Working Paper

58

ENVIRONMENTAL CHANGE AND DRYLAND MANAGEMENT IN MACHAKOS DISTRICT, KENYA 1930-90

LAND USE PROFILE

R.S. Rostom and Michael Mortimore

Results of ODI research presented in preliminary form for discussion and critical comment

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R.S. Rostom and Michael Mortimore

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OVERSEAS DEVELOPMENT INSTITUTE
Regent's College
Inner Circle, Regent's Park
LONDON NW1 4NS

UNIVERSITY OF NAIROBI
P O Box 30197
Nairobi
Kenya

MINISTRY OF RECLAMATION AND DEVELOPMENT
OF ARID, SEMI-ARID AREAS AND WASTELANDS
Nairobi, Kenya

Preface and Acknowledgements

ODI Working Papers present in preliminary form work resulting from research undertaken under the auspices of the Institute.

This Working Paper is part of a study which aims to relate long term environmental change, population growth and technological change, and to identify the policies and institutions which are conducive to sustainable development. The first stage, published in these Working Papers, is to measure and assess as precisely as the evidence allows the changes that have occurred in the study area, the semi-arid Machakos District, Kenya, over a period of six decades. Degradation of its natural resources was evoking justifiable concern in the 1930s and 1940s. By several measures it is now in a more sustainable state, despite a five-fold increase in population. A long-term perspective is essential, since temporary factors, such as a run of poor rainfall years, can confuse analysis of change if only a few years are considered. The study is developing a methodology for incorporating historical, physical, social and economic data in an integrated assessment. The final report will include a synthesis and interpretation of the physical and social development path in Machakos, a consideration as to how far the lessons are relevant to other semi-arid environments, and recommendations on policies for sustainable economic growth.

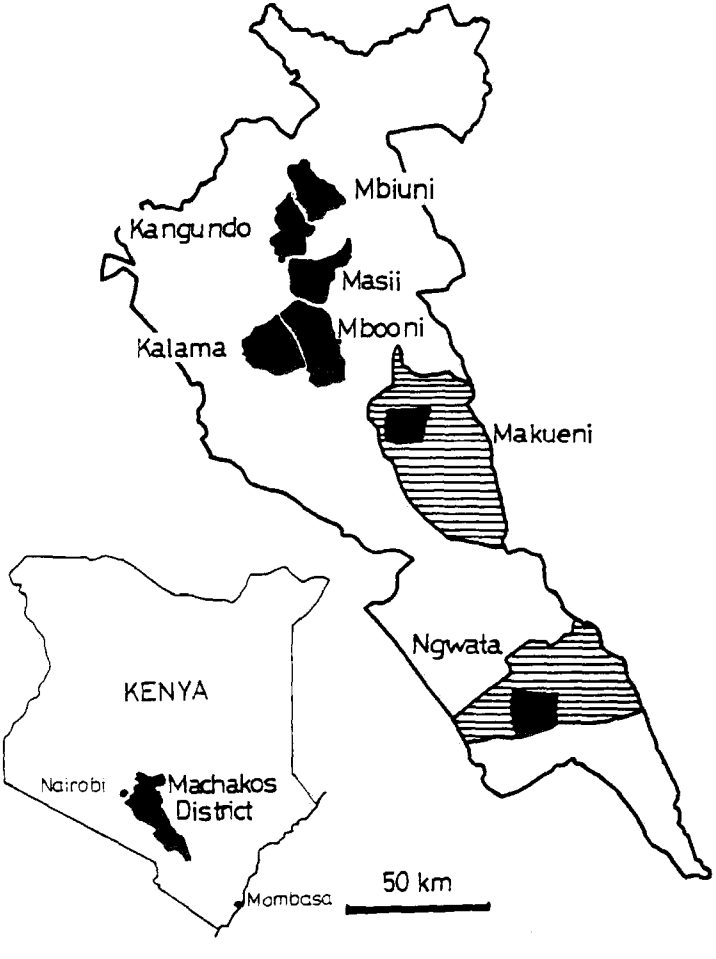
The project is directed at ODI by Mary Tiffen, in association with Michael Mortimore, research associate, in co-operation with a team of scientists at the University of Nairobi, and with the assistance of the Ministry of Reclamation and Development of Arid, Semi-Arid Areas and Wastelands in Kenya. We are grateful to Professor Philip Mbithi, Vice-Chancellor of the University of Nairobi, for his support and advice. We also thank the Overseas Development Administration, the Rockefeller Foundation and the Environment Department of the World Bank for their financial support. Views expressed are those of the authors and do not necessarily reflect the views of ODI or supporting institutions. Comments are welcome, and should be sent directly to the authors or project leaders.

Other titles in this series (in which more are planned) are:

Machakos District: Environmental Profile
Machakos District: Population Profile
Machakos District: Production Profile
Machakos District: Conservation Profile
Machakos District: Institutional Profile
Machakos District: Technological Change
Machakos District: Farming and Incomes Systems

R.S. Rostom (Professor in the Department of Surveying and Photogrammetry, University of Nairobi) and Michael Mortimore are the authors of this paper. It incorporates the findings of the Report of the GIS Team, whose members were: R.S. Rostom (Leader), J. Yego and G. Mulaku. The data and methodology section of this Report appears as an Appendix to this Paper. The authors acknowledge the co-operation of the Chairman of the Department of Surveying and Photogrammetry, University of Nairobi. The photointerpretation and the photogrammetric and cartographic work were undertaken by staff of the Department, assisted by Mr Ojuok (Water Resources Department, Machakos).

Preface Figure: **Machakos District, Kenya, showing study locations**
(In Makueni and Ngwata Locations, field studies were mostly within the areas shown black.)



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1. OBJECTIVES AND METHODS

This Paper provides one of a series of longitudinal profiles of environmental change and dryland management in Machakos district, Kenya, from the 1930s to 1990. Profiles of rainfall, soil erosion, soil fertility and natural vegetation are constructed elsewhere (see Environmental Profile), using appropriate available data sets. This Land Use Profile is based principally on the interpretation of air photography, supplemented by satellite imagery and official land use estimates.

The functional categories that can be analysed are determined by the properties of the data set. Taking into account the differences between the air photo cover of several dates and scales, it is possible to generate an internally compatible series for only a small number of land use classes. But the transfers of land that have taken place among these classes tell the story of dryland management over time in both mappable and quantifiable terms. In view of the scarcity of other compatible longitudinal series, air photography is a rich resource that justifies the expenditure of analytical effort. In this study, both forms of output are presented, using five study areas that are believed to be representative of the range of conditions found in the District as a whole.

An account of the methodology and data used is given in the Appendix.

An hypothesis, strongly supported by contemporary observations, local eye witnesses, and official statistics of estimated land use, is that land use in Machakos District during the period 1940-90 has been subject to change on a large scale, and in particular, extension of cultivated land at the expense of rangelands and woodland.

Objective verification of this hypothesis can be sought using the available remote sensing data which are classified into: (a) vertical black-and-white air photography (AP); (b) earth satellite imagery or data such as the Landsat thematic mapper(TM); and (c) systematic reconnaissance flight (SRF) low level air photography. The data available for Machakos District as a whole were as follows:

Resource	*Year*	*Scale*
A	1948	1:30,000
	1960-61	1:50,000
	1967	1:50,000
	1978	1:20,000
SRF	1981	1:6,770
	1985	
TM	1988* (October)	1:1,000,000

* This image was selected from those available.

1.1 Air Photography

Sequential AP interpretation is potentially a powerful method of evaluating environmental change, with a baseline four decades ago in many parts of Africa. As well as its greater time depth, it has finer resolution than earth satellite data. Subject to satisfactory interpretation, it can generate sufficiently accurate land use statistics. It is also more comprehensive in that a complete land cover classification can be quantified to include all land. Natural vegetation can be classified physiognomically. Areas of erosion can be measured. Photographs may be reproduced from negatives, after several decades, without loss of quality, provided they have been stored in the correct conditions.

Their limitations, however, should be borne in mind. Earlier photographs usually have inferior resolution, and the scope for interpretation error increases with older photographs as ground reference becomes impossible. Differences in scale between one set of photography and another create compatibility problems. Cloud cover and shadows occasionally obscure part of the surface; so quite small areas of cloud, appearing on several sets of photography, can have a damaging effect on sequential analyses which depend on study areas being standardised. Scale distortion on individual photographs (which occur more in hilly areas) must be compensated for. Finally, and most important for sequential analyses of environmental change, the months (seasons) in which the photographs were taken may not be identical from one set to another, and even if they are, inter-annual variability in rainfall distribution affects the images produced, and creates difficulties for the interpretation of change during the intervening years.

In the present study the information from air photographs was generated by visual interpretation. The method used is described fully in Appendix 1. The first step was to develop a land use classification compatible with the aims of the study and adaptable to the imagery, which was interpreted visually. The following four classes were adopted:

(i) Agricultural land (a) not terraced
(b) terraced

(ii) Bush/scrub/grazing land

(iii) Forest/woodland

(iv) Others (and unclassified land)

The land use class 'agricultural land' means land that is normally cultivated; 'bush/scrub/grazing land' means grassland with a more or less dense cover of woody plants, often of shrub form; and 'forest/woodland' means mature woodland or plantations with a continuous canopy. The distinction between dense bush/grazing land (on the one hand) and forest with some grassland (on the other) is necessarily arbitrary, and is made on the basis of interpretative criteria.

The second step was to interpret each stereopair of photographs according to the classification. The third step was to transfer the boundaries of the land use classes, via mosaics, on to base maps, using the standard 1:50,000 scale topographical map base. The

fourth step was to measure the areas of each class at each date of photography. Choice of this conventional methodology was imposed by the technical resources available, which did not include digital GIS facilities.

The methods described above were carried out for the three sets of photographs (1948, 1960-61 and 1978), in each of the five study areas. Mbiuni, Masii and Kalama locations were mapped in their entirety. In Makueni and Ngwata locations, in view of their size, the mapping was restricted to sample areas (see Preface Map). Altogether, 84,050 ha were mapped in 1948 and 1978, and a slightly reduced area (83,250 ha) in 1961.

1.2 Landsat TM Imagery

In order to extend the data series from 1978 to the present, two possibilities were investigated: earth satellite data, and systematic reconnaissance flight (SRF) data. With regard to the first, earth satellite data are technically available for many points in time from the 1970s to the present, and their use for monitoring environmental change in Africa has been frequently and forcefully advocated. Constraints of time, cost, and the technical facilities available restricted us to a limited methodological experiment on locally available, low cost Landsat TM false colour imagery, using a visual interpretation method. The conclusion of this experiment should indicate the scope of satellite data for integrated use with black and white air photography to generate long series data for measuring past environmental change. (See Appendix for an account of the method used.)

Land use maps were generated from a TM false-colour image for 1988, enlarged to the scale 1:50,000 to match those derived from the air photographs. The data produced from these maps are shown in Appendix Table 1. These data are not consistent with our series. In particular, cultivated land shows implausible decreases between 1978 and 1988 in Mbiuni and Kalama, while increasing in Masii and Makueni. The reason for the decreases is the presence of shadow effects in hilly areas, which confounds interpretation. Also the generalised classification at this scale and the relatively low spatial resolution (30m) may have contributed to these results.

It is concluded that the false colour imagery is incapable of harmonisation by visual interpretation with the land use classes identified on air photographs. (There is no reason to believe that digital data would be easier to use, since the incompatibility arises from differences between the spectral wave bands recorded by satellite sensors and the tonal/textural properties, with contextual associations, used in interpreting air photographs.)

If the interpretation difficulties are set aside, there remains a major incompatibility of scale resolution between even the best satellite capabilities and air photography. Furthermore, the cost escalates with improved scale resolution. Satellite data is therefore more suited to investigations at the regional scale, where its power to generalise local detail becomes an asset rather than a liability.

Failure to generate an integrated environmental data set from air photographs and satellite imagery does not, of course, affect the potential use of satellite data for generating internally consistent data sets for recent, contemporary and future environmental monitoring.

1.3 Low-level SRF Air Photography

In 1981 and 1985, Ecosystems Ltd. was commissioned by the Machakos Integrated Development Programme (MIDP) to carry out systematic low-level reconnaissance flights over the whole District, generating large-scale colour slide photographs according to a discontinuous, systematic sampling procedure (Ecosystems 1982; 1986). Each photograph covers a surface area of approximately 4 ha, and its large scale permits extremely detailed land cover data to be interpreted. Land cover areas are not mapped, but measured within reasonable statistical bounds of probability from counts, carried out on each slide projected on a screen.

If executed on a continuous basis, such a method would produce unmanageable quantities of photographs whose interpretation would be time-consuming and costly. The systematic sampling procedure used took one photograph every 1 or 2 km on parallel flight paths 1.5 or 3 km apart, depending on whether an area was lightly or densely populated. Thus the sample ratio varies from 1:40 to 1:150. The land cover data are projected from the sample photographs to a standard grid of 5 x 5 km squares. The values for these grids can be assembled according to locations, divisions or other desired units.

Two SRF surveys were carried out in 1981 and in 1985, separated by 4.5 years, and an analysis made of changes in land use, with a view to evaluating the impact of the MIDP's programmes in the District. The 1981, and 1985, photographs do not necessarily fall on the same spatial locations, leading to spatially uncorrelated changes in the land use. Standards for assessing the statistical significance of the changes were provided. The large-scale and high resolution of the air photographs, together with the District-wide sample, provide more detailed classes of land use than the conventional air photography. Against this advantage must be counted two disadvantages: the shallow time-depth of the comparison (less than five years), and difficulties of compatibility with the earlier air photography. The issue of compatibility was investigated thoroughly, and it was concluded that this data set could not be used in conjunction with the 1978 photography (Ecosystems, 1986).

The SRF data, however, do provide an internally compatible series for a short period in the 1980s, from which much can be learnt.

2. LAND USE CHANGE, 1948-78

The results of the air photo interpretation are presented in cartographic and tabular format.

2.1 Cartographic Presentation

The land use information was transferred from the reduced aerial mosaics on to the transparent base sheets (scale 1:50,000) by cartographic means (see Appendix). Figures 1-14 present reductions of these transparencies. There are three maps for each study area, representing the distribution of land use categories in 1948, 1961 and 1978 (except for Ngwata, where only two maps for 1961 and 1978 are presented). On the transparencies it is possible to discern spatial patterns from the contour lines and correlate it with the terracing. It is also possible to superimpose two (or more) of the transparencies of one area corresponding to different dates for the identification of changes of land use at particular locations for a certain epoch.

2.2 Tabular Presentation

In Table 1 the areas of each land use category in the three years are given, both in hectares and as percentages. In calculating the percentages, areas of unclassified land use have been subtracted from the total. (These areas arise from clouds, shadows, or missing photographs and also include the townships. Consequently, the unclassified area is variable from one year of photography to the next.)

The changes between years of photography in the areas of each land use category are given in Table 2, as percentage changes from the base year in each period.

Three periods of change are measured: 1948-61 (13 years), 1961-78 (18 years), and 1948-78 (30 years). The information for Ngwata study area was not compiled for 1948, thus only one period (1961-78) is represented.

Land under cultivation is subdivided into (a) non-terraced and (b) terraced land. Each block was assigned to its class according to whether terrace structures are identified on the photographs assisted by stereoscopic viewing. Table 3 presents the sub-categorisation of cultivated land on this basis. Terrace maintenance could not be assessed, nor the adequacy of the structures or design. Nevertheless, the data give an approximation of progress in conservation works on farm land.

The changes are shown in histogram form in Figures 15-18.

A brief commentary is now given on the changes observed in each study area, and an interpretation of change in the District as a whole.

Table 1: **Areas of the land use classes and percentage change**

Study area	*Size*	*1948*				*1961*				*1978*			
	(hectares)	*C*	*B*	*F*	*U*	*C*	*B*	*F*	*U*	*C*	*B*	*F*	*U*
Mbiuni	18,000	6,350	11,110	530	10	6,080	10,720	400	800	12,190	1,990	930	2,890
Kalama	23,000	3,120	19,580	300	0	3,190	18,420	820	570	11,860	8,950	1,070	1,120
Masii	16,050	3,740	11,560	650	100	4,420	11,160	440	30	7,150	6,530	360	2,010
Makueni	13,800	160	10,830	2,790	20	1,050	12,000	0	750	3,210	5,400	2,040	3,150
Ngwata	13,200	[a]	[a]	[a]	[a]	0	6,890	6,310	0	1,830	5,750	1,650	3,970[b]
Percentage of areas of class to study areas[c]													
Mbiuni		35.3	61.8	2.9	-	35.4	62.3	2.3	-	80.7	13.2	6.1	-
Masii		23.4	72.5	4.1	-	27.6	69.7	2.7	-	50.9	46.5	2.6	-
Kalama		13.6	85.1	1.3	-	14.2	82.1	3.7	-	54.2	40.9	4.9	-
Makueni		1.2	78.6	20.2	-	8.0	92.0	0.0	-	30.1	50.7	19.2	-
Ngwata		[a]	[a]	[a]	-	0	52.2	47.8	-	19.8	62.3	17.9	-
Σ Areas 1-4		18.9	75.1	6.0	-	21.5	76.1	2.4	-	55.8	37.1	7.1	-
Σ Areas 1-5						18.0	72.3	9.7	-	51.1	40.4	8.5	-

C = cultivation B = bush/scrub/grazing land F = forest U = unclassified

Notes: a = Ngwata study area was virtually unoccupied in 1948;
b = area shown unclassified in 1978 was mostly bushland in 1961;
c = unclassified areas subtracted.

Table 2: **Percentage increase (+) or decrease (-) in land use categories**

Study Area	*Cultivation*			*Bushland*			*Forest*		
	1948-61	*1961-87*	*1948-78*	*1948-61*	*1961-78*	*1948-78*	*1948-61*	*1961-78*	*1948-78*
Mbiuni	+0.3	+128.0	+128.6	+0.8	-78.8	-78.6	-20.7	+165.2	+110.3
Kalama	+4.4	+281.7	+298.5	-3.5	-50.2	-52.0	+184.6	+32.4	+276.9
Masii	+17.9	+84.4	+117.5	-3.9	-33.3	-35.9	-34.1	-3.7	-36.6
Makueni	+566.7	+276.2	+2,408.3	+17.0	-44.9	-35.5	[a]	[a]	-5.0
Ngwata				[b]	+19.3		[b]	-62.5	
Overall:									
Areas 1-4	+13.8	+159.5	+195.2	+1.3	-51.2	-50.6	-60.0	+195.8	+18.3
Areas 1-5	-	+183.8	-	-	-44.1	-	-	-12.3	-

Notes: a = no forest was identified in 1961, so change values are available only for 1948-1978;
b = no cultivation was identified in 1961.

Table 3: **Areas of terraced land (%)**

Area		*1948*	*1961*	*1978*
Mbiuni	(a) non-terraced	29.9	24.2	0
	(b) terraced	70.1	75.8	100
Kalama	(a) non-terraced	38.1	55.2	0
	(b) terraced	61.9	44.8	100
Masii	(a) non-terraced	86.9	71.3	0
	(b) terraced	13.1	28.7	100
Makueni	(a) non-terraced	a	99.0	0
	(b) terraced	a	1.0	100
Ngwata	(a) non-terraced	b	b	73.2
	(b) terraced	b	b	26.8
Overall	(a) non-terraced	48.0	50.3	3.7
	(b) terraced	52.0	49.7	96.3

Notes: a = only 160 ha under cultivation, about half terraced;
b = no cultivated land identified.

2.3 Mbiuni (Figures 1, 2, 3 and 15)

Cultivated land increased by 128% between 1948 and 1978, from 35% to over 80% of the study area. Virtually all this increase appears to have occurred after 1961. The area of bushland decreased accordingly, to less than 15%. Forest (with woodland) declined by 21% between 1948 and 1961 but increased by 165% between then and 1978. The total forest area involved is small (less than 1,000 ha), and reflects the re-classification of protected woodland on the Kanzalu Range, from bushland on 1961 photographs to forest on those of 1978. The effect of the Range on spatial patterns of land use and conservation is noticeable. In 1948 cultivation was concentrated to the west of the Range, and up till 1961, terraced cultivation was exclusively distributed on that side. By 1978, cultivation had increased markedly on the eastern side of the Range, and terracing had been extended to all (100%) cultivated blocks. However, taken as a whole, Mbiuni is noted for the fact that 70% of its cultivated land was already terraced in some form or other in 1948.

2.4 Kalama (Figures 4, 5, 6 and 16)

This area appears to have increased its cultivated area even more sharply than Mbiuni after 1961 - the rate of increase jumping from 4.4% before 1961 to 282%, generating an overall increase during the 30-year period of nearly 300%. However, in 1978, still only 54% was cultivated, and over 40% was under bushland, indicating a lower intensity of land use than in Mbiuni but somewhat higher than in Masii. Here, there was a progressive improvement

in the amount of forest and woodland, from only 1.4% in 1948 (when this location contained some of the most denuded areas) to 3.7% in 1961 and 4.9% in 1978 (just over 1,000 ha). Kalama also resembles Mbiuni in that a high proportion (62%) of cultivated blocks were already terraced in 1948. But this proportion fell (apparently) to 45% in 1961. Since the amount of cultivated land is not considered to have changed significantly (it was between 3,000 and 3,200 ha, or 13-14%), the evidence suggests that a substantial amount of terraces may have been abandoned. By 1978, the proportion terraced had risen again, to 100%.

2.5 Masii (Figures 7, 8, 9 and 17)

This study area contains no hill masses of major significance. A less pronounced acceleration in the extension of cultivated land (compared with Mbiuni) took place in Masii. Although the proportion more than doubled between 1948 and 1978, the percentage under cultivation only exceeded 50% by 1978. Consequently, the decline in bushland was less dramatic (from 72 to 46%) and reflects a lower intensity of farming, throughout the period, than in Mbiuni. Forest and woodland declined steadily to 360 ha; there is no evidence of a reversal of decline, like that observed in Mbiuni. Masii made spectacular progress in terracing after 1961. The percentage of cultivated land showing evidence of terraces increased from less than 30% in 1961 to 100% in 1978.

2.6 Makueni (Figures 10, 11, 12 and 18)

In this study area, the amount of cultivated land was negligible (160 ha) in 1948. The Makueni Resettlement Project had only just begun, in an area previously unfarmed. Cultivated land increased rapidly to 8% in 1961, and 30% in 1978, and bushland declined accordingly to about 50% in 1978. Forest was not identified on the 1961 photographs, but it is probable that the percentage (20% in 1948 and 19% in 1978) was constant throughout the period, and the poor quality and small scale of the 1961 photographs are to blame. Initially, farm land was not terraced at Makueni, but notwithstanding the gentleness of many of its slopes, all cultivated land had been terraced by 1978.

2.7 Ngwata (Figures 13 and 14)

This area was not settled in 1948, and on the 1961 photographs, still no cultivated land can be discerned. By 1978, a wave of settlement from the north of the District had brought 20% of the area under cultivation. There had also occurred an increase in the amount of bushland (from 52 to 62%) and a decrease in the amount of forest (by 62%, from 1961 to 1978). Such a large change seems unlikely to be an artifact of interpretation, in view of the fact that in Makueni, where conditions were similar, the 1961 interpretation appears to have underestimated the amount of forest. In Ngwata, alone among the five study areas, the process of terracing was incomplete in 1978, with only 27% of cultivated blocks terraced.

2.8 Overall

Two technical points - concerned with sampling and interpretation - have a bearing on any broad conclusions drawn from the data presented here. The first is that the sampled areas' representativeness for the District as whole is not known. Use of spatially continuous sample blocks, which is necessary for the methodology, does not permit randomisation of the sample population. The blocks were selected to represent a range of ecological and demographic conditions, however, and this range is representative of the District though its average may not be.

The second point to note is that while the internal compatibility of data sets, generated by standard methods of interpretation from black-and-white photography, is greater than that of data sets generated from different types of remotely sensed media, it is not perfect.

The smaller scale, greater amount of cloud cover, and inferior contrast of the 1960-61 photographs makes them less reliable than those of either 1948 or 1978. For this reason, undue weight should not be put on the 1961 data. Consequently the poor quality of the 1961 photographs may have contributed to the following:

(a) The increased rate of expansion in cultivated land after 1961 (especially in Mbiuni and Kalama location) may be due in part to difficulties in recognising small fields on some of the 1961 photographs.

(b) The apparent disappearance of forest and woodland from Makueni study area in 1961, only to reappear in 1978, may be due in part to difficulties in distinguishing forest from bushland on poor quality photographs.

(c) The decline in the extent of terracing in Kalama location between 1948 and 1961, which (as noted above) was absolute as well as relative, may be due in part to difficulties in recognising terrace structures, especially if in poor repair.

These qualifications made, the analysis of the land use data generated from the air photographs of 1948, 1960-61 and 1978 suggest the following conclusions:

(a) A gradient of land use intensity, expressed in the relative percentages of cultivated land and bushland, can be recognised from Mbiuni (81% cultivated in 1978) through Kalama (54%) and Masii (51%) to Makueni (30%) and Ngwata (20%).

(b) A second marker in this gradient is the chronology of terracing on farmlands. Mbiuni had terraced 70% of its farmland in some form by 1948, and Kalama 62%. Masii had only terraced 29% by 1961, and Makueni virtually none. All these areas reached 100% by 1978 (though this does not mean that no further need for conservation existed) but Ngwata, settled during the 1960s and 1970s, had terraced only 27% by 1978.

(c) There was a significant turnaround in the percentage of forest and woodland, beginning after 1948 in Kalama and after 1961 in Mbiuni. It seems that in Makueni, the percentage was relatively stable. The indicators are negative, however, for Masii

(continuing decline of a very small forest area) and Ngwata (showing woodland degradation to bushland).

(d) Even when the data for such dissimilar areas are averaged (Tables 1, 2 and 3), the figures suggest a sharp acceleration, after 1961, in both farmland extension and soil conservation on farms, along with a real improvement in the small areas of forest. Negative or ambivalent signals from the period 1948-61 imply that this was a watershed in the history of land use in the District. It is known that terrace construction stagnated or declined during the later part of that period (see Conservation Profile).

3. LAND USE CHANGE, 1981-85

Although separated by only 4.5 years, the two Ecosystems SRF Surveys of 1981 and 1985 picked up statistically significant changes in a number of land use variables (Ecosystems 1986d).

3.1 Arable and Cultivated Land

Total arable land (including both cultivated land and fallows) increased at the rate of only 1% per year in the District as a whole, notwithstanding the fact that under the classification employed, it occupies only 22% of the total area (Table 4). The average field size decreased by 30% from 0.24ha to 0.17ha, and the area under field dividers (hedgerows, fences, etc.) increased significantly. Cultivated land (land under crops) did not change significantly. These facts point to an intensification of farming on existing cultivated land and there is no evidence of a large scale extension of the cultivated area.

Table 4: Changes in cultivated land, 1981-85 (after Ecosystems, 1986d)

Land use	*1981*	*1985*	*% change*
		per cent of District	
1. Total arable land	20.9	21.9	1.06
2. Cultivated land	17.7	18.2	0.70 ns
3. Seasonal fallows and bare fields	1.0	1.5	9.03
4. Field dividers	1.3	1.7	7.55
5. Estate cash crops	0.9	1.0	0.70 ns
6. Smallholder cash crops	1.0	1.9	14.32
7. Smallholder staple crops	16.8	16.7	-0.05
8. Horticulture	0.1	0.5	31.19

Note: ns = not significant at P = 0.05.

3.2 Natural Vegetation

The total area of natural and managed vegetation remained quite stable between 1981 and 1985 (Table 5). A decrease was recorded in natural forest, but this was confined to Kibwezi Division, where the forested Chyulu Hills were being rapidly cleared for farming. All other divisions that had any forest showed a significant increase.

The bushlands decreased in all eight divisions reflecting the conversion of this vegetation class into open woodland or grassland, both of which increased significantly in area. Of 62,000 ha/year lost to bushland, roughly half was converted to each. It is interesting to note that the diminution in the area of bushland was largely unrelated to the expansion of agriculture. Only 1,775 ha/year were added to the cultivated area. The diminution of bushland is related to the smallholder livestock sector (see Environmental Profile, Section D). Plantations and woodlots showed contradictory trends. Woodlots diminished, but the evidence taken together suggests a slight decline in forest and woodland.

Table 5: Changes in natural and managed vegetation 1981-85 (after Ecosystems, 1986d)

Land use	*1981*	*1985*	*% change/year*
		per cent of District	
1. Total	75.7	74.7	-0.32 ns
2. Natural forest	2.8	1.2	-17.43
3. Bushland	39.3	19.6	-14.32
4. Woodland	5.7	15.7	25.17
5. Grassland	18.6	28.6	10.05
6. Plantation forest	0.2	0.2	3.5
7. Woodlots	0.3	0.2	4.5

Note: ns = not significant at P = 0.05.

3.3 Land Use Change by Study Area

Since the Ecosystems data are mapped by 25 km^2 grid cells covering the whole District, it is possible (though the samples are small) to assemble land use change data from those cells corresponding to the study areas analysed from 1948 to 1978. The results of this exercise are shown in Table 6.

The study areas appear from left to right in the Table, according to the same gradient as before (see Tables 1, 2 and 3), that is to say from higher, wetter, densely populated and intensively farmed on the left to lower, drier, lightly populated and extensively farmed on the right. The rates of change recorded between 1981 and 1985 are consistent with the differences noted earlier. With the exception of Ngwata, where agriculture stagnated, the processes of extending the cultivated area, and increasing the area under cash crops, proceeded fastest towards the right; getting out of staple crops and into horticulture proceeded fastest towards the left.

By contrast, bushland conversion proceeded everywhere; woodland continued to increase in Kalama, reversed its decline in Masii, and increased quite rapidly in Makueni and Ngwata.

Table 6: Rates of land use change in study areas (after Ecosystems, 1986d) (ha/km²/yr)

Land use	*Mbiuni*	*Kalama*	*Masii*	*Makueni*	*Ngwata*
1. Arable (incl. fallow)	-1.5	1.0	2.4	2.5	0.1
2. Smallholder cash crops	-1.0	0.4	1.0	0.8	0.2
3. Smallholder staple crops	-2.4	-0.4	-0.4	1.0	-4.2
4. Horticulture	0.5	0.3	0.1	0.04	0.06
5. Fruit trees	0.1	0.1	0.1	0	0
6. Bushland	-2.0	-5.0	-4.0	-2.5	-3.0
7. Woodland	-1.7	6.0	1.5	4.7	3.7
8. Grassland	1.0	3.2	1.5	2.1	3.0

4. LAND USE CHANGE, 1930-62

Using official statistics, Table 7 sets out estimates of land use in 1930 and in 1960-62. These estimates derive ultimately from agricultural officers' field observations and the records of government interventions in forestry and coffee planting. Though not strictly compatible with data derived from air photography, they provide an independent data set extending the history of land use a further 18 years into the past.

The cultivated percentage (including temporary crops, fallow and permanent crops) was estimated to be 15 in 1930 in the Reserve. In 1937, 19% was estimated to be under cultivation (Maher, 1937) and the locations in which the study areas then fell were estimated at 19, 25 and 37%. In 1948 (Table 1) the cultivated percentages in the three study areas that fall within the old Reserve boundary (Mbiuni, Masii and Kalama) were 35, 23 and 14. An average of 24% for the Reserve at that time would be consistent with an increase of about 10% over the preceding 18 years of population growth.

In 1960-62 the official estimates gave a cultivated percentage of 26. This is consistent with the average of the measured cultivated percentages of Mbiuni, Masii and Kalama (25) derived from the air photography of 1960-61 (Table 1).

The areas of pasture and bush given in Table 7, if combined (69%), are similarly consistent with the percentages of bushland in Mbiuni, Masii and Kalama given in Table 1 (72%). The only significant differences are in the areas of forest, which are larger, according to air photo interpretation (3%), than in official estimates (1%).

The percentages given for the District as a whole in 1960-62 (cultivation 18-19%, pasture and bushland 78%) are broadly consistent with the averages given for all five study areas in Table 1 (cultivation 18%, bushland 7%). This implies that the averages given in Table 1 for 1978 (51% cultivated, 40% bushland) are also reliable indicators of the District-wide percentages.

Such satisfactory convergence between the two data sets - notwithstanding the fact that the study areas used for air photo interpretation could not be strictly representative in a statistical sense - provides good confirmation of the reliability of both series, and indicates that data generated from air photo interpretation can be integrated with administrative statistics (within an acceptable margin of error) for the larger land use classes.

The SRF data for 1981 and 1985, however, cannot be incorporated into an integrated series, since there is no question of the cultivated area having fallen from over 50% in 1978 to under 20% in 1981. But these data provide an internally consistent series, and the changes recorded between 1981 and 1985 are consistent with earlier trends.

Table 7: **Land use, 1930 and 1960-62, in hectares and percentages**

	Temporary crops	*Temporary fallow*	*Permanent crops*	*Total cultivated*	*Pasture*	*Bush*	*Total pasture & bush*	*Forest*	*Other*	*Total*
A.1930 Reserve Area[1]										
ha	56,000	28,000	-		370,000	100,000 [2]		-	-	554,000
%	*10*	*5*	-	*15*	*67*	*18*	*85*	-	-	*100*
B. 1960-62										
Reserve Area (1960-61)										
ha	112,080	5,880	6,320[3]		276,480	40,360 [2]		4,600	14,760	460,480
%	*24*	*1*	*1*	*26*	*60*	*9*	*69*	*1*	*3*	*100*
Yatta										
ha	6,040	-	-		102,760	-	-	-	108,800	
%	*5*	-	-	*5*	*95*	-	*95*	-	-	*100*
Scheduled areas (1962)										
ha	2,080	-	15,200[4]		194,880	-		1,920	-	21,480
%	*1*	-	*7*	*8*	*91*	-		*92*	*1*	*-100*
Machakos District										
Total[5]	120,200	5,880	21,520		574,120	40,360		6,520	14,760	783,360
%	*15*	*<1*	*3*	*18-19*	*73*	*5*	*78*	*1*	*2*	*100*

Notes:
1. Excludes Yatta and Crown Land in the south including Makueni and Chyulu Hills. It nevertheless seems larger than the Reserve Area in 1962.
2. Bush that was unutilisable due to tsetse etc; if utilisable it is pasture.
3. Mainly coffee.
4. Almost all sisal.
5. Temporary and permanent crops = cropped area. Cropped area + pasture + fallow = farmed land.

Sources: 1930: Land Commission, 1933.
1960/61: Kenya 1962. Agricultural Sample Census, 1960/61.
1962: Kenya 1963. Kenyan Agricultural Census, 1962. Scheduled Areas and Coastal Strip.

5. CONCLUSION

Data have been derived from three major sources: air photography of medium scale for three years (1948; 1960-61; 1978); SRF photography of large scale for two years (1981; 1985); and official estimates for 1930 and 1960-62. Satellite imagery failed to generate compatible data.

The analysis of medium scale air photography confirms the initial hypothesis of a major expansion of agricultural land at the expense of bush/grazing land and forest/woodland. In addition, it shows that terracing (in some form) was extended to almost all agricultural land, except in the south of the District, by 1978. There was a gradient of land use intensity (expressed in the percentage cultivated), and the chronology of terracing conformed to this gradient, the more intensively cultivated (hilly) areas being terraced earlier. In some areas, the position of woodland improved during the period. All types of change accelerated after 1960-61.

The SRF photography showed that in the District as a whole, there was an intensification of farming between 1981 and 1985, rather than a large scale extension of the cultivated area. The rates of change observed were consistent with the ecological gradient noted above, with tendencies to change from staple crops to horticulture in the intensively farmed areas, and to extend cultivation and increase cash crops in the less intensively farmed.

Finally, a comparison of official land use estimates for 1930 and 1960-62 is found to be compatible with the results of the air photo interpretation. While the SRF data are insufficiently compatible to be combined in the same data series, the observed trends are consistent with those derived from the other series.

The Land Use Profile, therefore, sets out the spatial dimensions of agricultural extension, conservation, and intensification under the impact of the growth and redistribution of the population, and of economic and technical change.

Figure 1: Mbiuni study area: land use, 1948

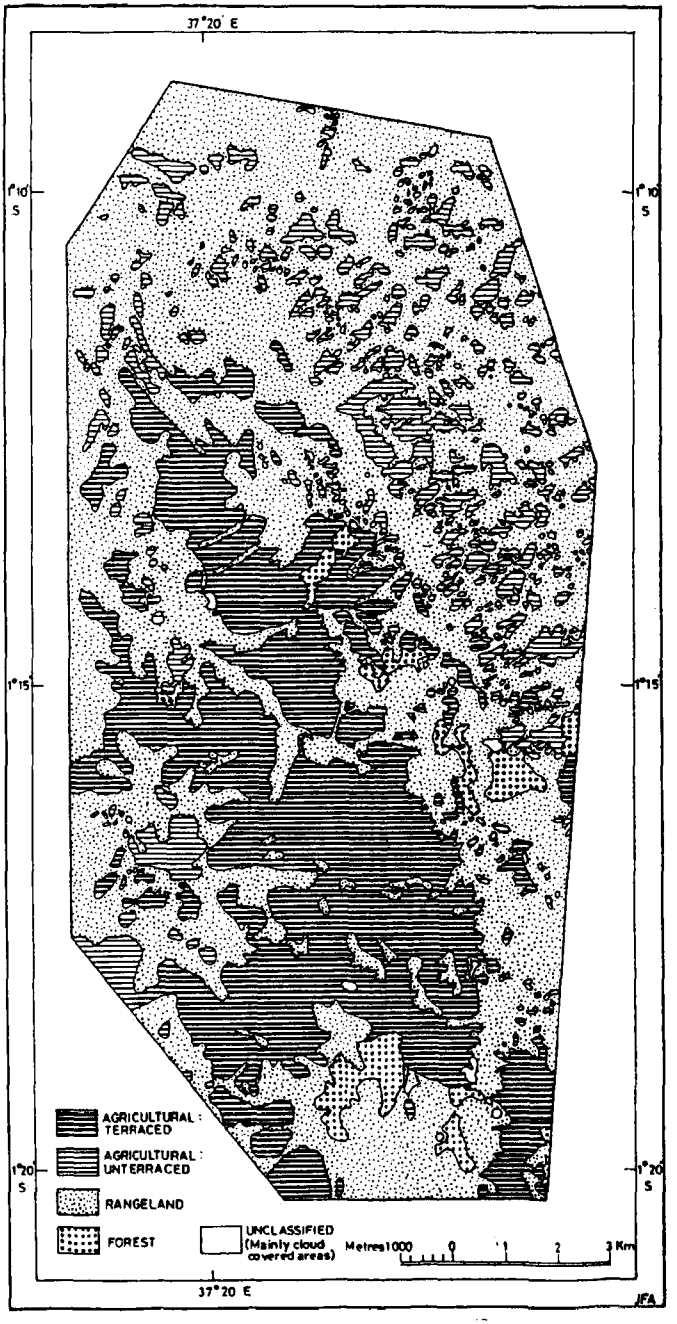


Figure 2: Mbiuni study area: land use, 1960

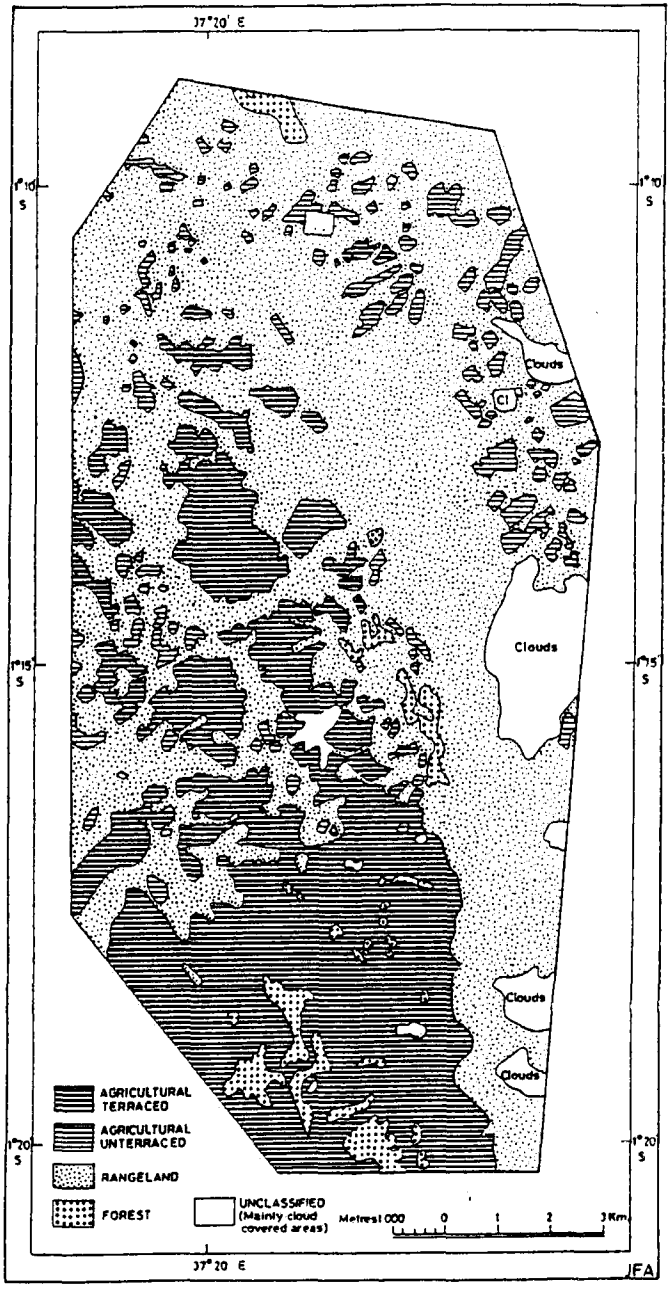


Figure 3: Mbiuni study area: land use, 1978

Figure 4: Kalama study area: land use, 1948

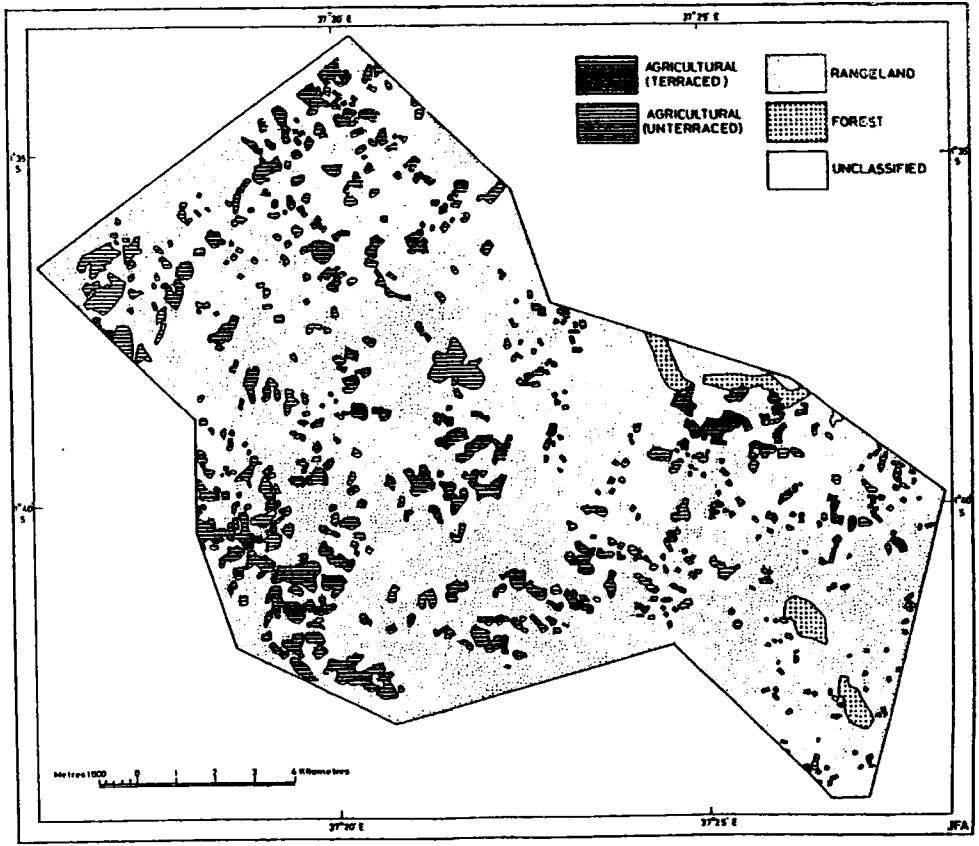


Figure 5: Kalama study area: land use, 1960

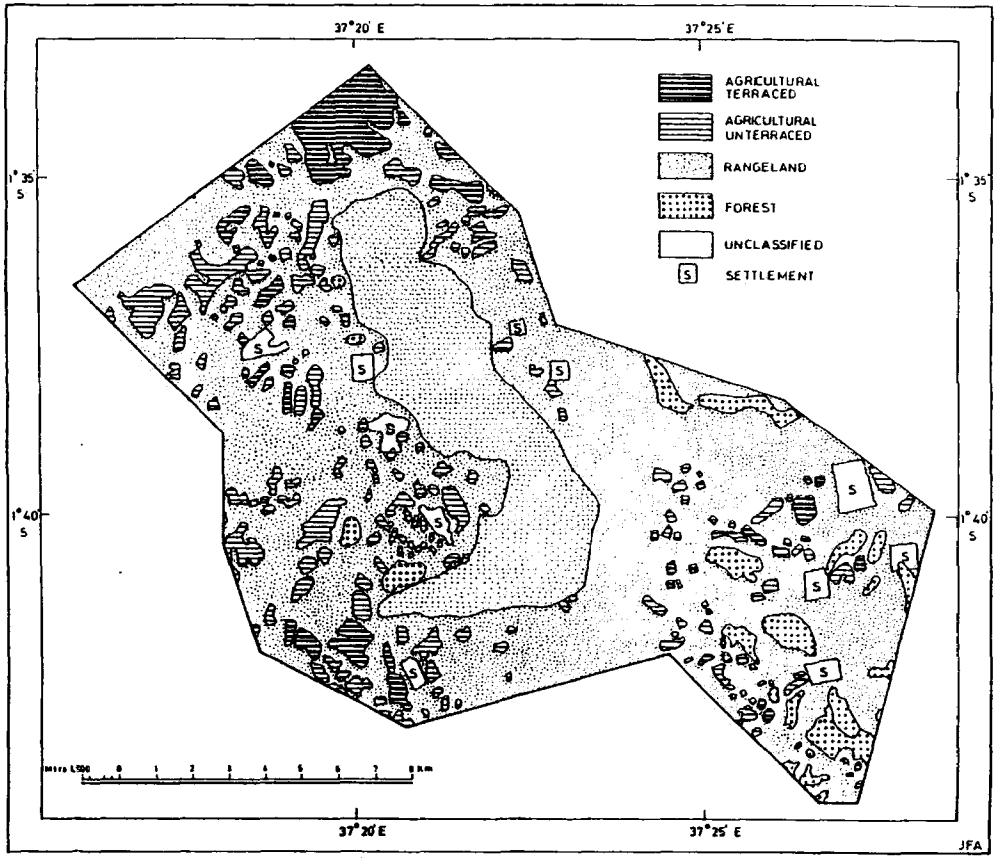


Figure 6: Kalama study area: land use, 1978

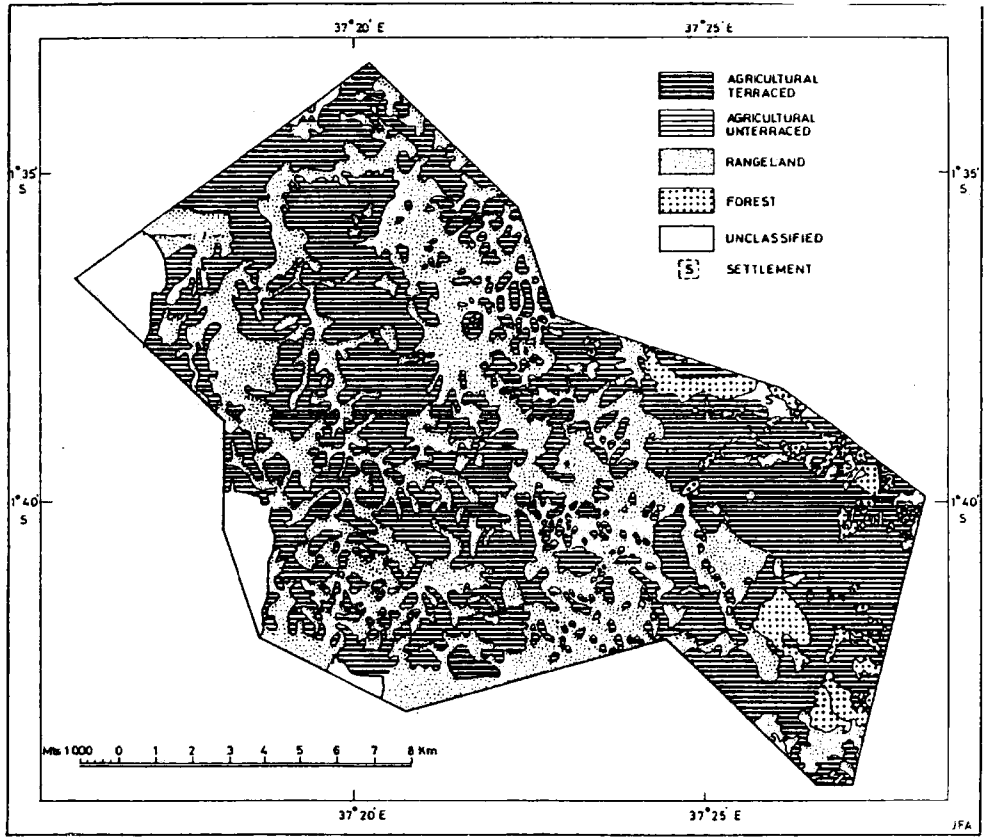


Figure 7: Masii study area: land use, 1948

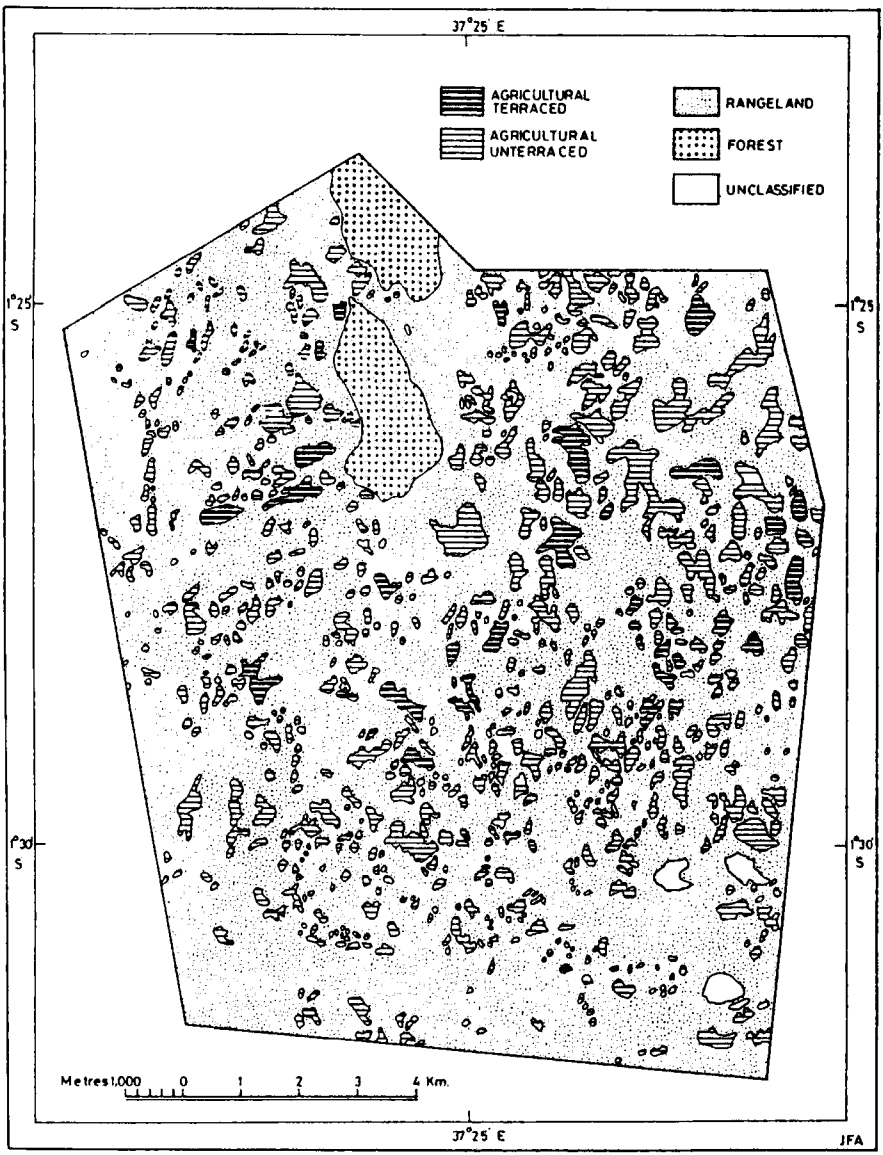


Figure 8: Masii study area: land use, 1960

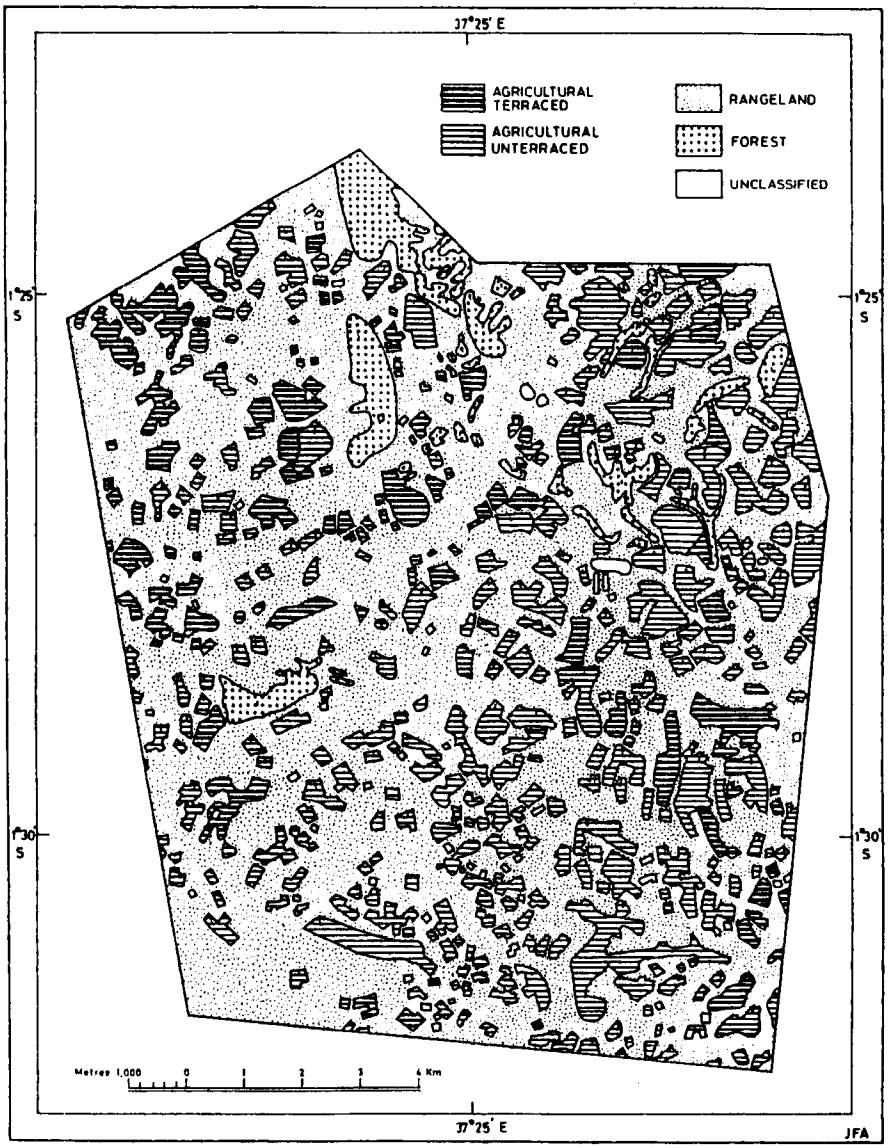


Figure 9: Masii study area: land use, 1978

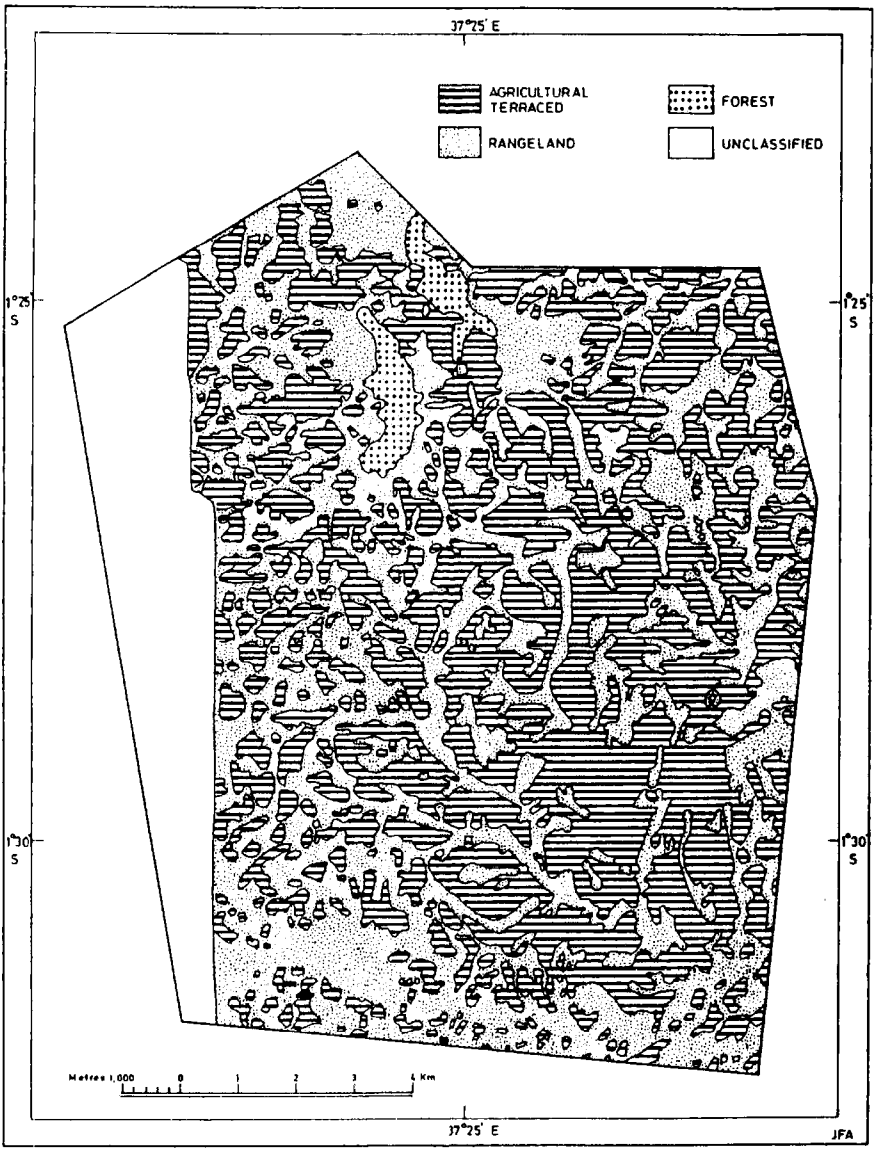


Figure 10: Makueni study area: land use, 1948

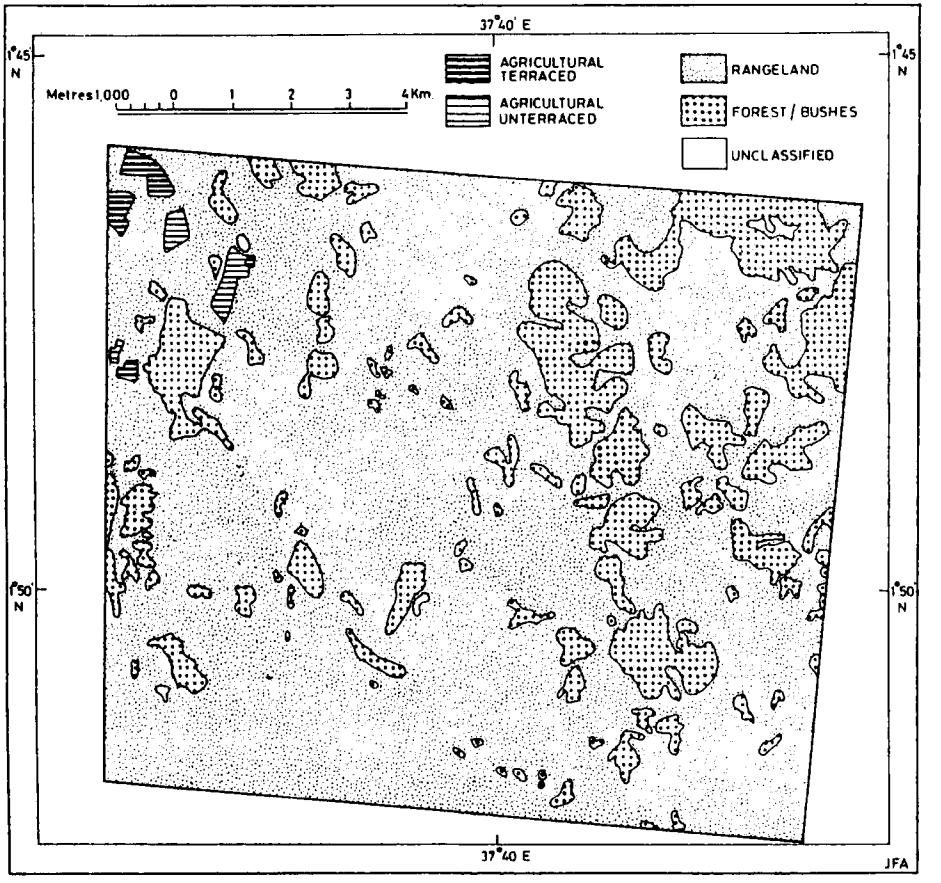


Figure 11: Makueni study area: land use, 1960

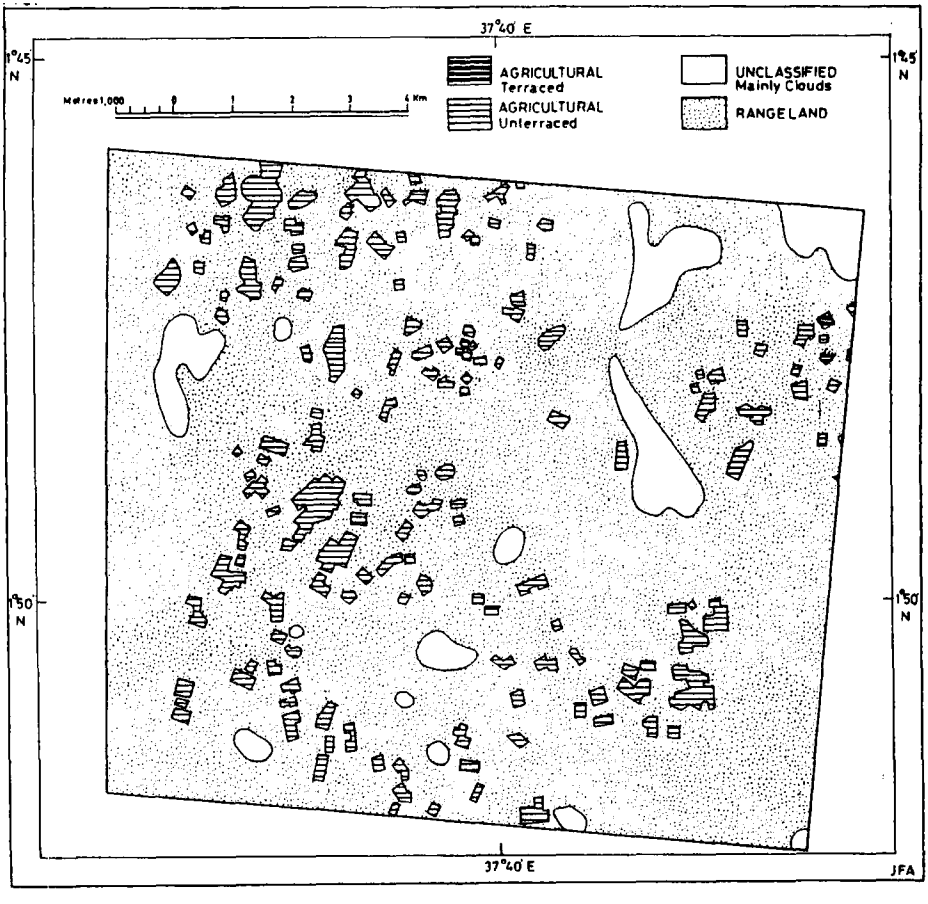


Figure 12: Makueni study area: land use, 1978

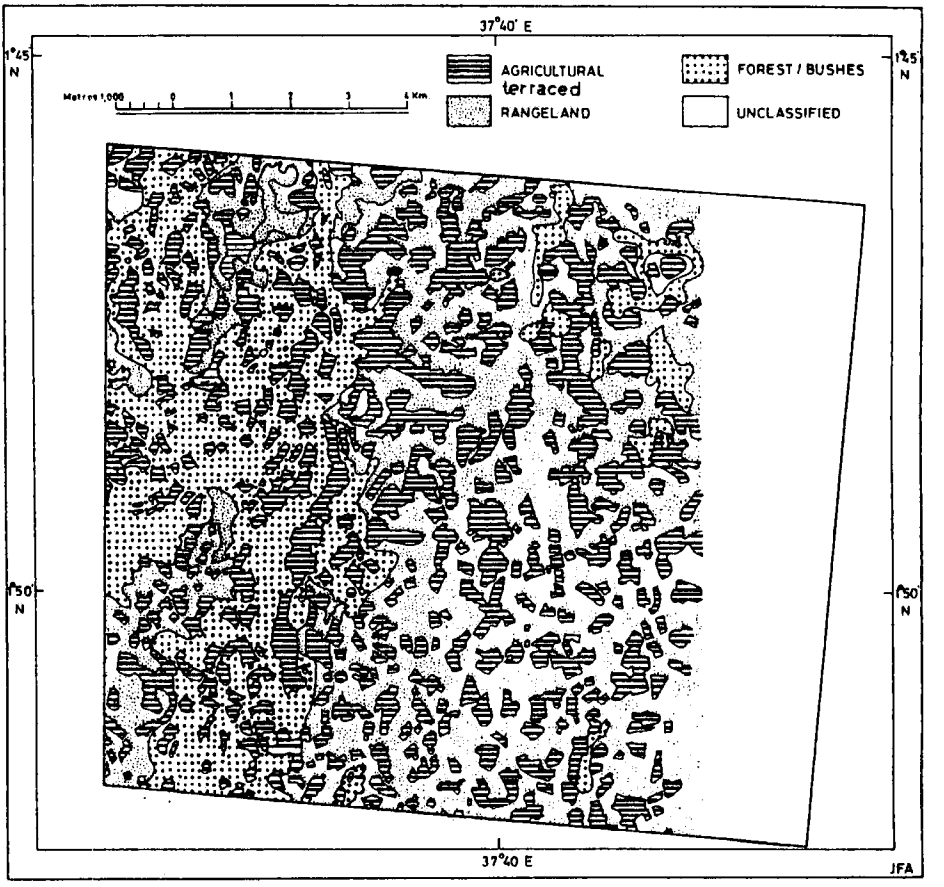


Figure 13: Ngwata study area: land use, 1960

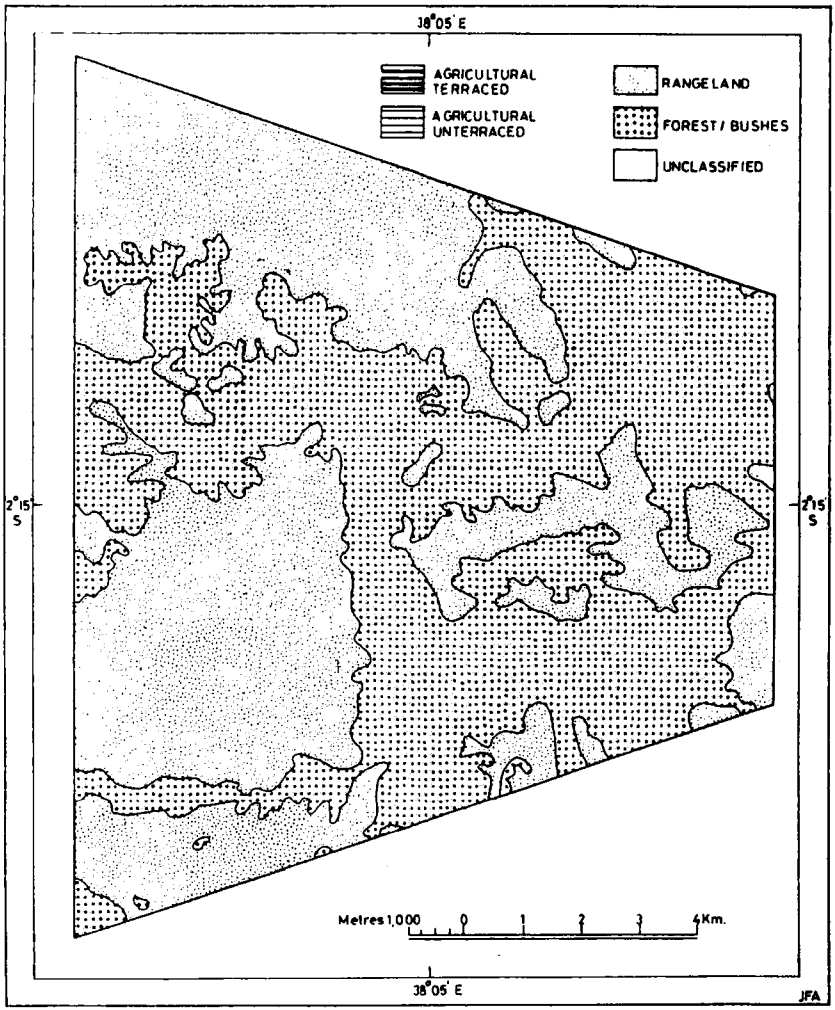


Figure 14: Ngwata study area: land use, 1978

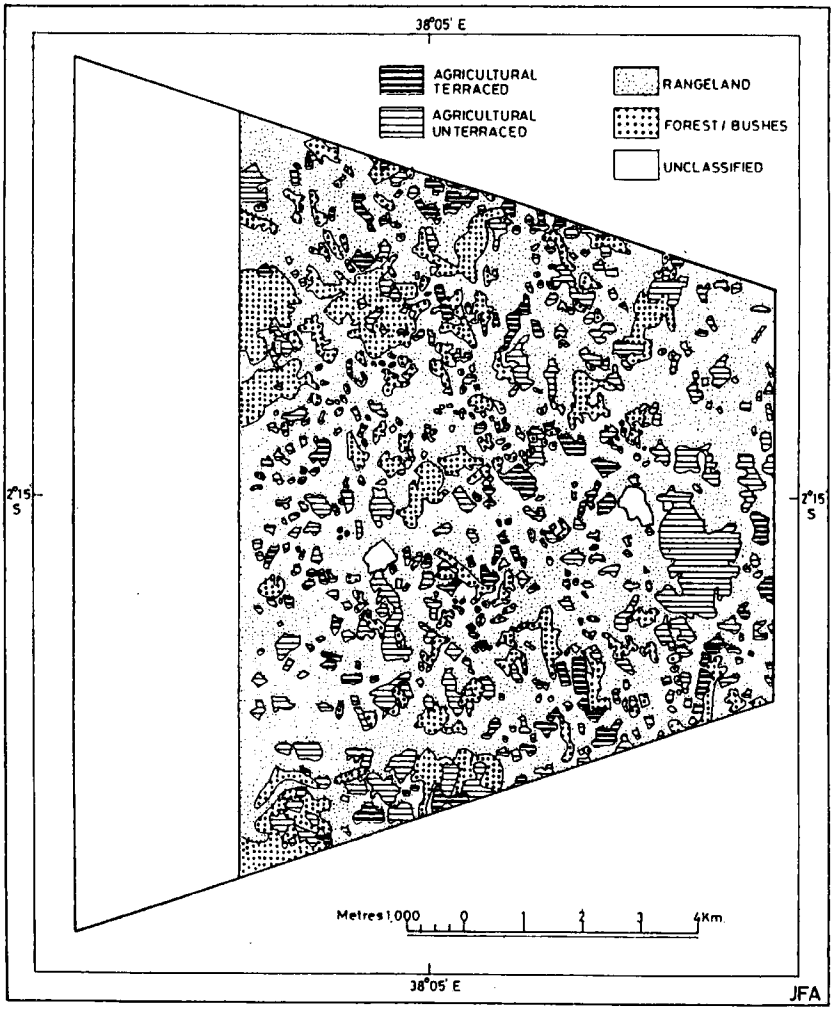


Figure 15: Percentage of land use in Mbiuni Location

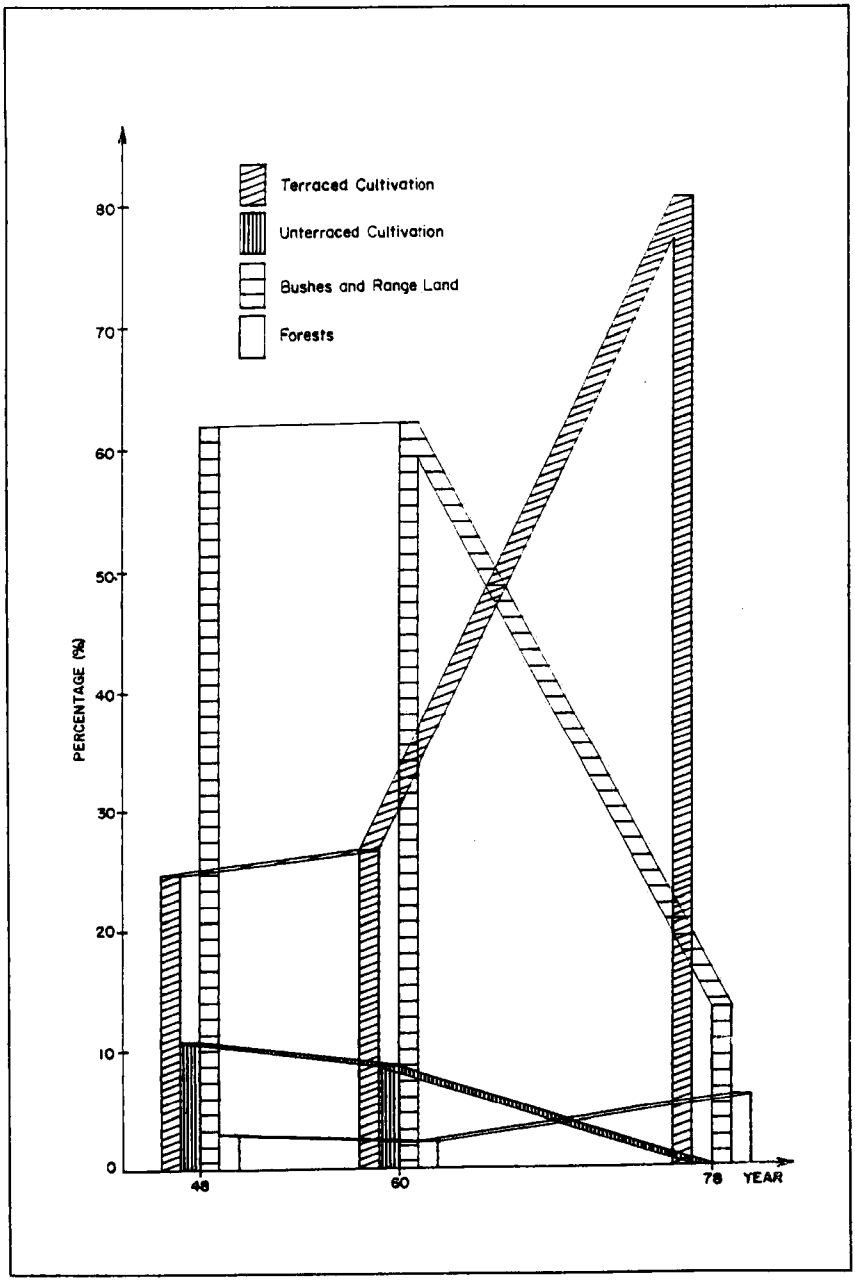


Figure 16: Percentage of land use in Kalama Location

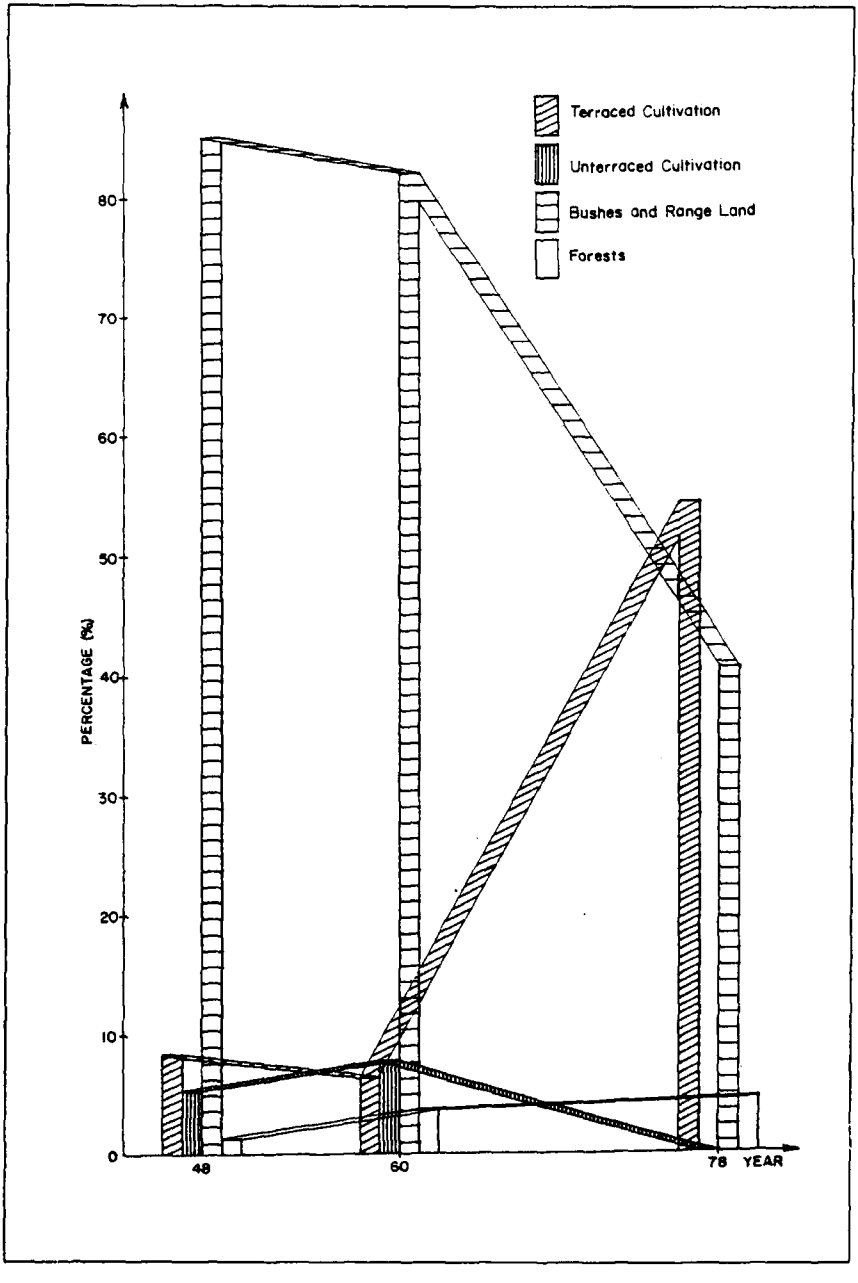


Figure 17: Percentage of land use in Masii Location

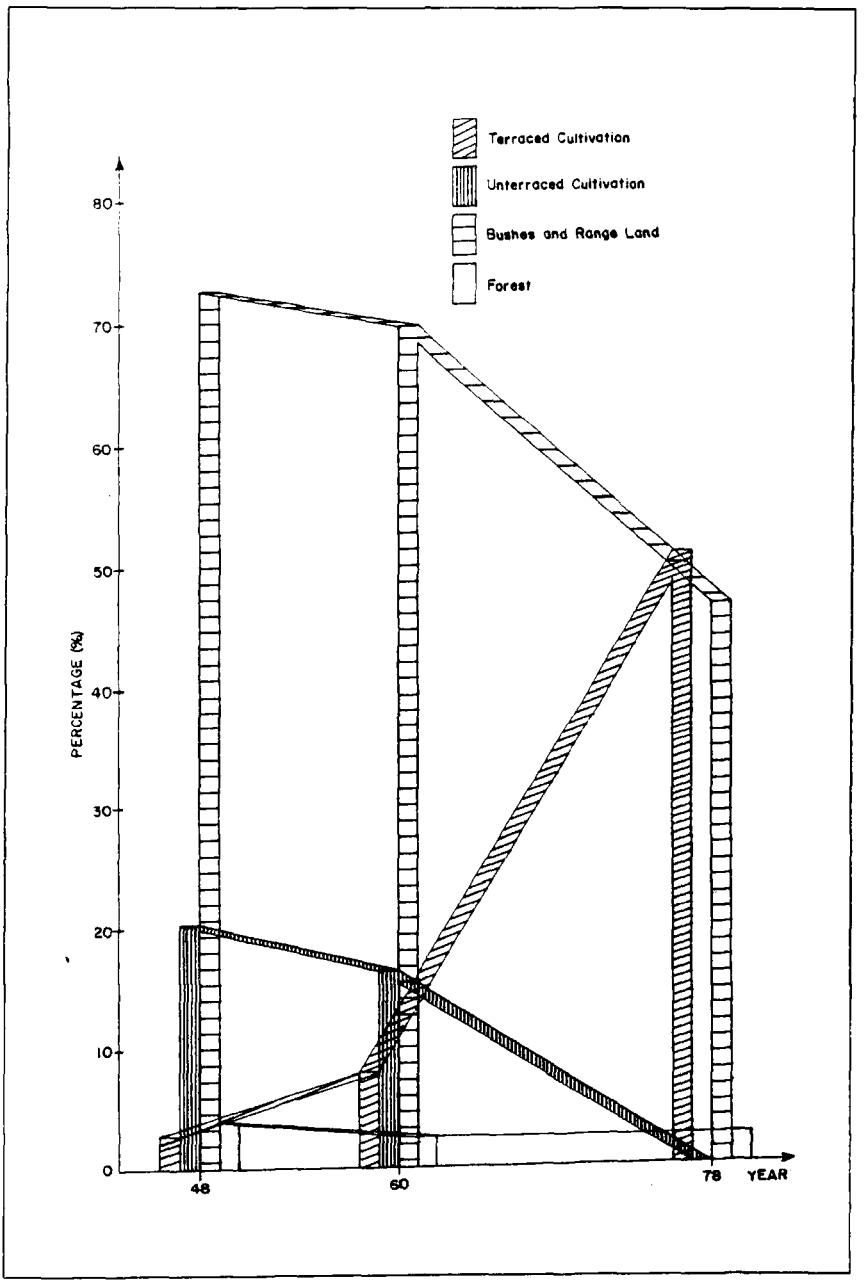
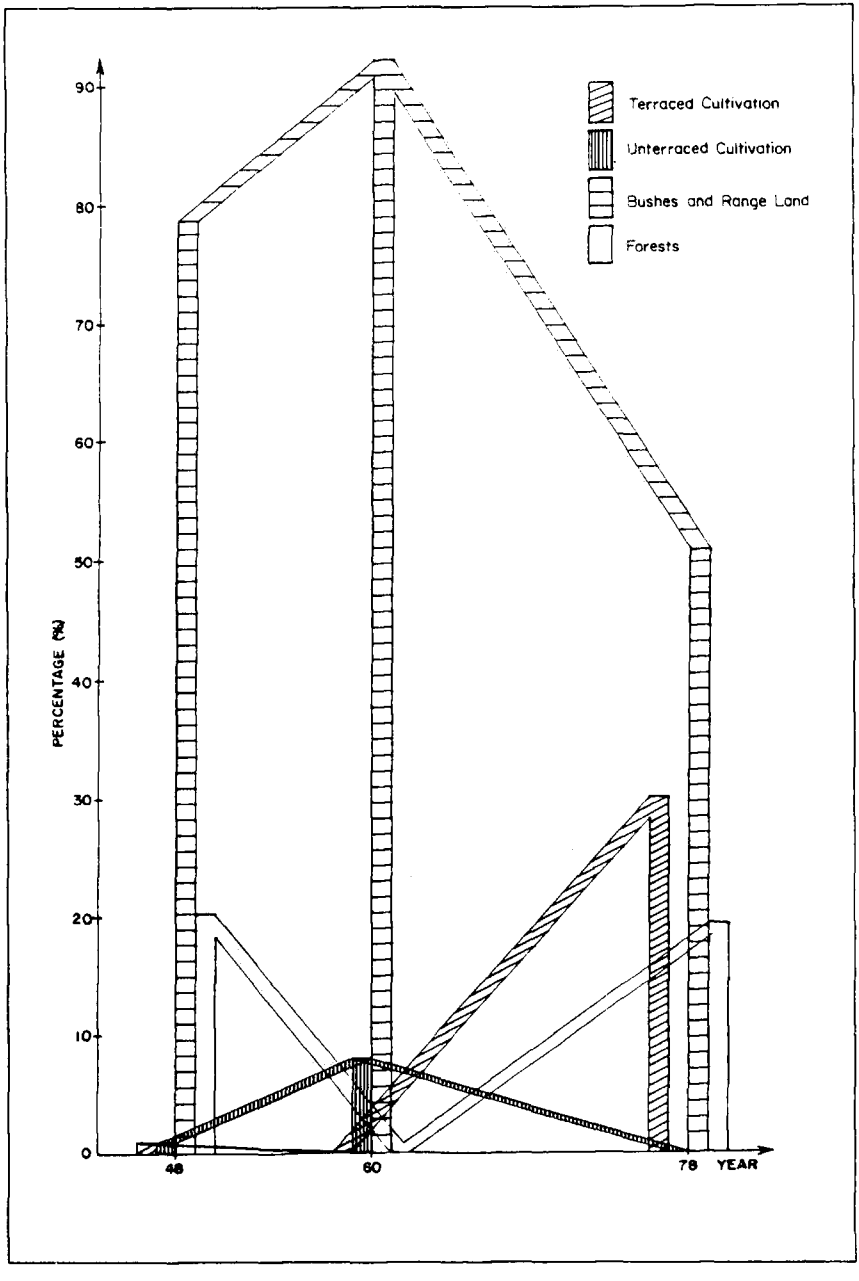


Figure 18: Percentage of land use in Makueni Location



APPENDIX

METHODOLOGY AND DATA

The GIS group, which was responsible for mapping land use change was charged with the acquisition of temporal land use data and the subsequent assembly of a manual data base. This involved three steps, namely:

- Classification development
- Image interpretation
- Data transfer

1. Introduction

The development of a classification scheme is crucial in that many man-hours can be wasted if a series of maps are produced that are of little use because they are incompatible with the other elements of a mapping system or because the categories are impractical (Yego, 1984).

Classification development in this project took into consideration the needs of the project, the time and financial resources available to do the work and the types of imagery available for use in the project.

The initial step was to develop an ideal classification. This was done in two ways. First, potentially useful classification systems were considered, including the USGS land use/land cover classification system (Anderson et al., 1976) and the classification for rangelands in East Africa (Pratt and Gwynne, 1977). Members of other groups were consulted to determine practical categories that would be in harmony with the other themes considered in the study.

An ideal classification was then sifted through a screen of reality with three aims, bearing in mind that the method of visual interpretation would be used:

(i) to evaluate their adaptability to existing imagery;

(ii) to consider the data's spatial accuracy, resolution and quality; and

(iii) to evaluate the time and financial resources available.

A classification was then adopted to include the following classes of land use/land cover:

(i) Agricultural land

(ii) Bush/Scrub/Grazing land

(iii) Forests

(iv) Others/unclassified

Black and white aerial photographs for various years (1948, 1960-61, 1978) constituted the data source for land use mapping. The detail of this medium-scale data is often of such quality that usable data can be interpreted and mapped with little if any field checking.

For this project the 1:50,000 scale maps were adopted as the base maps with overlay procedures adopted for data transfer. This procedure not only serves the current needs of the study, but also forms a basis for a computerised GIS in the future.

2. Data Acquisition

The District is covered by 1:250,000 Series Y 503 Nos. SA - 37-1,2,5,6,9,10 and 34 topographical maps at the scale of 1:50,000, published by the Survey of Kenya.

Aerial photographic coverage of the study area was available for the years 1948, 1960-61, 1967 and 1978. However, these coverages are incomplete to varying degrees. The average scale of the photographs was 1:30,000 for the 1948, 1:50,000 for the 1961 and 1967, and 1:20,000 for the 1978 photography. The 1978 photographs are of acceptable quality, while those from 1961 and 1967 have poor contrast and a lot of cloud cover. The 1948 photography is also of poor quality and the negatives for the production of prints are in the United Kingdom. The necessary prints were purchased from the Survey of Kenya and the Royal Air Force, Huntingdon.

3. Delineation of the Study Areas

The boundaries of the selected study areas were transferred to the 1:50,000 topo-maps as follows:

		Sheet
1.	Mbiuni	149/2,4
2.	Masii	149/4, 162/2
3.	Kalama	162/2
4.	Makueni	163/3
5.	Ngwata	183/1

It was decided to provide land use cover maps for the years 1948, 1961 and 1978 from the aerial photographs.

At a later stage, it was realised that the Makueni and Ngwata locations did not show substantial changes in the early period and are large in size. For these reasons, it was decided to cut down these areas to sample portions only.

4. Methodology

In the absence of a computer based facility, it was decided to produce a manual GIS, producing a land use transparency for each year which, if overlaid, would show the land use changes both in extent and location. The transparencies, therefore, would have to be of the same format. The base maps for all the transparencies were derived from the 1:50,000 topo-maps of the area.

Production of the transparencies

The topo-maps covering each area were assembled, the boundary of the area carefully drawn, and the areas on the map outside the boundary masked out by opaque paper. The grid and graticule values in the margins were kept as frame information. This information would be particularly useful for later digitizing. The assembly was then edited and appropriately titled. The transparencies were produced from the maps so assembled by contact photography through the negative and positive processes. The positive process was adjusted to be in faint print to better show up the subsequent land use information.

Photo interpretation

The interpretation was done by visual methods. Stereo models were constructed under the mirror stereoscope and the delineation of each land use category was indicated on the photographs by different colours and symbolization. Whenever necessary, differences in height were measured by parallax bar to aid in interpretation. A sample stereopair in each strip was interpreted by an expert to serve as a reference key for other models in the strip. The rest of the models in the strip were then given to well-trained technicians for interpretation. The photographs interpreted by the technicians were then checked by the experts.

Construction of aerial mosaics

Mosaics were assembled from the aerial photographs with the delineated land use categories. The assembly was done on cartridge boards, and the only control criterion adopted was to form a continuous image of extended photographed features. The aerial mosaics were then reduced to the required transparency scale of 1:50,000 by photographic means.

Transfer to land use sheets

The land use information was transferred from the reduced aerial mosaics onto the transparency base maps by tracing. The main guide during this transfer was the local registration of corresponding map and mosaic features such as rivers, roads, hills, etc. This approach minimized positioning errors due to tilt, relief and, more important, due to their accumulation in the mosaic assembly.

Interpretation of terraced cultivated land

The photointerpretation of the 1948, 1961 and 1978 photographs included subclassifying the cultivated land into terraced and unterraced. Under the mirror stereoscope the terracing lines

between two levels of terraces are very clear in the stereomodels of the 1978 photographs, owing to their large scale and good quality. However, on the 1960-61, and 1948 photographs, the interpretation of the terraced cultivated land was not easy, due to the smaller scale (1:50,000) and/or the poor quality of these photographs. The identified terraced cultivated land parcels were indicated on the photographs and marked on the copies of the land-use map transparencies.

5. Results and Analysis

Area computations

The area of each land use category on every map was measured by planimeter and dot grid. The area unclassified was subtracted from the total to indicate the sum of the areas representing classified categories (cultivation, bushes, forest). Each of these categories were referred to the sum as percentage. The percentage change D taking place in 1978 as compared with 1960 was calculated as

$$D = [(A1978-A1960)/A1960] \times 100\%$$

Assessment of precision

1. *Interpretation*

   Assuming that the minimum resolving power of the camera used in producing the aerial photographs is 10 l/mm, then the ground resolution of the 1948 photographs is 3m., 1961 photographs is 5m, and that of 1978 photographs is 2m.

   Based on other investigations (Aronoff, 1982; 1985), the results of similar projects, and other practical considerations, the accuracy of interpretation of the 1948 and 1978 photographs should be better than 95%. Due to the smaller scale of the 1961 photographs and their inferior quality, accuracy is estimated as 90%. Ordinarily a minimum level of 85% interpretation accuracy is desired for optimal results (Anderson, 1976). Using visual techniques, this kind of accuracy is possible to achieve.

2. *Positioning*

   The estimated planimetric displacement is within 1-2mm (50-100m on the ground). Although this accuracy is less than that of the 1:50,000 base map, it is acceptable because the important task is the interpretation in which high positional accuracy does not serve any purpose. Therefore, the positional accuracy of 1-2mm of the line boundaries between land use categories is considered acceptable.

3. *Areas*

   Considering the order of the height variations in the study areas, the error in an individual area may be up to 5%-8%. However, as these errors vary in magnitude

and sign from one place to another, the errors in any category on a map sheet should be considered as random in nature. Therefore, the sum of the errors in the total area of a certain category should tend to zero. Thus the accuracy of the areas corresponds to the measuring accuracy by planimeter or dot grid. The sums of the areas in each category were rounded to the nearest 10 ha.

6. Landsat Thematic Mapper (TM)

Landsat Thematic Mapper Imagery, though incompatible with the aerial photography for quantitative analysis, was very recent (1988), and might indicate the current trend of land use and confirm the trends established from the aerial photography.

Landsat MSS image frames for the study area were available from different years at the Regional Centre for Services in Surveying, Mapping and Remote Sensing. However, due to its better resolution and less cloud cover, 1988 Landsat TM imagery covering most of the district was chosen. SPOT imagery, with higher spatial resolution, could have been used, but its acquisition was going to be time-consuming and expensive.

TM image frame No.168/061 of 17.10.88 EOSAT TM4 432 M1032 adequately covered the first four study areas. The fifth area, Ngwata, lay in an adjacent frame which had excessive cloud cover. This area was therefore excluded. The first four areas were marked on the TM image, and then blown up to a scale of 1:50,000 using the topo-maps as reference.

The interpretation of false colour TM imagery at scale 1:50,000 was done by visual techniques, using mainly the elements of colour and texture to identify categories of land use cover.

Only three categories could be identified:

(i) Agricultural land under cultivation - identified by whitish speckles in a light reddish background. This is believed to represent a mixture of cultivated fields interspersed with fallow fields with possibly planted vegetation along the edges.

(ii) Forest - identified by a continuous reddish tone - showing continuous cover of vegetation.

(iii) Bushland/scrubland/other - identified by a greenish to dark tone. This includes unclassified shadow areas (completely dark) and bush/scrubland with a greenish colour typical of vegetation devoid of significant chlorophyll content with open soil areas. This coloration is characteristic of vegetation of semi-arid environments.

The resolution of the TM imagery in the digital mode is 30m, and in the analogue version used, is much less. Therefore, it is evident that the results of visual interpretation of the TM imagery are not compatible with those of the aerial photographs. The visual interpretation of the TM limited the number of classes that could be achieved, thus also limiting the

accuracy of interpretation. The interpretation accuracy can be assessed as only 70%. The results of the TM image interpretation are set alongside those from the 1978 air photographs in Appendix Table 1.

Appendix Table 1: **Comparison of air photo and TM imagery land use interpretation**

Area		*Air photographs (1978)*					*TM imagery (1988)*				
		C	*B*	*F*	*U*	Σ	*C*	*B*	*F*	*U*	Σ
Mbiuni	ha	12,190	1,990	930	2,890	18,000	11,640	6,020	340	-	18,000
	%	67.7	11.1	5.2	16.0	100	64.7	33.4	1.9	-	100
Masii	ha	7,150	6,530	360	2,010	16,050	9,520	5,470	-	1,060	16,050
	%	44.7	40.7	2.2	12.5	100	59.3	34.1	-	6.6	100
Kalama	ha	11,860	8,950	1,070	1,120	23,000	6,490	9,720	4,130	2,660	23,000
	%	51.5	38.9	4.7	4.9	100	28.1	42.3	18	11.6	100
Makueni	ha	3,210	5,400	2,040	3,150	13,800	8,130	5,670	-	-	13,800
	%	23.3	39.1	14.8	22.8	100	58.9	41.1	-	-	100

C = Cultivations B = Bushes F = Forest U = Unclassified Σ = Total area.

Appendix Table 2: **Inventory of air photographs**

Year: 1948; Scale 1:30,000
Contract: CPE/KEN

Location	Run	Photo No.	Total
Mbuini	125	5096-5101	6
	162	5117-5123	7
	114	5037-5045	9
	125	5225-5228	4
			26
Masii	114	5066-5071	6
		5030-5034	5
		5132-5136	5
			16
Kalama	114	5075-5078	5
	114	5024-5027	4
	114	5123-5130	8
	113	5488-5492	5
	113	5462-5465	4
			26
Makueni	105	5251-5255	5
	103	5114-5118	5
	103	5059-5062	4
			14

Year: 1960/63; Scale 1:50,000

Location	Run	Photo No.	Total
Mbiuni	V-13a 1036	108-111	4
		060-064	5
	1097	049-052	4
		057-059	3
			16
Masii	1036	113-118	6
		053-060	8
		001-006	6
	1097	052-053	2
			22
Kalama	1036	007-009	3
		050-054	5
		0118-0122	5
		0150-0154	5
			18
Makueni	1040	069-077	9
	1042	093-096	4
		007-018	12
	1101	009-016	8
		061-073	13
		095-104	10
			56
Ngwata	1101	128-137	10
	1102	022-030	9
		097-106	10
		120-129	10
	1103	030-037	8
	(1963)	145-149	5
	V13B/420	0024-0029	6
			58

Year: 1978; Scale 1:20,000
Contract 781

Location	Run	Photo No.	Total
Mbiuni	14	574-588	15
	15	655-673	19
	16	748-762	15
	17	838-850	13
	18	926-936	11
	19	1017-1024	8
			81
Masii	14	566-573	10
	15	649-659	11
	16	738-750	13
	17	827-840	14
Masii (C'd)	18	918-923	11
	19	1008-1019	12
	20	1115-1129	15
			86
Kalama	11	344-355	12
	12	409-421	13
	13	477-489	13
	14	551-562	12
	15	632-647	16
	16	722-737	16
	17	813-821	9
	18	905-912	8
	19	992-1001	10
			109
Makueni	23	1425-1432	8
	24	1535-1551	17
	25	1535-1551	17
	26	1749-1767	19
	27	1855-1874	20
	28	1962-1982	21
	29	2064-2084	21
	30	2184-2210	27
	31	2314-2331	18
	32	2445-2466	22
	33	2552-2563	12
	34	2639-2648	10
	35	2720-2725	6
			220
Ngwata	38	2904-2922	18
	39	2935-2951	17
	40	2997-3010	14
	41	3060-3071	12
	42	3116-3126	11
		(gap)	-
	44	3169-3179	11
			83

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Overseas Development Institute
Regent's College
Inner Circle
Regent's Park
LONDON NW1 4NS
England
Telephone: 071-487 7413
Fax: 071-487 7590
Telex: 94082191 ODIUK