow pattern | 15 |
| rills | 14 |
| gullies | 15 + |
| maximum score: | 100 |

The scores for the individual SSF are separated into five different classes:

| class | score | |
|---|---|---|
| stable | 0 or 3 | |
| slight | 6 | (5) |
| moderate | 9 | (8) |
| severe | 11 | (12) |
| critical | 14 | (15) |

The decision rules to separate between different classes as well as the definitions of the different SSFs is given in appendix 1. The above numbers in brackets indicate exceptions (see appendix 1).

The total of weight values of the seven SSFs for an observation point determines the overall erosion condition. Again five erosion condition classes are determined:

| erosion condition class | total score |
|---|---|
| stable | 1 - 20 |
| slight | 21 - 40 |
| moderate | 41 - 60 |
| severe | 61 - 80 |
| critical | 81 - 100 |

Note that when in an observation point one of the SSFs is not potentially present no evaluation is given for this SSF. In the Kiambu case this happened for the SSF rock fragments. A soil having no rock fragments in its profile nor another potential rock source is not addressed the value 0. In this case the maximum total of weight values is decreased with 14. This results in a maximum *possible* total score of 100-14=86. The total of weight values of the remaining SSFs is multiplied by $^{100}/_{86}$ to represent the true erosion condition class.

Figure 6.1 Range land with rock outcrop; total score 72

Figure 6.2 Coffee without potential rock; total score 17

No mention is made of the size the area represented by one observation point. In this study the observations are made along transects. Each sample area is described by three transects. The transects are outlined parallel of each other in a 300 m interval. Every 50 m an observation is made. In sample area 1, 2 and 3, respectively 99, 71 and 42 observations are made. It means the sample areas are described very detailed. This allows for comparisons between sample areas but also within sample areas. In case observations are made within one stratified unit, of course no significant differences are expected. The transects have an orientation perpendicular to the stream direction. This way a larger variation in land use, slope degree and subsequent erosion condition is expected. For logistic reasons the sample areas are observed one by one.

Except for the SSFs other variables are observed (see Appendix 2: observation form). In every observation point the land use, canopy (%) and surface cover (%) are recorded. With an inclinometer the percentage slope of the transect is determined including the maximum slope upstream and downstream. Initially, every four observation the soil colour and texture class were taken but this information is not used in the analyses. Special characteristics concerning conservation structures and management practises (intercropping, irrigation, row or plant distance) are noted incidently. Like sedimentation observations these characteristics are not explored structurally but serve as a feedback when analyzing the other parameters.

The transect are outlined on the topographic map scaled 1:50,000 and the 1978 photographs. In the field a compass is used for the orientation. A measuring tape is used to determine the distance between the observation points and between the transects.

## §6.3 Evaluation of the observation practice.

When taking observations along transects in a densely populated area like Kiambu most landowners have noticed the observers already in advance. One does not have to look for the landowner, he/she will come to you. In the Kiambu area this is very useful because most plots are small. In one transect measurements on five to ten different plots are taken. By walking transects it is clear to people where you are going to take your observations and they will give permission. Some farmers became suspicious because they thought the measuring tape was used for land demarcation.

In the field the determination of SSFs is not always easy. Clark states that the total of SSFs obtained by different observers, has an accuracy of ±5 units of the actual value. In this study all the observations are taken by one person. Possible errors made are expected to be structural not influencing the ratio between different observations points.

Especially the discrimination between recent and older erosion features is difficult. In Appendix 1 the determination of the factors soil movement, rock fragments and flow pattern describes recent features. In coffee estates one can clearly see an accumulation of soil and surface material on the upper sides of the trunks and a removal on the lower sides. On the lower side often roots are partly bare. This however is the result of decades of erosive forces. The size of the stem gives an indication of the age of the coffee trees. To recognise recent erosion features use is made of lichen and algae covering the stem. The part of the stem not covered by lichen is used as an indicator for soil movement. The same accounts for the determination of rock fragments. The sedimentation is often estimated relatively to other observations points.

In the small scale farming area the field conditions were disturbed. The crop was just harvested or soil preparation had taken place. Sometimes the crop residues were only temporarily left on the field. It could be difficult to tell wether the surface litter and soil were removed by runoff or by human influence. In most cases undisturbed spots could be found representing the disturbed sites. In general one can say, that the observations represent only the conditions in the small scale area, at one stage in the cultivation process. In the large scale area the crops and surface conditions are more constant. In the range area the burning of grasslands is a disturbance factor only influencing the surface cover.

Figure 6.3 Large scale coffee tree with visible lichen, bare roots and accumulated litter on the upper side of the stem.

# CHAPTER 7 OBSERVATION ANALYSESS

## §7.1 Large scale tea & coffee

In the tea zone only slight changes in land use can be detected. Young tea plants on the 1978 API, have matured. Other slopes which were covered with trees and shrubs are now replaced by tea plants. Compared to the 1978 situation the area of the large scale tea has increased.

Agricultural expansion is occurring primarily in areas with steep slopes. These areas are mostly situated near the stream beds and were formerly used for forest and woodlot. This accounts both for tea and annual crops in small scale farming. Farmers plots, as they were identified on the 1978 APs, appeared to be subdivided. This clearly indicates the diminishing landownership per capita. From conversations with farmers it became clear conflicts have arisen between the tea estate management and neighbouring small scale farmers. More and more farmers are penetrating the estate to cultivate unused land. The estate management replied by demolishing bridges, crossing the stream and by covering the unused sites with tea.

Severe to critical erosion conditions occur in the young planted tea on steep slopes. The washed topsoil obstructs increase of the foliage. On convex and steep parts of the slope, the canopy of tea is less developed. These areas are also considered to be most vulnerable to sheet erosion.

Figure 6.1 Young tea (approximately three years old) on steep slope

In large scale coffee the erosion intensities differ according to the slope, coverage and litter. Most significantly however is the variation according to the level of input. When shadow trees are planted, the erosion condition is best, due to the extra amount of surface litter. In the second sample area pits are dug in between four coffee trees, for irrigation. If these pits are not cleaned regularly they will be filled with sediment, causing excess water to flow down stream, into the next pit. Then very local erosion occurs. Overall the erosion is limited.

Almost all roads in the coffee and tea estates showed signs of active erosion. Runoff, concentrated along road sides, is therefore believed to contribute considerable to the total erosion in the large scale estates. A survey performed by Lewis et al (1984), revealed that 94% of the gullies in the Kiambu District, had been caused by runoff, emanating from roads, culverts and buildings. In the tea estate 1 m broad paths, crossing the tea fields like a grid, form perfect pavements for runoff to concentrate. At intervals, pits are dug to decrease the runoff impact. It is not clear what the contribution of these paths to the total erosion is. The surface covered by these paths is estimated on less than 1% of the total surface of the tea plantations.

## §7.2 The second sample area

The second sample area is situated on the boundary between the sloping and level lands. This boundary, based on a change in gully density, denotes a break in the landform. During the field observations a waterfall was found as prove for this boundary. This was also visible on the APs. The gully type changed sharply, from U-shaped with side slopes <30% and a relief intensity of 15m, into a V-shape with sideslopes of >50% and a relief intensity of >30 m. The erosion risks downstream this waterfall therefore are higher and the area should be left under natural condition.

The geomorphological causes for this change in flow pattern are not clear. Normally a change in parental material or rock explains the occurrence of a fall. The abrupt change may also be the result of natural erosion that causes the river to scour through the rock layer, at this point. However an equal situation arises in a parallel stream at 5 km distance.

In the large scale high input coffee estate the irrigation induced detachment and sedimentation of soil into the nearest pit can be defined as lateral erosion.

## §7.3 The range lands

A discrimination can be made between areas dominated by lateral erosion and areas dominated by vertical erosion processes. Especially in the ranging landuse in the third sample area vertical erosion is dominant in the vertisols. The surface of vertisols is dark and characterised by deep cracks. Cracks can be as deep as 0.50 m with a the surface roughness of 0.20 m. This is caused by the gilgai effect: swelling and shrinking of the clay soil. This gilgai effect will considerably reduce the runoff, due to increasing surface roughness. Soil particles detached by the impact of rain drops or wind are deposited in the cracks. Still the infiltration capacity of the soils is very limited.

Concerning the API of 1978, misinterpretations have been made identifying sheet eroded areas. In the range land different sharp delineated faces of light and dark grey tones appear on the APs. Soils, overlaying rock on the summit of the slopes, are washed away by sheet erosion. On these sites dark rock outcrop is visible. In this case not only light but also dark grey tones, on the APs, manifest sheet erosion.

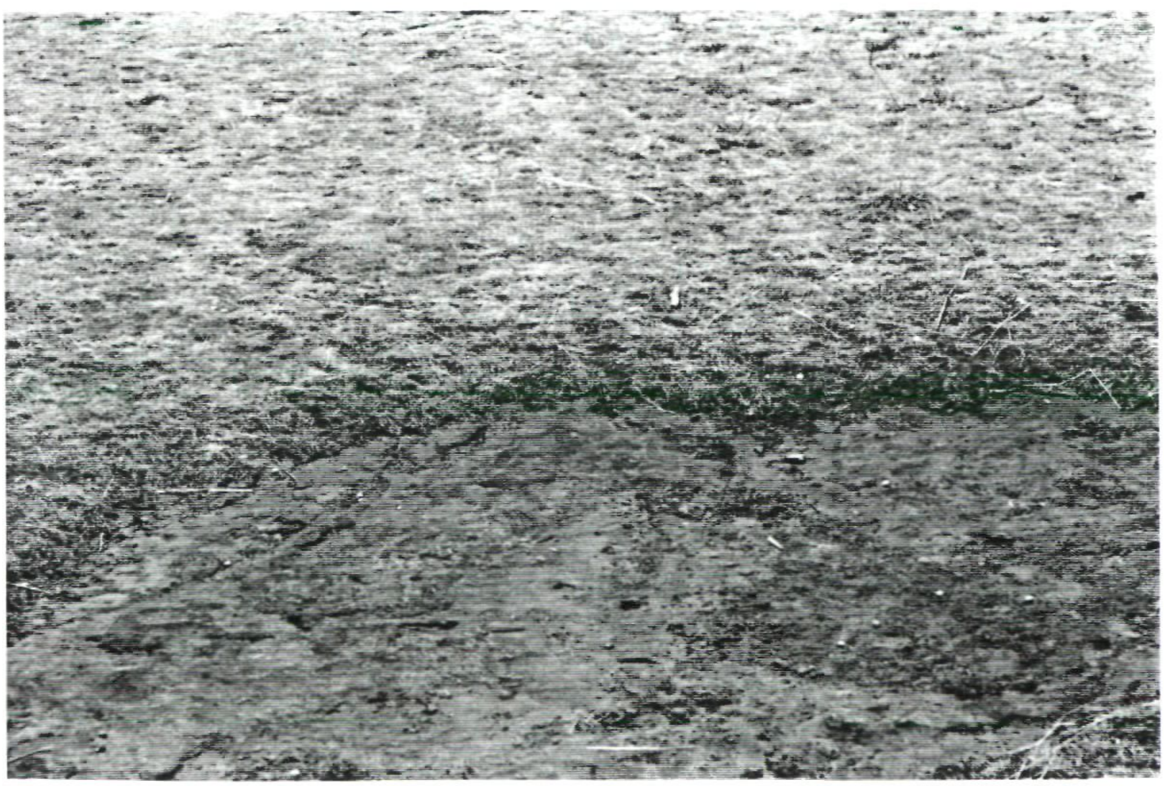

Figure 6.2 Sheet erosion causing rock outcrop - on APs represented by a dark greytone due to the dark rock colour

Although the erosion did not appear very seriously on the APs, during the field investigations a remarkable high amount of pedestals was found. The cover in the area was fairly dense (40%-60%) and the slope percentage on the plains did not exceed 4%. Possibly sheet erosion only takes place in local depressions. Especially the vertisols are undulating and this local slope variation is not expressed in the overall slope. Still it is likely another explanation can be found in the amount of wind erosion. Although the coverage is fairly dense the vegetation height is limited (<50 cm) because of grazing. This increases wind velocity and its capacity to detach and transport soil particles. Frequent noted whirlwinds prove the increasing influence of wind erosion compared to the other sample areas.

One of the reasons why the crests of the stream sides are increasingly vulnerable for sheet erosion is the combined effect of shallow soils with rock outcrop and the intensified grazing of cattle sheep and goat. This means soils with underlying rock largely influence the erosion condition in this semi arid range area.

Erosion is further accelerated by large scale burning. One month before the rain is expected to fall herdsmen set the grasslands on fire. For instance one month after the fieldobservations were made less than half of the surface cover as recorded was left due to this burning. This makes the soil more vulnerable for splash and sheet erosion. According to the herdsmen it is the best way to guarantee a fresh green grass cover.

On the steeper parts near the stream woody shrubs are found. It makes the area attractive for the burning of charcoal. In a circle of 10 to 20 m the shrubs are cut and burnt on a central place. To generate the charcoal the fire is covered with soil. This soil is gathered by digging the topsoil from a neighbouring site. These pits are believed to have a high potential for initiating rill and eventually gully erosion as they are mostly found on sloping sites. But during the fieldobservations no prove was found. This might be because people have started burning charcoal only recently and the pits do not yet substantially affect the vegetation cover.

The APIs of 1967 and 1978 enlighten a change in land use in the plains. The delineation of the rectangular fields, visible on the 1967 APs, has faded on the 1978 APs. In this period already some of the sisal plantations were not operational anymore. Close to the streams the white resolution has increased. This is probably due to more tracks and higher activity of both man and cattle.

Since 1985 the sisal plantation are redistributed among farmers from densely populated high production areas. Although most plots are redistributed already not all farmers have settled in the area yet. However more and more plots are started to be cultivated. The most interesting plots are situated close to the stream on the crest of the slope or covering the slope. These plots have access to water but are also vulnerable to runoff erosion. People have started to clear the protective cover both for cultivating the land and for creating watering places for cattle, sheep and goat.

# CHAPTER 8: STATISTICAL ANALYSES IN SPSS

## §8.1 Comparing between sample areas

Sofar the stratification as described in chapter 4 has been used to delineate the area according to factors like land use and landform. They are considered to determine the distribution of erosion intensities. First it should be analyzed wether these criteria and the erosion conditions in the area differ significantly. The field investigations have a ratio scale and are suited to serve this goal. First the means of the erosion conditions in the three sample areas will be examined with a T-test.

A T-test is used to test the hypothesis that the means are equal against an alternative hypotheses. The alternative hypothesis reads that the means are not equal. In this case there is no expectation of one mean being greater than the other and the T-test is performed in a two-tailed way. If this two-tailed probability is very small, for instance smaller than a degree of significance of 0.05, the hypothesis is rejected and the means are considered significantly different. However in this case, there mostly is an expectation about the size of the two means to be compared. One mean is expected to be greatest. The alternative hypothesis will read that mean A is greater than mean B. In that case only a one tailed probability is needed. Therefore a degree of significance of 10% is used.

Although the observations do not have a normal distribution the high number of observations is believed to give a reliable mean of the variables. It should also be known wether the variances, of the groups of observations to be compared, are equal or not. If the variances are equal the Pooled Variance Estimate method is used to perform a T-test. If the variances are significantly different the Separate Variance Estimate method is used. The SPSS program automatically performs a F-test to analyze the variance. Again a probability is calculated to indicate wether the hypotheses, that the variances are equal, is true.

First the means of the erosion condition are tested between the different sample areas. It is also expected that the slope and cover conditions are significantly different.

Table 8.1 The T-tests between sample area 1 & 2, comparing the means of: erosion condition (EROCOND), slope degree (SLOPE) and the combined canopy and surface cover (COVERX).

Group 1: **SAMPLE** EQ 1 Group 2: **SAMPLE** EQ 2
t-test for: **EROCOND**

| | Number of Cases | Mean | Standard Deviation | Standard Error |
|---|---|---|---|---|
| Group 1 | 99 | **25.7273** | 14.620 | 1.469 |
| Group 2 | 69 | **33.3478** | 16.868 | 2.031 |

| | | Pooled Variance Estimate | | | Separate Variance Estimate | | |
|---|---|---|---|---|---|---|---|
| F Value | 2-Tail Prob. | t Value | Degrees of Freedom | 2-Tail Prob. | t Value | Degrees of Freedom | 2-Tail Prob. |
| 1.33 | **.193** | -3.12 | 166 | **.002** | -3.04 | 132.62 | .003 |

Group 1: SAMPL EQ 1 Group 2: SAMPL EQ 2
t-test for: **SLOPE**

| | Number of Cases | Mean | Standard Deviation | Standard Error |
|---|---|---|---|---|
| Group 1 | 99 | **15.1111** | 12.501 | 1.256 |
| Group 2 | 69 | **10.0725** | 8.938 | 1.076 |

| | | Pooled Variance Estimate | | | Separate Variance Estimate | | |
|---|---|---|---|---|---|---|---|
| F Value | 2-Tail Prob. | t Value | Degrees of Freedom | 2-Tail Prob. | t Value | Degrees of Freedom | 2-Tail Prob. |
| 1.96 | **.004** | 2.87 | 166 | .005 | 3.05 | 165.87 | **.003** |

Group 1: SAMPLE EQ 1 Group 2: SAMPLE EQ 2
t-test for: **COVERX**

| | Number of Cases | Mean | Standard Deviation | Standard Error |
|---|---|---|---|---|
| Group 1 | 99 | **74.7475** | 25.965 | 2.610 |
| Group 2 | 69 | **43.9130** | 17.083 | 2.057 |

| | | Pooled Variance Estimate | | | Separate Variance Estimate | | |
|---|---|---|---|---|---|---|---|
| F Value | 2-Tail Prob. | t Value | Degrees of Freedom | 2-Tail Prob. | t Value | Degrees of Freedom | 2-Tail Prob. |
| 2.31 | **.000** | 8.64 | 166 | .000 | 9.28 | 165.52 | **.000** |

In Table 8.1 sample area 1 and 2 are compared. The probability of the F-value for the variance of the erosion conditions in the two sample areas is 0.193. This is larger than the level of significance of 0.05, which means the variances of the erosion conditions in sample area 1 are equal to the variances of the erosion conditions in sample area 2. For the T-Test in this case the Pooled Variance Estimate is used with a probability of 0.002. In this case there is no clear expectation of which of the average erosion conditions would be higher. The hypothesis is rejected. The means of the erosion conditions of sample area 1 (25.7) and sample area 2 (33.3) are significantly different.

It would be premature to conclude that the conditions influencing erosion in the stratified mapping units, which are represented by sample area 1 and 2, are significantly different. Therefore it is tested whether the criteria for the stratification, as described in chapter 4, also differ.

The criteria are first concerned with landform. In the field investigations the slope degree is taken as an indicator. It is expected that the slope conditions are steeper in the first sample area compared to the second. This T-test is one-tailed. The means are 15.1 and 10.1 respectively. The variances are not equal. The slope mean with a probability of 0.003 is significantly steeper in the first sample area .

A third delineation criterium is formed by land use. For the comparison between the three different sample areas, the combined canopy and surface cover is used as an indicator of land use.

Percentages surface cover and canopy are chosen to represent the effect of land use on the erosion condition in an area. The percentages have a ratio scale and can be analyzed parametrical. A COVER variable is calculated based on field observations concerning the canopy* and the surface cover.

$$\text{COVER} = \text{surface cover} + {}^{2}/_{3} * (100 - \text{surface cover}) * \text{canopy}/100$$

In the equation the percentage surface cover is given a higher weight, compared to the canopy percentage. This is in accordance with Bakker (1990), who performed research in the C-factor of the USLE equation. The C-factor is calculated from four subfactors: ground cover, canopy, soil reconsolidation and high organic matter. The last two subfactors are only accounted for in forest fields. If results of the above equation are compared with non-forest C-factors, given by Bakker, a correlation coefficient of 98% is obtained. If the crop conditions for the calculations of the C-factor, as performed by Bakker, are assumed not to differ from the crop conditions in the Kiambu area, the COVER variable is a good indicator for the land use.

The factor ${}^{2}/_{3}$ is chosen arbitrarily. For two reasons it is believed that the percentage bare soil (100 - surface cover), on sites not covered by

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* *Canopy is not measured for vegetation with a limited height (< 0.5 m)- for instance: grass lands and crops like napier grass, potatos and beans.*

canopy, is 1.5 times as high, compared to sites under canopy. First, under vegetation with a measured canopy, the surface cover will consist of surface litter, originating from this crop. Secondly, as observed in the field, the surface litter will concentrate under the crop, on the upper side of the stems, due to transportation by runoff water.

The final calculated COVER variable is rounded off to decimal numbers to come to the COVERX variable. This variable is used in the analyses.

From table 8.1 it is clear the percentages cover in sample area 1 are significantly higher than in sample area 2. This is no surprise since part of the observations are taken in a large scale tea estate. Mature tea reaches a a canopy of 100%. Since the pruned residuals are left under the crop also the surface cover can be as high as 100%.

Table 8.2 T-tests between sample area 2 & 3 comparing the means of: EROCOND, SLOPE and COVERX

Group 1: SAMPLE EQ 2 Group 2: SAMPLE EQ 3
t-test for: **EROCOND**

| | Number of Cases | Mean | Standard Deviation | Standard Error |
|---|---|---|---|---|
| Group 1 | 69 | **33.3478** | 16.868 | 2.031 |
| Group 2 | 42 | **41.5952** | 10.707 | 1.652 |

| F Value | 2-Tail Prob. | Pooled Variance Estimate: t Value | Degrees of Freedom | 2-Tail Prob. | Separate Variance Estimate: t Value | Degrees of Freedom | 2-Tail Prob. |
|---|---|---|---|---|---|---|---|
| 2.48 | **.002** | -2.84 | 109 | .005 | -3.15 | 108.77 | **.002** |

Group 1: SAMPLE EQ 2 Group 2: SAMPLE EQ 3
t-test for: **SLOPE**

| | Number of Cases | Mean | Standard Deviation | Standard Error |
|---|---|---|---|---|
| Group 1 | 69 | **10.0725** | 8.938 | 1.076 |
| Group 2 | 42 | **3.1429** | 6.222 | .960 |

| F Value | 2-Tail Prob. | Pooled Variance Estimate: t Value | Degrees of Freedom | 2-Tail Prob. | Separate Variance Estimate: t Value | Degrees of Freedom | 2-Tail Prob. |
|---|---|---|---|---|---|---|---|
| 2.06 | **.014** | 4.41 | 109 | .000 | 4.81 | 106.95 | **.000** |

Table 7.2 continued

Group 1: SAMPLE EQ 2 Group 2: SAMPLE EQ 3
t-test for: **COVERX**

| | Number of Cases | Mean | Standard Deviation | Standard Error |
|---|---|---|---|---|
| Group 1 | 69 | **43.9130** | 17.083 | 2.057 |
| Group 2 | 42 | **49.5238** | 16.373 | 2.526 |

| | | Pooled Variance Estimate | | | Separate Variance Estimate | | |
|---|---|---|---|---|---|---|---|
| F Value | 2-Tail Prob. | t Value | Degrees of Freedom | 2-Tail Prob. | t Value | Degrees of Freedom | 2-Tail Prob. |
| 1.09 | **.781** | -1.70 | 109 | **.091** | -1.72 | 89.61 | .088 |

In table 8.2 the T-tests between sample area 2 and 3 are given. Here the examined means also differ significantly, except for the means of the cover of sample area 2 and sample area 3. The mean is 43.9% for sample area 2 and 49.5% for sample area 3. The variances of the means are equal. The T-test is performed two-tailed since there is no expectation about the cover means except that they are different. The two-tailed T probability is 0.091. No significant difference exists between the covers. However, no reasonable explanation can be found why the cover in both sample areas should be considered equal. This calls for some more detail.

The land use in sample area 2 is divided into 29 observations made in large scale coffee, with a mean cover of 56.6%, and 40 observations made in small scale farming, with a mean cover of 34.8%. In the 42 observations made in sample area 3 only range lands occur. This is classified as an separate land use with a mean of 49.5%. The average cover for the two land uses in sample area 2 is 43.9%. The suspicion rises that it is just a coincidence that the two means for the cover in the sample areas are within the confidence interval. It is believed the cover means are unjustly considered not different. It merely indicates that the cover variable is unreliable when evaluating differences *between* sample areas, when the groups are not differentiated into different land use.

## §8.2 Comparing different land use

The third stratification criterium for the stratification of the study area is land use. The cover of the vegetation is used as a indicator to measure the influence of different land uses on the erosion conditions in an area. Broad land use zones are identified forming four different land use classes:

-large scale coffee -large scale tea -small scale farming -range lands.

Since sample area 3 is situated in the range lands and is only covered by grass lands it is not analyzed in this session. This session concentrates on the differences between large scale coffee, large scale tea and small scale farming. The cover conditions and subsequent erosion conditions are expected to differ significantly, especially between small scale and large scale farming areas.

Again the T-test is used to examine the means of groups of observations. These groups are formed by differentiating the observations according to the land use classes. The assumptions made are the same. In this case there are expectations about the cover and the erosion condition in the three different land uses. In tea the cover percentage is expected to be highest and the erosion condition lowest; in small scale farming the cover percentage is expected to be lowest and the erosion conditions high.

Table 8.3 T-tests between different land uses* comparing EROCOND within **sample area 1**

Group 1: LANDUSE EQ 1 Group 2: LANDUSE EQ 2
t-test for: **EROCOND**

| | Number of Cases | Mean | Standard Deviation | Standard Error |
|---|---|---|---|---|
| Group 1 | 22 | **25.6364** | 7.487 | 1.596 |
| Group 2 | 46 | **20.4565** | 16.198 | 2.388 |

| | | Pooled Variance Estimate | | | Separate Variance Estimate | | |
|---|---|---|---|---|---|---|---|
| F Value | 2-Tail Prob. | t Value | Degrees of Freedom | 2-Tail Prob. | t Value | Degrees of Freedom | 2-Tail Prob. |
| 4.68 | **.000** | 1.42 | 66 | .159 | 1.80 | 65.97 | **.076** |

The results of the performed T-tests show that significant differences exist between the different land uses in sample area 1, concerning erosion condition, cover and slope. The T-test in table 8.3 gives a result for the erosion condition. The two-tailed T probability is 0.076. Since it is expected that the mean erosion condition in the large scale tea area would be significantly lower than the mean erosion condition under large scale coffee,

* 1 = large scale coffee; 2 = large scale tea

only a one-tailed probability is needed. This probability is 0.076/2 = 0.038. This value is a little smaller than the level of significance of 0.05. This results in a significant lower erosion condition in large scale tea compared to large scale coffee. The result is not so convincing as most other T-test results. Concerning the results of the cover of the land uses no surprising results occur. The cover percentage in large scale tea is highest with 91.6%. Large scale coffee has a coverage of 69.1% and small scale farming 53.2%.

The average small scale farming cover percentage for 31 observations in sample area 1 seems relatively high. This is probably because the observations are taken in the highest productive sample area with better climatological conditions. Also the impression exists that in sample area 2 more field already had been harvested, although this is not quantified. Examinations of the average cover of the 40 observations in the small scale farming area, in sample area 2, give a percentage of 34.8%. The erosion conditions for small scale farming differ as expected. In sample area 2 the erosion condition is significantly higher; 33.6 in sample area 1 and 42.9 in sample area 2.

From T-tests performed within sample area 2 it can be concluded that the slope, cover and erosion conditions are significantly different for the two differentiated land uses. T-test analyses, performed between the three different transects within each sample area, prove that there are no significant different field conditions within a single sample area.

## §8.3 Linear regression analyses

Finally it is investigated how the slope and land use conditions in the area, relate to the erosion condition. This is important if any statements are to be made about the relation between changing land use on different slopes and changing erosion conditions. Eventually insights in this relation can, for instance, indicate what changing land use causes the highest, and least favourable, erosion condition. Most important is first, to show that a causal relationship between these factors is expressed in the three variables: SLOPE, COVERX and EROCOND.

Regression analyses are used to estimate linear correlations between a dependent variable and one or more independent variables. In this session investigated whether the distribution of erosion conditions in the study area can be explained by the independent SLOPE and COVER variables. It is assumed there is a causal relationship between the three variables. The cover is expected to have a negative correlation with the erosion condition and the slope will have a positive correlation. Except for testing the relationship, expressed in a correlation coefficient, also a numeric estimate of the relationship will be given. The numeric estimate will be an equation of the form:

$$Y = \beta 1 + \beta 2 * X1 + \beta 3 * X2$$

where: Y = predicted erosion condition
ß1 = constant
ß2 = regression coefficient for the SLOPE variable (X1)
ß3 = regression coefficient for the COVER variable (X2)

The results for a linear regression for the total of observations is given in table 8.4. First the correlation matrix for the variables is given. Next, three different correlation coefficients are given.

- R stands for the simple correlation coefficient between the observed values of the erosion condition (EROCOND) and the estimated values.
- $R^2$ represents that part of the variance of EROCOND that is explained by the independent variables SLOPE and COVERX.
- The adjusted R square ($Ra^2$) corrects the $R^2$ for the number of independent variables (2) and the number of observations (210).

$$Ra^2 = R^2 - 2(1-R^2) / (210-2-1)$$

In the analysis of variance the total of variance of EROCOND is divided into two parts. One part is explained by the independent variables (Regression). The other part is the residue. Finally an F test is performed. The hypothesis is that $R^2$ equals 0. In this case the F significance is lower than 0.05 and the hypothesis is rejected.

Table 8.4 Regression analyses for the total of observations

```
N of Cases =   210
Correlation:

              EROCOND       SLOPE      COVERX

EROCOND        1.000         .326       -.699
SLOPE           .326        1.000        .025
COVERX         -.699         .025       1.000

Multiple R            .77874
R Square              .60644
Adjusted R Square     .60264
Standard Error      10.01995

Analysis of Variance

                  DF      Sum of Squares      Mean Square
Regression         2         32023.90619      16011.95309
Residual         207         20782.68905        100.39946
F =    159.48246       Signif F =  .0000

------------------ Variables in the Equation ------------------

Variable              B        SE B        Beta          T  Sig T
COVERX        -.431539     .026601    -.707590    -16.223  .0000
SLOPE          .483541     .061389     .343562      7.877  .0000
(Constant)   51.650256    1.836909                 28.118  .0000
```

In the lower part of the table, 'Variables in the Equation', an estimate for the equation is given. Column 'B' gives the regression coefficients plus a constant. 'Beta' gives the relative importance of the two independent variables. In column 'SE B' the standard deviations are given. This value is used to perform a T-test to test the hypothesis that the regression coefficient equals 0. T = B / SE B.

The correlation coefficient ($Ra^2$) equals 0.60. This means 60% of the variation of the erosion condition is explained by the cover and slope variables. There is little interaction between the two independent variables. Their covariance is 0.025. The cover variable contributes more than twice as much to the erosion condition than the slope variable (see 'Beta'). The estimating equation reads:

$$Y = 51 + 0.48 * X1 - 0.43 * X2$$

where: Y = predicted erosion condition; X1 = slope(%): X2 = cover(%)

In this analyses all observations are used. They are not differentiated into

different sample areas. As showed with the T-test analyses the conditions in the three sample area differ significantly. It is interesting to see whether the correlation coefficient will be higher for linear regressions in the separate sample areas.
In table 8.5 the regression analyses is performed for the first sample area. The $Ra^2$ is surprisingly higher than for the total of observations and equals 0.77. The relative importance of the cover variable is more than 1.5 times the importance of the slope variable.

Table 8.5 Regression analyses for sample area 1

N of Cases = 99
Correlation:

| | EROCOND | SLOPE | COVERX |
|---|---|---|---|
| EROCOND | 1.000 | .580 | -.775 |
| SLOPE | .580 | 1.000 | -.227 |
| COVERX | -.775 | -.227 | 1.000 |

| | |
|---|---|
| Multiple R | .87863 |
| R Square | .77200 |
| Adjusted R Square | .76725 |
| Standard Error | 7.05313 |

Analysis of Variance

| | DF | Sum of Squares | Mean Square |
|---|---|---|---|
| Regression | 2 | 16169.95540 | 8084.97770 |
| Residual | 96 | 4775.68096 | 49.74668 |

F = 162.52297 Signif F = .0000

------------------ Variables in the Equation ------------------

| Variable | B | SE B | Beta | T | Sig T |
|---|---|---|---|---|---|
| COVERX | -.381625 | .028176 | -.677779 | -13.544 | .0000 |
| SLOPE | .498232 | .058524 | .426016 | 8.513 | .0000 |
| (Constant) | 46.723948 | 2.562412 | | 18.234 | .0000 |

The correlation coefficients for linear regression analyses for sample area 2 and 3 are 0.61 and 0.59. Remarkable are the values of relative importance of the independent variables for sample area 2. For the cover the 'Beta'-value equals 0.42. For the slope variable this equals 0.56. For the estimation of the erosion condition in sample area 2 the cover is more important.
The equation reads:

$$Y = 41 + 1.05 * X1 - 0.42 * X2$$

where: Y= predicted erosion condition; X1= slope(%); X2= cover(%)

The $Ra^2$ for sample area 3 is lowest. It means the slope and cover observations only explain 59% of the variation of the erosion condition in the range lands. This is probably because of the influence of wind erosion. Despite the low slope degree in the area, the observed erosion condition scored high, compared to the other sample areas. Also a large number of pedestals were found. This was translated into a relative high impact of wind erosion. Wind erosion is not represented by the slope or cover variables which results in a low correlation coefficient.
The 'Beta'-values are -0.75 for the cover and 0.40 for the slope variable. The cover is almost twice as important in determining the erosion condition. The estimating equation reads:

$$Y = 63 + 0.69 * X1 - 0.49 * X2$$

where: Y= predicted erosion condition; X1= slope(%): X2= cover(%)

## §8.4 Discussion of the results and recommandations

The erosion conditions and the slope conditions differ significantly between the different sample areas. The erosion condition are highest in sample area 3 and lowest in sample area 1. If the sample areas are considered to represent the stratified units of broad landforms, it means the units are significantly different. This is what needed to be checked. Based on the chosen delineation criteria it can be concluded that the Kiambu area is stratified into logic mapping units to investigate erosion.

The cover variable proves to be unreliable for testing differences between areas but shows significant differences between land uses. In fact, cover tests the stratification criterium based on land use. Significant differences for the land use zones are found. The erosion conditions also differ significantly. It is concluded that the erosion conditions are significantly different under different land uses. Large scale tea will have the lowest and small scale farming will have the highest erosion condition.

Ranging lands are most vulnerable for erosion. From the relative low correlation coefficient in the regression analyses it is concluded that wind erosion contributes more to the total erosion condition in sample area 3 compared to the other sample areas.

Despite the steeper average slope in sample area 1 the erosion conditions are lowest. This is also confirmed by the comparison between small scale farming in sample area 1 and 2. Sample area 1 scores lower for the erosion condition. Apparently climatological conditions in the northwestern part of the study area are favourable for crops reducing the erosion impact on the soil.

The performed regression analyses for sample areas 1, 2 and 3 give correlation coefficients ($Ra^2$) of 0.77, 0.61 and 0.59. It can be stated that

Goodness of fit

correlation coefficients higher than 60%, can have predictive powers. However, the obtained regression equations form a statistical model for estimating the erosion condition. The model represents the 210 field observations and needs to be tested. Therefore field observation on the physical parameters of cover, slope and erosion condition have to be taken in other parts of the Kiambu area. Only after a comparison between the observed and predicted erosion conditions a definite answer can be given on the quality of this statistical model.

To overcome difficulties with the normal distributions of the different variables a better design of the observations is necessary. It is not so much the number of observations that matters. It is of greater concern that the number of transects is increased. That way not the means of the direct observations have to be distributed normally. Every transect can be considered a sample and the means of each sample will have a normal distribution. They will form the indirect variables that can be tested with the T-test.

# CHAPTER 9 DISCUSSION AND CONCLUSIONS

## §9.1 Discussion

For the interpretation of areal photographs indicators are used which are considered to be highly correlated with the distribution of erosion conditions. These indicators are concerned with the factors landform and land use. The drainage density and pattern, representing landform, differentiate the area into six broad landform units. Three stratified units in the level plains are arbitrary and not tested on any significant difference. Also the sloping land with mixed drainage pattern is not covered by a sample area. To investigate more sample areas would have been too time consuming in the range of this study.

Other factors like soil and climate are assumed to be less relevant in the distribution of erosion conditions in the semi-detailed scale of the study. However stratified boundaries are probably the result of soil related processes. In the level plains different soils can even be detected on the APs. This influence is not investigated although it is expressed in the erosion conditions. Between the sloping and the level land also climate, especially rainfall (±400 mm), is a factor influencing the different erosion conditions. It is assumed that these different climatic conditions are expressed in different crop cover, in the sloping and level land.

Concerning the differentiation according to land use, four different broad land use zones are discriminated: large scale tea, large scale coffee, small scale farming and ranging. Time and the scale of the photographs did not allow to define more land use zones. More land use zones will provide more detail and a clearer answer on wether or not land use zone will have different erosion conditions. In this study, generalisations were inevitable. This means in areas stratified like e.g. large scale tea also small scale farming will occur, especially in the steeper parts of the slope near gullies and in the gully beds (these sites are not suited for tea). The classification of the unit as tea indicates the dominant land use is large scale tea.

For the field observations and statistical analyses the variables COVER and SLOPE are used, representing the delineation criteria of the APIs: land use and landform. Based on these variables the stratified units are considered significantly different. COVER is assumed to represent land use. The amount of inputs and level of operation of different crops are neglected. They will certainly influence erosion processes but are hard to express in a ratio scale, which makes them not suitable for parametric statistical analyses.

All investigations concentrate on water erosion. Wind erosion will play a part in the ranging lands. The Clark method used does not provide in good observations of wind erosion.

## §9.2 Conclusions

In the Kiambu study area the dominant erosion type is sheet erosion. Active rill and gully erosion hardly occur.

The drainage density, the drainage pattern and broad land use zones form good indicators to stratify the Kiambu area in meaningful erosion units, with significant different erosion conditions. In API these indicators can give a quick insights in the distribution of erosion conditions.

The erosion conditions are best in the dendritic sloping land, dispite the higher average slope percentages. The erosion conditions are highest in the level land. It is concluded that land use is more important in determining the erosion condition in the area, compared to the slope percentage.

Large scale tea provides the best cover conditions. Large scale coffee offers slightly less favourable conditions. Annual crops in small scale farming generate the most intense sheet erosion especially on steep parts of the slopes.

The erosion conditions in the sloping lands are considered stabilised. Only due to an intensified cultivation in marginal sites on steep slopes, sheet erosion has increased incidently. In the current range lands the erosion has intensified due to dramatic land use changes. Due to overgrazing and an expanding area of cultivation the erosion is believed to increase further.

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# APPENDIX 1: Features and evaluation of different Soil Surface Factors according to Clark.

Form 7310-12

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT

DETERMINATION OF EROSION CONDITION CLASS
SOIL SURFACE FACTOR (SSF)

By ________ Date ________

Location ________

Total SSF ________

| | | | | | |
|---|---|---|---|---|---|
| Soil Movement | Depth of recent deposits around obstacles, or in microterraces; and/or depth of truncated areas, is between 0 and .1 in. (0 to 2.5 mm). 0 or 3 | Depth of recent deposits around obstacles, or in microterraces; and/or depth of truncated areas, is between .1 and .2 in. (2. to 5 mm). 5 | Depth of recent deposits around obstacles; or in microterraces; and/or depth of truncated areas, is between .2 and .4 in. (5 to 10 mm). 8 | Depth of recent deposits around obstacles, or in microterraces; and/or depth of truncated areas, is between .4 and .8 in. (10 to 20 mm). 11 | Depth of recent deposits around obstacles, or in microterraces; and/or depth of truncated areas is over .8 in. (20 mm). 14 |
| Surface Litter | No movement, or if present, less than 2 percent of the litter has been translocated and redeposited against obstacles. 0 or 3 | Between 2 and 10 percent of the litter has been translocated and redeposited against obstacles. 6 | Between 10 and 25 percent of the litter has been translocated and redeposited against obstacles. 8 | Between 25 and 50 percent of the litter has been translocated and redeposited against obstacles or removed from that area. 11 | More than 50 percent of the litter has been translocated and redeposited against obstacles or removed from the area. 14 |
| Surface Rock Fragments | Depth of soil removal around the fragments, and/or depth of recent deposits around the fragments is less than .1 in. (2.5 mm). 0 or 2 | Depth of soil removal around the fragments, and/or depth of recent deposits around the fragments is between .1 and .2 in. (2.5 to 5 mm). 5 | Depth of soil removal around the fragments, and/or depth of recent deposits around the fragments is between .2 and .4 in. (5 to 10 mm). 8 | Depth of soil removal around the fragments, and/or depth of recent deposits around the fragments is beteeen .4 and .8 in. (10 to 20 mm). 11 | Depth of soil removal around the fragments, and/or depth of recent deposits around the fragments is over .8 in. (20 mm) 14 |
| Pedestalling | Pedestals are mostly less than .1 in. (2.5 mm) high and/or less frequent than 2 pedestals per 100 sq. ft. 0 or 3 | Pedestals are mostly between .1 to .3 in. (2.5 to 8 mm) high and/or have a frequency of 2 to 5 pedestals per 100 sq. ft. 6 | Pedestals are mostly between .3 to .6 in. (8 to 15 mm) high, and/or have a frequency of 5 to 7 pedestals per 100 sq. ft. 9 | Pedestals are mostly between .6 and 1 in. (15 to 25 mm) high, and/or have a frequency of 7 to 10 pedestals per 100 sq. ft. 11 | Pedestals are mostly over 1 in. (25 mm) high, and/or have a frequency of over 10 pedestals per 100 sq. ft. 14 |
| Flow Patterns | None, or if present, less than 2 percent of the surface area shows evidence of recent translocation and deposition of soil and litter. 0 or 3 | Between 2 and 10 percent of the surface area shows evidence of recent translocation and deposition of soil and litter. 6 | Between 10 and 25 percent of the surface area shows evidence of recent translocation and deposition of soil and litter. 9 | Between 25 and 50 percent of the surface area shows evidence of recent translocation and deposition of soil and litter. 12 | Over 50 percent of the surface area shows evidence of recent translocation and deposition of soil and litter. 15 |
| Rills | Rills, if present, are mostly less than .5 in. (13 mm) deep, and generally at infrequent intervals over 10 ft. 0 or 3 | Rills are mostly .5 to 1 in. (13 to 25 mm) deep, and generally at infrequent intervals over 10 ft. 6 | Rills are mostly 1 to 1.5 in. (25 to 38 mm) deep, and generally at 10 ft. intervals. 9 | Rills are mostly 1.5 to 3 in. (38 to 76 mm) deep, and at intervals of 5 to 10 ft. 12 | Rills are mostly 3 to 6 in. (76 to 152 mm) deep, and at intervals of less than 5 ft. 14 |
| Gullies | No gullies, or if present, less than 2 percent of the channel bed and walls show active erosion (are not vegetated), gullies make up less than 2 percent of the total area. 0 or 3 | Between 2 and 5 percent of the channel-bed and walls show active erosion (are not vegetated), or gullies make up between 2 and 5 percent of the total area. 6 | Between 5 and 10 percent of the channel bed and walls show active erosion (are not vegetated), or gullies make up between 5 and 10 percent of the total area. 9 | Between 10 and 50 percent of the channel bed and walls show active erosion (are not vegetated), or gullies make up between 10 and 50 percent of the total area. 12 | Over 50 percent of the channel bed and walls show active erosion (are not vegetated) along their length, or gullies make up over 50 percent of the total area. 15 |

APPENDIX II: Survey form for Kiambu District erosion mapping, 1993

SAMPLE AREA NR. 1 2 3 DATE
TRANSECT NR..... SECTION NR..........
DISTANCE from.......m till .........m

---

TOPSOIL
texture:............
color :............

RELIEF
slope of section:......(%)
max. slope uphill:......(%)
downhill:......(%)

remarks:

---

VEGETATION

| type | height (m) | coverage (%) |
|---|---|---|
| large scale tea | | .... |
| large scale coffee | | .... |
| trees | | .... |
| shrubs | | .... |
| pasture | | .... |
| mixed small scale | | |
| types:.... | | .... |
| .... | | .... |
| .... | | .... |
| bare soil | | .... |

remarks:

---

SITUATION SKETCH

0M 10M 20M 30M 40M 50M 10M 20M 30M 40M 50M

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0M 10M 20M 30M 40M 50M 10M 20M 30M 40M 50M

APPENDIX II: continued

SOIL SURFACE FACTORS

| EROSION FEATURES | IDENTIFIED FACTORS | POSSIBLE FACTOR |
|---|---|---|
| SOIL MOVEMENT: | | |
| SURFACE LITTER: | | |
| SURFACE ROCK: | | |
| PEDESTALLING: | | |
| FLOW PATTERN: | | |
| RILLS: | | |
| GULLIES: | | |

SEDIMENTATION

total lenght:
1 soil mounds above vegetation
2 in furrows
3 in fans

GULLY EROSION

real width:......(m)
bottom slope:.......(%)

shape: V W U
side wall erosion: Y N

incipient
active
stabilised

REMARKS: