A RECONSTRUCTION OF THE HISTORY OF LAND DEGRADATION IN RELATION TO LAND USE CHANGE AND LAND TENURE IN PEDDIE DISTRICT, FORMER CISKEI

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VINCENT KAKEMBO
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Contents

List of figures

List of tables

List of plates

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Abstract

A history of land degradation is reconstructed in a part of the dividing ridge between the Great Fish and Keiskamma rivers, in Peddie District, former Ciskei. The study entails a comparative investigation of the progressive changes in land use, vegetation and soil erosion in three tenure units, namely: former commercial farms, traditional and betterment villages.

Analysis of the sequential aerial photography of the area for 1938, 1954, 1965, 1975 and 1988 is employed. This is backed by groundtruthing exercises. Data thus obtained are quantified, and linkages between degradation, anthropogenic and physical factors are derived using PC ARC/INFO GIS. Differences in land tenure systems emerge as the main controlling factor to variations in land degradation. Confinement of vegetation diminution and erosion to traditional and betterment villages is observed at all dates. Scantily vegetated surfaces and riparian vegetation removal are a characteristic feature of both areas throughout the study period. 'Betterment,' introduced in the early 1960s to curb land degradation is, instead observed to exacerbate it, particularly soil erosion.

Trends in land use change are characterised by the abandonment of cultivated land, which is noted to coincide with a sharp rise in population. Erosion intensification into severe forms particularly between 1965 and 1975, coincident with a period of extreme rainfall events, emerges as the most significant degradation trend. A close spatial correlation between abandoned cultivated land and intricate gullies is identified. So is the case between grazing land and severe sheet erosion.

Within the grazing lands, an examination of erosion and categories of vegetated surfaces reveals that erosion occurs predominantly on the scanty vegetation category. Such erosion-vegetation interaction largely explains the non-recovery of the scanty vegetation category, even during periods of intense rainfall. Extensive channel degradation is evident along stream courses with scanty riparian vegetation.

Physical factors are noted to have a significant bearing on erosion. The high prevalence of erosion

on the Ecca group of rocks confirms its erosion-prone nature. Pockets of colluvium and alluvium accumulation in the steep bottomlands are identified as the sites of the most severe gully erosion. Field surveys at some of the sites indicate that a dolerite sill through the area forms a boundary of colluvium accumulation and the upslope limit to gully incision. That these sites are recognised as formerly cultivated land, portrays the interaction between physical and anthropogenic variables with regard to inducing degradation in the area.

1. Introduction

Land degradation - the reduction in the capability of land to satisfy a particular use (Blaikie 1985) - has reached alarming rates in some parts of South Africa. The problem is more pronounced in the former black homelands, where in many areas, levels range from severe degradation with an irreversible impact to moderate degradation with skeletal production potential left. The paucity of data regarding the magnitude of degradation gives rise to uncertainty amongst experts in the field and policy makers as to the severity of the problem and possible remedial measures (McKenzie 1994). This phenomenon is not a recent one in these areas. Kruger (1991, p.44) quotes from a report by a government commission in the 1930s which described its findings thus: "In the Middledrift district, there are large areas where the surface soil has been entirely eroded and no grass whatever grows......"

The quality of land in many parts of the former Ciskei homeland has deteriorated considerably. Its ecological status has been reduced by serious levels of vegetation diminution and soil erosion. The major symptoms of land degradation, namely: falling crop yields, increased morbidity and mortality of cattle and other animals (Blaikie 1987), replacement of palatable by unpalatable plant species, sheet, rill and gully erosion are characteristic features of these areas. Soil erosion, in particular, stands out as one of the most perilous degradation forms plaguing the region. "Mapping and classification of eroded areas must be regarded as a priority research area, since regular updating of erosion maps can give a clear indication of the rate of land degradation and the efficiency of conservation measures" (Garland 1982, p.141).

Weaver (1988a) points out that the determination of rates of land degradation in Southern Africa by sequential mapping and classification of soil erosion is a neglected area of research. Whereas several investigations into land degradation forms, for instance soil erosion, have been conducted at different scales, far fewer studies have attempted to monitor the problem over a longer time period (Marker 1988). For a better understanding of the factors controlling land degradation, an assessment of its variation in both spatial and temporal contexts is essential. "A simultaneous study of changes in the past and present is necessary for a better understanding and identification of processes, rate and trend of change" (Stromquist *et al* 1985 p3). It is in this framework that this geographical inquiry seeks to probe into the historical perspective of land degradation and attempt to establish the controlling factors of both its spatial and temporal variations.

The present study is, in the main, intended to evaluate the potential causes of temporal and spatial variations in degradation levels within an environment considered to be physiographically and ecologically homogeneous, situated on the dividing ridge between the Great Fish and Keiskamma rivers. Trends in two forms of land degradation, namely soil erosion and vegetation diminution, are focused on. To achieve this, both the temporal and spatial aspects of the physical and human landscape, for instance vegetation type and cover, soil erosion, land tenure and land use variations are examined. It is by establishing the origins and trends of the land degradation process and assessing its present status that measures for land restoration and conservation can be determined.

Land degradation has, quite often, been attributed to inappropriate and unsustainable land use practices (Blaikie 1987, Brinkcate and Hanvey 1996). However, it is noteworthy that different scales of degradation are controlled by a number of intrinsic variables. These must be examined and understood before it can be determined whether the problem is human induced or otherwise. In their study of the changes in the extent of erosion in the Tugela catchment, Garland and Broderick (1992) recorded a decrease in the eroded area. They point out that this reduction cannot be found in a simplistic explanation of changes in land use. "Erosion as a geomorphological system has controlling variables which are subject to medium or long term temporal fluctuations largely uninfluenced by man. It is only in exceptional circumstances that human interference is likely to reverse a natural geomorphological trend and then only at a local scale for short periods."(Garland and Broderick 1992 p.48). Thus, an attempt is made in the present study to identify and elucidate the dynamic geomorphological and anthropogenic factors responsible for land degradation variations in the study area in space and time.

Research objective and aims

The sole objective of this study is:

- To reconstruct the history of land degradation in a sub-catchment of the Great Fish and Keiskamma rivers.

The study, conducted within the framework outlined above, is intended to achieve the following specific aims:-

(i) To investigate the progressive changes in the extent and severity of degradation in the study area, in terms of vegetation diminution and soil erosion.

(ii) To examine the trends in change of land use regimes and relate them to land degradation.

(iii) To establish the influence of natural physical factors on the spatial and temporal variations of land degradation.

(iv) To assess the extent to which differences in land tenure systems are a controlling factor to land degradation variations.

Pursuant to the realisation of the above aims, analysis of sequential aerial photographs dating from 1938 is employed as an approach to the understanding of the temporal variations of land degradation in the study area. Extensive ground surveying is carried out to assess the extent and severity of degradation. An insight into the interplay between natural physical and anthropogenic factors with regard to land degradation inducement is thus achieved.

This chapter serves as a brief introduction to the importance of the historical perspective to the understanding of land degradation variations in space and time. It is by way of this approach that the trends and the present status of the problem can be established and solutions formulated. The available literature on the study of land degradation is discussed in Chapter 2. Natural physical factors are examined side by side with anthropogenic ones. The environmental setting of the study area is presented in Chapter 3. Chapter 4 examines the methods of data collection relevant to the fulfilment of the aims of the study. The results of the study are presented and analysed in Chapter 5. Their interpretation and discussion are carried out in Chapter 6. Recommendations regarding degradation remedial measures are given in the same chapter. Conclusions drawn from the study and directions for future research are presented in Chapter 7.

2. Theoretical background

The land degradation problem is a complex response to interrelated natural physical and anthropogenic causes. Analysed through the systems approach, these causes operate through self-amplifying positive feedback mechanisms. Land is a system of variables that are interconnected so that a change in one variable begets an effect upon the others (Selby 1981), apparently related to the original cause (Thornes 1980). In this chapter, natural physical variables are examined side by side with anthropogenic ones. A series of self -amplifying feedback loops which display the interrelationship between these variables are shown in Figure 2.1.

The dominant variables controlling spatial and temporal variation of degradation forms, notably erosion, differ with the scale of analysis. Morgan (1986a) points to climate as the most important controlling variable responsible for spatial variation of erosion at meso and macro-scale (Table 2.1). At the micro-scale where climate is relatively uniform, soils, topography, rock type, vegetation cover and land use become important (Gregory and Walling 1973, Thornes 1980, Morgan 1986a). Temporal variations at all the three scales of analysis are strongly influenced by individual climatic events which may trigger off significant geomorphic responses within a very short time. Variables which exert a strong influence on spatial and temporal variations of degradation at the micro-scale - which is the level of analysis in the present study - will be discussed in this chapter.

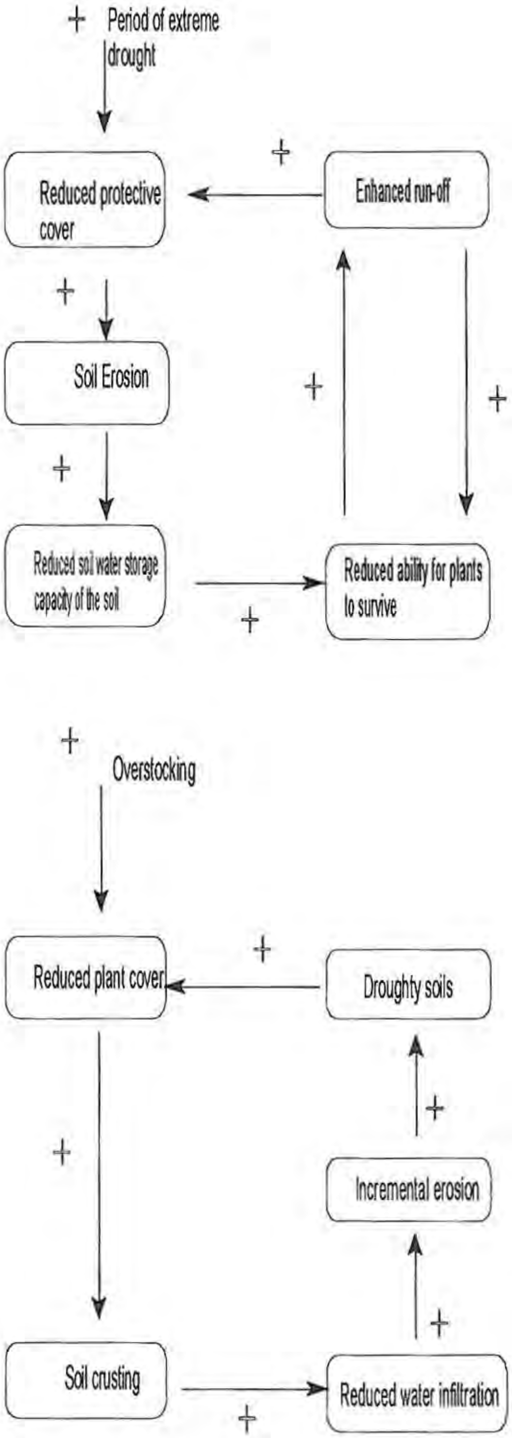

Figure 2.1: Self amplifying feedback loops showing the interrelationship between natural physical and anthropogenic variables. (+ Signs indicate augmentation).

Table 2.1 Scheme for scale effects on factors influencing spatial variation of land degradation (After Morgan 1986a).

Scale of analysis			Evidence
Macro	Meso	Micro	
Climate	Lithology Relief		Sediment Yield Of rivers
Climate	Lithology Relief	Micro-climate Lithology (Soil)	Drainage density
Climate	Altitude Relief		Studies of Erosion rates
Climate		Plant cover Micro-climate	Studies of soil Loss from Hillslopes

SPATIAL VARIATIONS

2.1 Soil characteristics

Fore - knowledge of certain soil characteristic parameters (Thwaites 1986) is necessary for a better understanding of spatial variations in land degradation. Soil erodibility - the measure of the soil's susceptibility to detachment and transport by the agents of erosion - is an important physical factor that affects the magnitude of soil erosion (Lal 1988). The vulnerability of soil to erosion is dependent upon inherent characteristics, particularly the physical and chemical composition (Morgan 1979, Selby 1981, Thwaites 1986). Other factors remaining the same, differences in erosion up to 30-fold have been observed due to differences in soil properties (Lal 1990). A number of soil erodibility indices have been developed by many a scholar on the basis of specific soil properties. The most commonly used indices are shown in the table below.

Table 2.2 Most commonly used erodibility indices (Modified after Bryan 1976 and Morgan 1979)

Dispersion ratio (Middleton 1930)
Erosion ratio (Middleton 1930)
Clay ratio (Bouyoucos 1935)
Surface- aggregation ratio (Anderson 1954)
Erodibility index (Chorley 1959)
Erosion index (K) (Wischmeier and Mannering (1969)
Water-stable aggregates (WSA): >3mm, >2mm, >1mm, >0.5m
Slaking loss
Slaking loss/WSA: >2mm
Moisture equivalent: >2mm
Dry aggregates >3mm, 2-3mm

The 'K' factor is a more commonly used erodibility index for the universal soil loss equation (USLE) (Wischemier and Smith 1978). It represents the soil loss per unit of EI_{30} which is the product of kinetic energy of a storm and its 30 minute intensity (Salako *et al* 1991), as measured in the field on a standard bare soil plot, 22m long and of 5^0 slope (Morgan 1979).

The most important soil physical properties that affect the ability of a soil to resist erosion are; texture, structure, shear strength, organic and chemical content and water retention and transmission properties (Morgan 1979, Gerrard 1981, Thwaites 1986, Lal 1990, Hofmann and Ries 1991). Weaver (1988b) noted a significant relationship between soil type and the spatial variation of erosion in the former Ciskei. Soils with high clay content and a well structured A-horizon e.g. Milkwood, Arcadia and Shortland series, tend to have relatively low erosion levels. Duplex soils with restrictive horizons which differ sharply in structure and permeability, e.g. Valsrivier and Sterkspruit series, exhibited higher erosion levels.

In her studies of gully erosion in Baringo District, Kenya, Rowntree (1991) noted that the morphology of individual gullies was related to the host material. 'Entrenched gullies', characterised by a U-shaped cross section and a steep headcut were associated with silt rich soils of low salinity. Conversely, 'dendritic gullies', with a V-shaped cross-section were identified with saline clay-rich soils. Similarly, Whitlow (1994a) noted that piping was restricted to the clay-rich, sodic subsoils in the columnar soil profiles, in the wetlands of Zimbabwe.

It is noteworthy, however, that the relevancy of certain soil properties to erodibility are site-specific and not necessarily applicable in a wider context (Gerrard 1981, Lal 1990). Besides, soil erodibility is a dynamic soil attribute which may change between seasons or with time due to changes in soil properties (Thornes 1980, Lal 1988, Lal 1991) and these changes are related to fluctuations in organic matter production and surface crusting (Stocking 1987).

2.2 Topography

Topography is a fundamental natural physical variable which influences variations in soil erosion and plant cover. The main components of topography that are important in this regard are slope steepness, slope length, slope shape and slope aspect (Thornes 1980, Gerrard 1981, Zachar 1982, Lal 1990). These are discussed individually below.

2.2.1 Slope steepness

Erosion increases with slope steepness because of the increased downslope component of gravity (Gerrard 1981, Lal 1990). The runoff coefficient increases with slope steepness. Increased slope steepness results in an increase in the velocity of flow, leading to greater capacity for both entrainment and transportation (Thornes 1980). Smith and Wischmeier (1962) established a polynomial relationship between slope steepness and soil loss with the equation:

$$A = 0.43 + 0.30s + 0.043s^2 \qquad (1)$$

Where: A = soil loss (in ton / acre)

s = slope (per cent)

2.2.2 Slope length

Slope length is a surrogate measure for distance from the point at which flow commences (Cooke and Doornkamp 1990) to the point where either the slope gradient decreases enough that deposition begins (Lal 1990) or where runoff enters a well defined channel that may be part of a drainage network (Mitchell and Bubenzer 1980). Erosion potential is greater on long slopes because of a downslope increase in surface flow depth (Gerrard 1981). The length of slope is important in the detachment and transport by wash as total discharge increases with slope length for a given gradient (Thornes 1980). Long slopes tend to augment overland flow quantities and consequently erosion, particularly near the slope foot (Verstappen 1983). Morgan (1986a) quotes Zingg (1940) who developed an empirical relationship between soil transport and surface wash to slope length and slope gradient thus:

$Qs = \tan^{1.4}.SL^{0.6}$ ....(2)

Where Qs = soil loss per unit area

S = slope gradient

L = slope length

2.2.3 Slope shape

The profile characteristics of the slope are fundamental determinants of the susceptibility of slopes to erosion. Slope shape affects soil erosion by influencing the amount and velocity of overland flow (Lal 1990). Thornes (1980) cites studies conducted by Young and Mutchler (1969) and Meyer and Kramer (1969), according to which, the depth of erosion downslope increased linearly with distance and dropped to almost zero on convex and concave slopes respectively. Maximum erosion depth was found to be least on concave slopes, followed by uniform slopes, complex slopes and convex slopes. Soil erosion on convex sections increases rapidly as slope steepness and slope length increase downslope. Gerrard (1981) points out that information from soil profiles and sediments indicated aggradation in the concave sections and erosion on the convex sections.

According to Seuffert (1994), there has been a tendency to ignore the surface geometry parameter in slope erosion studies. It is common knowledge that natural slopes widen or narrow downslope or display a combination of increase or decrease of surface area in the downslope direction. Seuffert's field investigations yielded results to the effect that diverging slopes increase the quantity of surface runoff and of material eroded, while converging slopes decrease the water and material budget. The weaker the individual rainfall event is, the more effective these slope geometry influences are.

2.2.4 Slope aspect

Differences in degrees of insolation occurring on sunny versus shaded slopes constitute the effect of slope aspect. The rate of evapotranspiration, organic matter decomposition, soil salt concentration and that of other processes tends to be accelerated on the sunny slopes due to higher temperatures (Zachar 1982). Studies by Sil'vestrov (1949), Midriak (1965), Ibragimov (1972) all quoted by Zachar (1982) show that erosion due to the above processes is more pronounced on sunlit slopes than on shaded ones. Slope orientation has a significant influence on soil properties, notably soil organic carbon distribution with depth, pH, and percent exchangeable bases (Birkeland 1974). Greater moisture and vegetation cover are a characteristic of shaded slopes (south-facing slopes in the southern hemisphere) as compared to the hotter and drier north-facing ones. Weaver (1988a) refers to a study by Trollope (1987), who established the effect of slope orientation on fires. He noted that vegetation on the south facing-slopes contains less turpentines, hence is less prone to fires.

These components of topography as discussed above have a direct bearing on the spatial variation of soil erosion and vegetation distribution and thus degradation. As noted by Palmer and Avis (1994) in their mid-Fish River zonal study, microclimatic differences are attributed to aspect and slope, with southern slopes experiencing cooler, moist conditions, and the north facing slopes being warmer and drier.

2.3 Rock type

"The effect of bedrock is manifest in the properties of the soil forming parent material which conditions the principal properties of soils, namely their structure, texture, and the content of mineral and chemical substances which, with organic substances, regulate the soil formation processes." (Holy 1980, p.72). According to Verstappen (1983), the distributional pattern of erosion by water is considerably governed by lithological controls. He singles out certain rock formations in the Chama valley in the Venezuelan Andes e.g. the Mesozoic, LaQuinta as the most vulnerable. Weaver (1988a and b) noted that soils in the former Ciskei, underlain by shales and mudstones of Beaufort group were more badly eroded than those underlain by dolerite. Besides, Weaver (1991), cites a study by Mountain (1952) and Bader (1962), who noted that the dolerite soils of the Ciskei are less erosion prone than the soils associated with the sedimentary rocks of the Beaufort group. According to Johnstone (1981), soils derived from the Ecca group have been shown to be highly dispersive and susceptible to both compaction and erosion. Liggitt and Fincham (1989) noted that the Dwyka Tillite category of rocks showed the highest incidence of erosion in the Mfolozi catchment, KwaZulu-Natal.

Given such a close relationship between lithology and soil erodibility, Verstappen (1983) recommends the demarcation of terrain into litho-morphological units in erosion studies and specification of the susceptibility to the various processes of erosion of each of them. Weaver (1988a) suggests that soil erodibility index maps can thus be produced since boundaries between different geological formations are more distinct than those between different soils.

2.4 Vegetation cover

The protective role of vegetation cover against erosion and, ultimately, land degradation is well documented (Stocking 1980, Thornes 1980, Zachar 1982, Morgan 1986a, Garland 1987, Rowntree 1988). An investigation into factors responsible for its diminution constitutes an integral part of this study. Rowntree (1988) highlights the intimate relationship that exists between vegetation and soil as the stability in one is reflected in the stability of the other. The qualitative effects of vegetation include protection of soil from raindrop impact and increase in infiltration capacity (Rowntree 1988). It binds the soil mechanically, diminishes microclimatic fluctuations in the uppermost layer of the soil and improves the physical, chemical and biological soil properties (Gerrard 1981, Zachar 1982). Ground cover between 20-30% is considered to be critical for sheet wash (Rowntree 1988), while rill erosion is completely eliminated when cover exceeds 40% (Govers 1991).

Different types of vegetation provide a varying protective effect to the soil. Holy (1980) singles out forest vegetation as the most effective, followed by grass and row crops. A dense grass cover may be as efficient as forest in reducing erosion (Morgan 1979). Notwithstanding the fact that raindrop interception is the main way that vegetation counteracts erosion, it is not the panacea to soil erosion control. According to Stocking (1988), empirical evidence has shown that the erosion- cover relationship is curvilinear rather than linear. Figure 2.2 illustrates this and the fact that there is little difference in erosion whether cover is 60% or 100%.

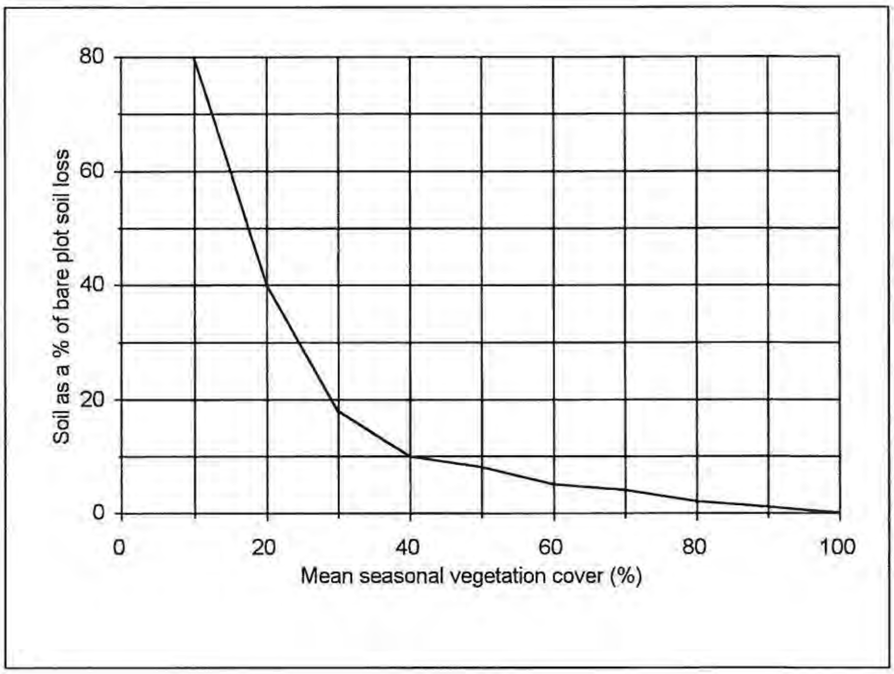

Figure 2.2 Erosion-cover relationship (After Stocking 1988).

This view is augmented by Morgan (1986a) who observes that forest canopy may lead to the coalescence of raindrops on leaves to form larger and more erosive drops. He quotes studies conducted by Mosley (1982) and Wiersum (1985) who found that material detached by rainsplash under forest canopy was 3.1 and 1.2 times that in open ground respectively. Stocking (1988) cites another example in Mondoro, Zimbabwe, where trees planted for gully control appear to have exacerbated the rate of headward recession of the gullies.

Acocks (1975) observes that, locally, soil type, topography, and aspect are the important factors controlling moisture availability and therefore vegetation characteristics. This signifies the intimate functional relationship that exists between the variables discussed thus far. The indispensability of moisture availability is further augmented by Verstappen (1983) who notes that grass resources (biomass) fluctuate in phase and in proportion to the water resources. Noteworthy is the fact that vegetation is a dynamic component responding to both natural conditions, for instance rainfall and management. An observation made by Rowntree (1988) that aerial photographs taken in high rainfall years or seasons indicate better vegetation cover than observed during dry years, illustrates this. The vulnerability of vegetation to human manipulation is documented (Trimble 1990).

2.5 Land use

Besides natural physical factors discussed above, man has considerably altered and often deteriorated the quality of land. Inappropriate land use regimes have accelerated soil erosion rates beyond tolerable levels (Lal 1990). Overgrazing of natural grasslands, burning practices, deforestation and slashing of scrubs for agricultural land use and fuel wood in marginal areas are examples of inappropriate land use practices which contribute to gradual deterioration of land (Verstappen 1983). Such forms of land utilisation have been linked to certain systems of land tenure. The communal form of land tenure, in particular, has been singled out as responsible for land degradation (Williams 1986, Gregory and Walling 1987). The detrimental impact of some forms of injudicious land utilization is discussed below.

2.5.1 Overgrazing

Overgrazing as one of the main contributing factors to vegetation diminution is mainly a function of poor land management. It leads to the gradual replacement of perennial grasses by annual grasses (Thornes 1980, Proctor 1990) and succulent vegetation which provides little dry season pasture and allows faster erosion (McLean 1971). It also leads to reduced water infiltration due to soil crusting (McKenzie 1994). The replacement of palatable by unpalatable species is a form of vegetation degradation which is mainly a result of species selective grazing (Trollope 1995), as livestock tend to eat palatable perennial grasses first followed by annual species. The table below shows the principal encroaching species and the affected veld types in the Eastern Cape. Trampling and subsequent compaction of the soil by livestock accelerates erosion as observed along cattle tracks and watering points (Weigel *et al* 1990). Evidence of gullying along cattle tracks is widespread in many rural areas of the Eastern Cape.

Table 2.3 Principle encroaching natural grass species and the affected veld types (After Trollope 1995).

Encroaching grass species	Affected Veld type
Elionurus muticus -koperdraad	Dohne Sourveld/ *Themeda Festuca* Alpine veld/Eastern Province Thornveld/ Coastal Forest and Thornveld/False Macchia
Merxmeullera disticha -suurpol	Karroid *Merxmeullera* Mountain veld/Themeda *Festuca* Alpine veld/Valley BushVeld
Festuca costata -rwashu	Dohne Sopurveld/ Themeda *Festuca* Alpine veld
Miscanthidium capense *Cymbopogon marginatus* - thatch grass	Dohne Sourveld/ Coastal forest and Thornveld
Cymbopogon plurinodis -turpentine grass	Eastern Province grassveld/ False thornveld of Eastern Province

2.5.2 Burning

Considerable vegetation changes are induced by burning (Thornes 1980). According to Cooke and Doornkamp (1990), water repellant soils are created through the coating of soil particles with hydrophobic organic substances during a fire. This change reduces the infiltration capacity, thus serving to accelerate erosion. However, Garland (1987) points out that a distinction should be made between a catastrophic fire and several years of regular systematic burning as it is important to establish the context of the burn within the long term conditions of soil development. A balance may be created between the soil and the burning process. He quotes studies by Stiffler and Morgan (1979) and Watson (1983) which recorded insignificant sediment yield and soil loss after burns. Conversely, plot and catchment studies by Radley (1965) and Imeson (1971), also cited by Garland (1987) indicated that burning of vegetal cover promotes erosion. The rate of recovery of vegetation and amount and intensity of rainfall occurring soon after the burn are the controlling factors (Garland 1987).

2.5.3 Impact of cultivation

Poor ploughing methods, for example up and down the slope, accelerate erosion. Intensified agricultural land use in marginal areas in the absence of sound conservation measures will result in gradual soil deterioration and soil loss. Cultivation has been linked to the loss in soil organic matter content, resulting from the destruction of macroaggregates (Franzluebbers and Arshad (1996). A strong positive correlation between organic matter content and resistance to splash erosion has been established (Trimble 1990). He refers to a study by Wischmeier and Mannering (1965), where organic matter explained about 45% of the runoff for a standardized rainstorm of 6.35cm. A predictive equation for runoff for such storm was developed thus:

$$Y = 4.01-0.56X \qquad (3)$$

Where Y = runoff, cm
X = percent organic matter (OM)

There is a tendency to associate traditional methods of cultivation with soil erosion. On the contrary, studies by Weaver (1987) in the King Williams Town district recorded more erosion on white owned commercial farms than the adjacent traditional black farms over a 9 year monitoring period.

Land degradation resultant from other forms of land use, for example, footpath and artificial drainage, have also been documented (Coleman 1981, Garland 1987, Beckedahl and Dardis 1988, Sumner 1995). Prolonged frequent human trampling along footpaths causes greater soil compaction, reduced infiltration capacity and consequently erosion (Garland 1987). Sumner (1995) identified a threshold footpath gradient of 13^0 - 14^0 above which erosion rates accelerate rapidly. He suggests that footpaths exceeding this threshold require careful maintenance and monitoring.

Beckedahl and Dardis (1988) noted that artificial channelling of surface runoff associated with the road network in the former Transkei has contributed significantly to soil erosion. In a similar study by Kakembo (1995) near Alice culverts under the railway line were noted as points at which runoff from a steep slope was concentrated, thus acting as knickpoints at which vigorous vertical incision is induced into the surrounding terrain.

Caution must be taken not to overemphasize land use as an overriding factor in the inducement of land degradation. As pointed out by Rowntree (1988), the problem must be seen in the context of natural environmental conditions and long term geomorphological processes. The discussion below regarding the temporal aspect of degradation elucidates this.

TEMPORAL VARIATIONS

According to Thornes (1980), the type and rate of processes may vary with time, resulting in variations in the pattern and magnitude of land degradation forms, notably soil erosion. Three levels of temporal variations are identifiable: short term changes, for example in a storm lasting a few hours, seasonal effects lasting a few months, and long term changes reflected in natural processes, for instance runs of drought years and the effects of human activity. Climate, as already pointed out above, is singled out by Morgan (1986a) as the dominant variable responsible for variations at all the three levels mentioned above and at all scales of analysis.

Erosivity is an outstanding attribute of rainfall that governs the rate of degradational processes by erosion in the short, intermediate or long term. Rainsplash has been recognised by various researchers as the fundamental cause of soil erosion (Morgan 1986b, Beckedahl *et al* 1988, Mualem *et al* 1990). The compaction of soil and destruction of the aggregate structure at the soil surface by rain drops was established by Mualem *et al* (1990). Morgan (1986b) concluded that 'rainwash', which is a combination of splash and wash, is the dominant form of soil loss on most slopes. When the two are considered individually, splash exceeds wash as an erosive agent, but should be considered collectively for all high erosivity conditions. The role of rain drop impact in inducing erosion is minimal on level ground (Beckedahl *et al* 1988) as it just leads to a redistribution of soil particles (Clowes and Comfort 1982). Conversely, there is net loss of material downhill on sloping ground, as particles splashed towards lower parts of slope have longer trajectories than those moving upslope from the point of impact.

A number of rainfall erosivity indices have been developed; the single parameter indices e.g. the

A (the total rainfall amount), the I (rainfall intensity) (Ulsaker and Onstad 1984), and the E (the rainfall total kinetic energy) developed by Wischmeier and Smith (1978). However, these parameters were found to have low correlation coefficients with soil loss quantities. Calles and Kulander (1995) point out that there is no single rainfall variable that has been shown to stand out as better than all the others.

Compound parameters e.g. the KE>25 (the rainfall total kinetic energy falling at intensities greater than 25mm/hr) were developed by Hudson (1971). The EI_{30} index developed by Wischmeier and Smith (1978) is commonly used in the Universal Soil Loss Equation (USLE) as an approximation for rainfall erosivity (Beckedahl *et al* 1988). Such compound parameters formed by the product of two or more single variable erosivity factors have been found to be the best estimators of soil loss. Their major disadvantage is that their computation requires more detailed rainfall records than exist in many parts of the world (Ulsaker and Onstad 1984). It is also noteworthy that, although they are long term erosivity indices, they do not in themselves demonstrate temporal variations.

Long term temporal variations of relevance to this study are both anthropogenic and climatic. Forms of land misuse and their impact have been discussed already and will not be repeated here. Practiced over long periods of time, they are likely to reinforce degradation associated with climatic variations. With regard to climate, seasonal contrasts in rainfall lead to seasonal contrasts in direct runoff (Thornes 1980) and long term climatic changes. Rainfall over Southern Africa is highly variable both spatially and temporally and is characterised by the alternation of wet and dry spells, especially during the twentieth century (Tyson 1986). According to Verstappen (1983), dry years occur in groups rather than at random.

The alternation of wet and dry periods has important implications for vegetation changes and geomorphic activity. Watson (1995) noted that wet and dry spells between 1937 and 1983 exerted a strong influence on the areal extent of the grassland, woodland and forest vegetation categories in the Mfolozi catchment, KwaZulu-Natal. According to Loureiro and Coutinho (1995), rainfall erosivity and land degradation in the Algarve, Portugal, between 1931 and 1991, are related to the rainfall regime. There is a tendency for the protective vegetation cover to diminish during long dry seasons. This promotes geomorphic activity during the subsequent wet phases.

Extreme rainfall events, in particular, may elicit significant geomorphic responses within a relatively short time. Morgan (1986a) reports rainstorms with a specific return period of e.g. once in a hundred years, to initiate headward erosion of gullies. He cites a study by Thornes (1976) which recorded extensive changes to hillside and channel forms during a three day storm of 196mm.

An intimate relationship exists between land use, natural environmental conditions and geomorphological processes. Such geomorphic responses mentioned above could be exacerbated under conditions of misuse of land. The effect of intrinsic variables can be augmented by that of extrinsic ones. Periods of drought might lead to overgrazing and overcropping thus further degrading the protective cover before geomorphic activity reintensifes during the subsequent wetter period (Stromquist *et al* 1985). Thus, inasmuch as land degradational forms are a result of natural forces, they are an integral part of both the natural and cultural environment (Morgan 1986a).

This study examines the physical factors which arise as a result of anthropogenic activity, rather than the cause of that activity. Socio-economic factors, which are the focus of many land degradation researchers (Mannion and Boulby 1990, Cock and Koch 1991), lie beyond the scope of this study.

3. The study area

3.1 Introduction

The study area forms part of the dividing ridge between the Keiskamma and Great Fish rivers (Figure 3.1). It extends from 33^0 3' S, 27^0 0' E to 33^0 13' S, 27^0 12' E and has a surface area of 178.2 Km^2. The town of Peddie is situated near the southern boundary of the study area. The study area was selected on the basis of ecological homogeneity - it has topographic, pedologic and geologic continuity and, according to the South African Weather Bureau (1972) and Acocks (1975), falls within a homogeneous rainfall and vegetation zone respectively. Despite such presupposed homogeneity, a better understanding of the spatial and temporal variation of such phenomena like land degradation at a such scale of analysis calls for close scrutiny of the different catchment dynamics.

Besides physiographic and ecological homogeneity, land tenure systems, settlement and other land use history are the other parameters that were taken into consideration. The area consists of traditional villages of the Upper Tyefu location, betterment villages to the north- east of Peddie town, previously white owned farms and a small peri- urban area (Peddie town and environs) (Figure 3.2). Such spatial variation in the tenure system and other land use regimes is deemed to have a differential impact on the quality of land. In the present study, a comparative analysis of the spatial and temporal trends of land use and degradation is conducted in the first three land tenure units which constitute most of the study area. Traditional villages will, hereinafter, refer to the land area in which settlement is in the form of dispersed villages and their surrounding lands. Betterment villages will likewise refer to the land area in which settlements were spatially restructured into gridiron street patterns (Childs 1989) and their surrounding lands.

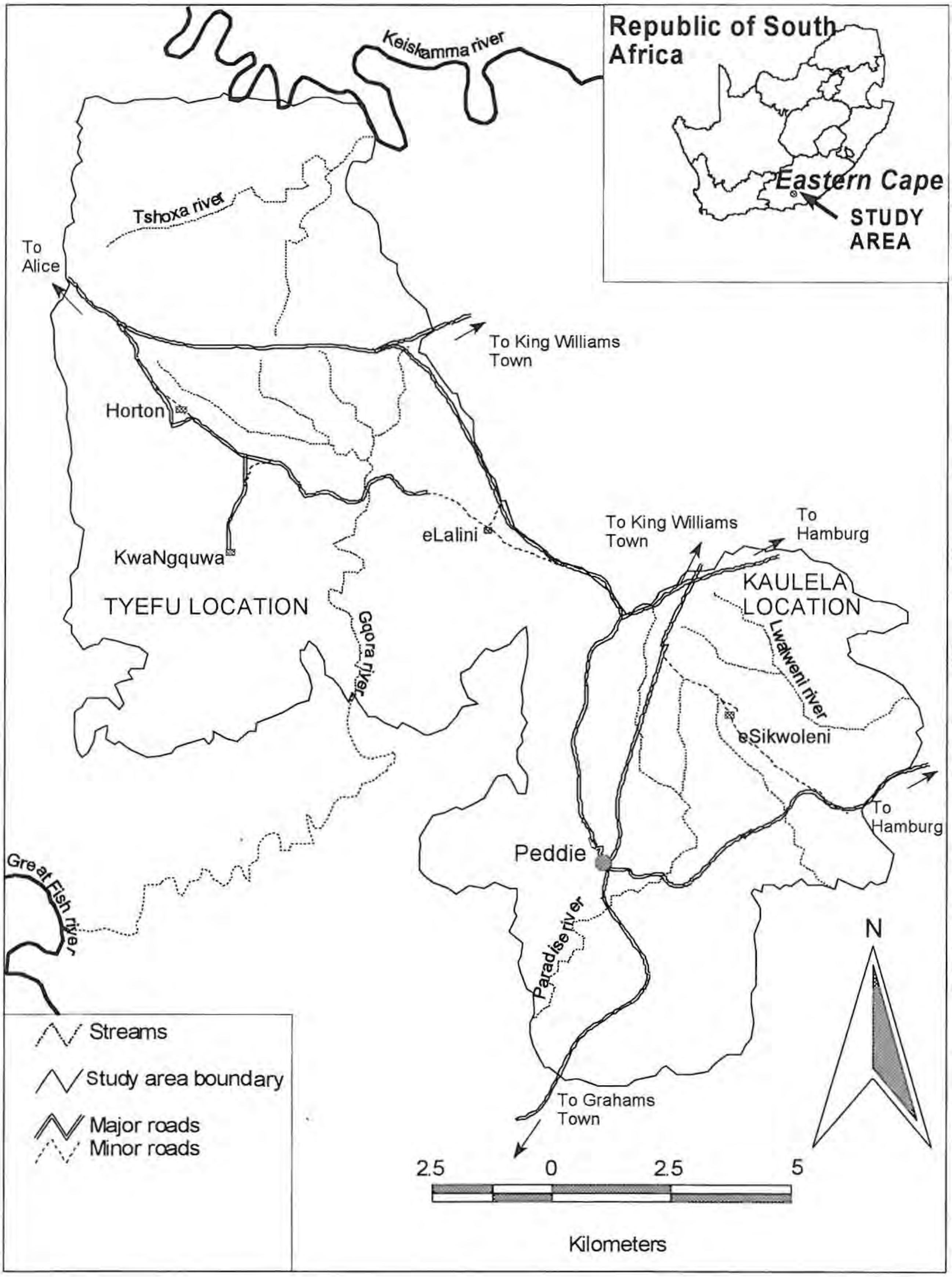

Figure 3.1 Location of main settlements and features in the study area

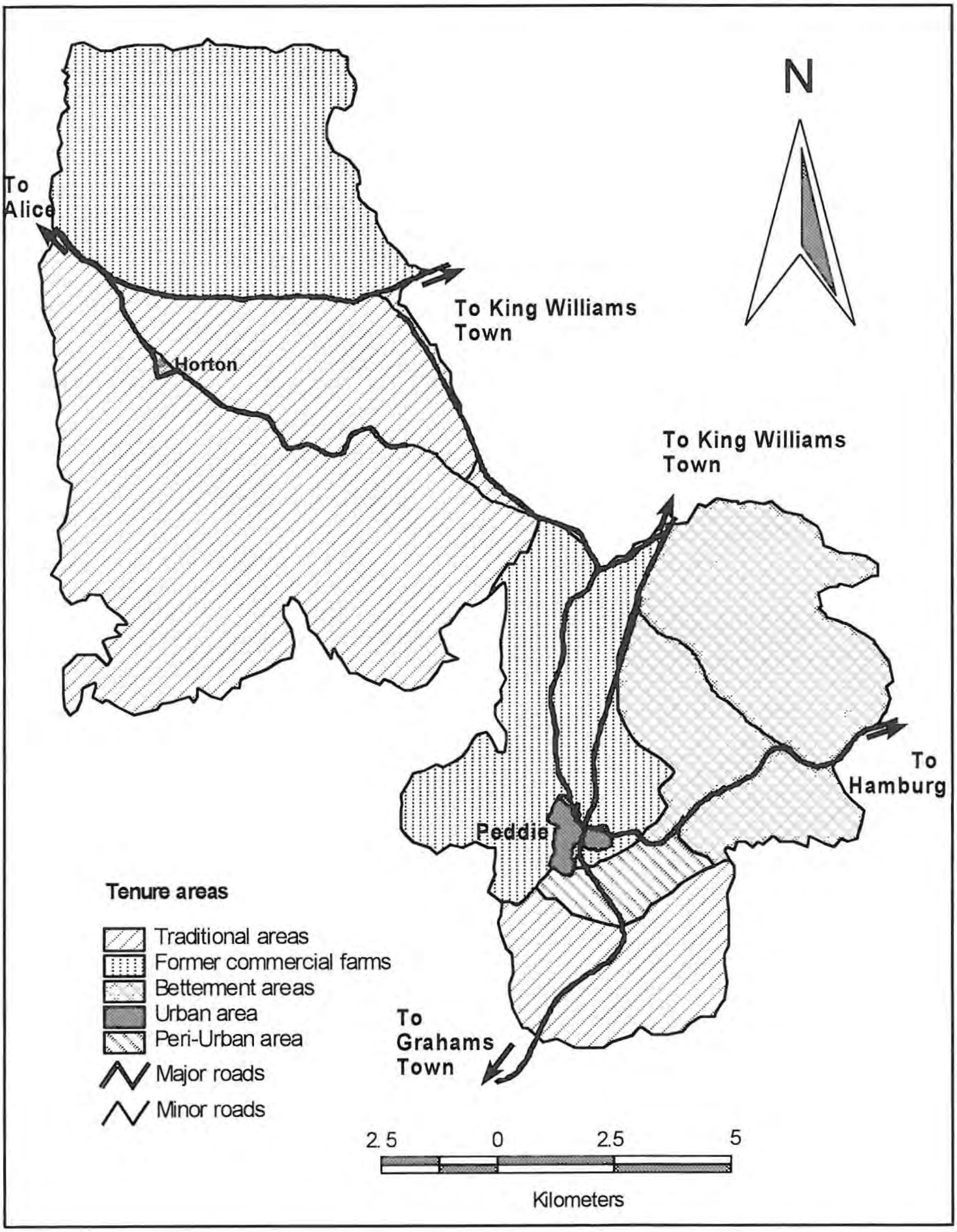

Figure 3.2 Location of the study area

3.2 Topography and Drainage

The altitudinal range of the catchment is from 300m above sea level near Keiskamma river and around Peddie town to 460 m on the northern boundary of the Tyefu location. The slope frequency graph of the area (Figure 3.3) indicates that up to 50% of the slopes are gentle. Slopes get steeper towards the stream valleys (Figure 3.4). One characteristic feature of most stream valleys of the study area is that their slopes rise steeply right from the stream channels. Many of these slopes display a degree of convexity right from the valley bottoms, particularly towards the Great Fish and the Keiskamma rivers which lie in the vicinity of the southern and northern boundaries of the study area respectively.

The south facing slopes of the area are extensively dissected by ephemeral streams which drain into the southerly flowing Gqora tributary of the Great Fish river (Figure 3.1). Tributaries of the Keiskamma river drain the north facing slopes. The overall drainage density of the area is 1.58 Km/Km^2.

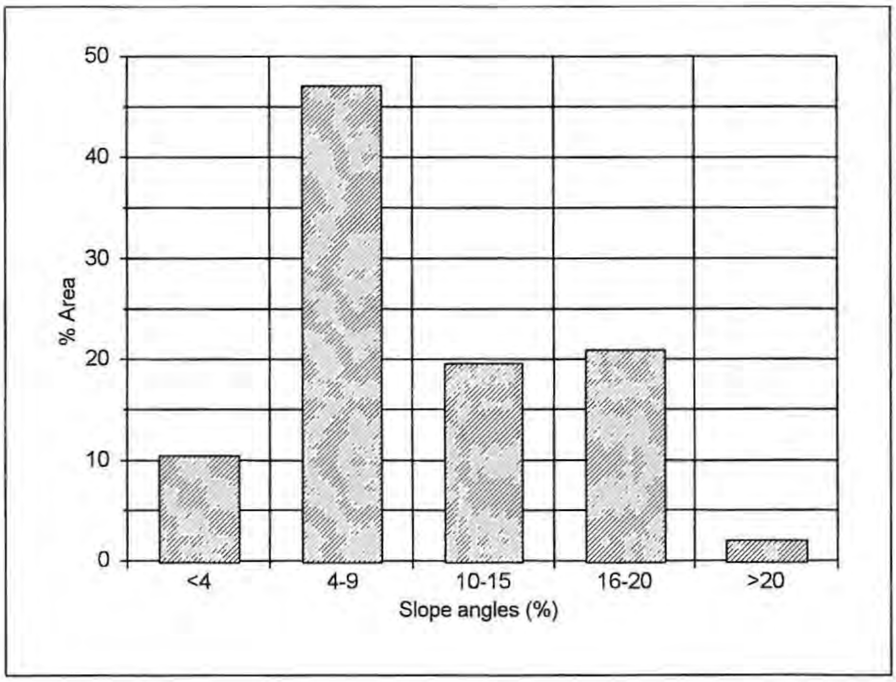

Figure 3.3 Slope frequency of the study area

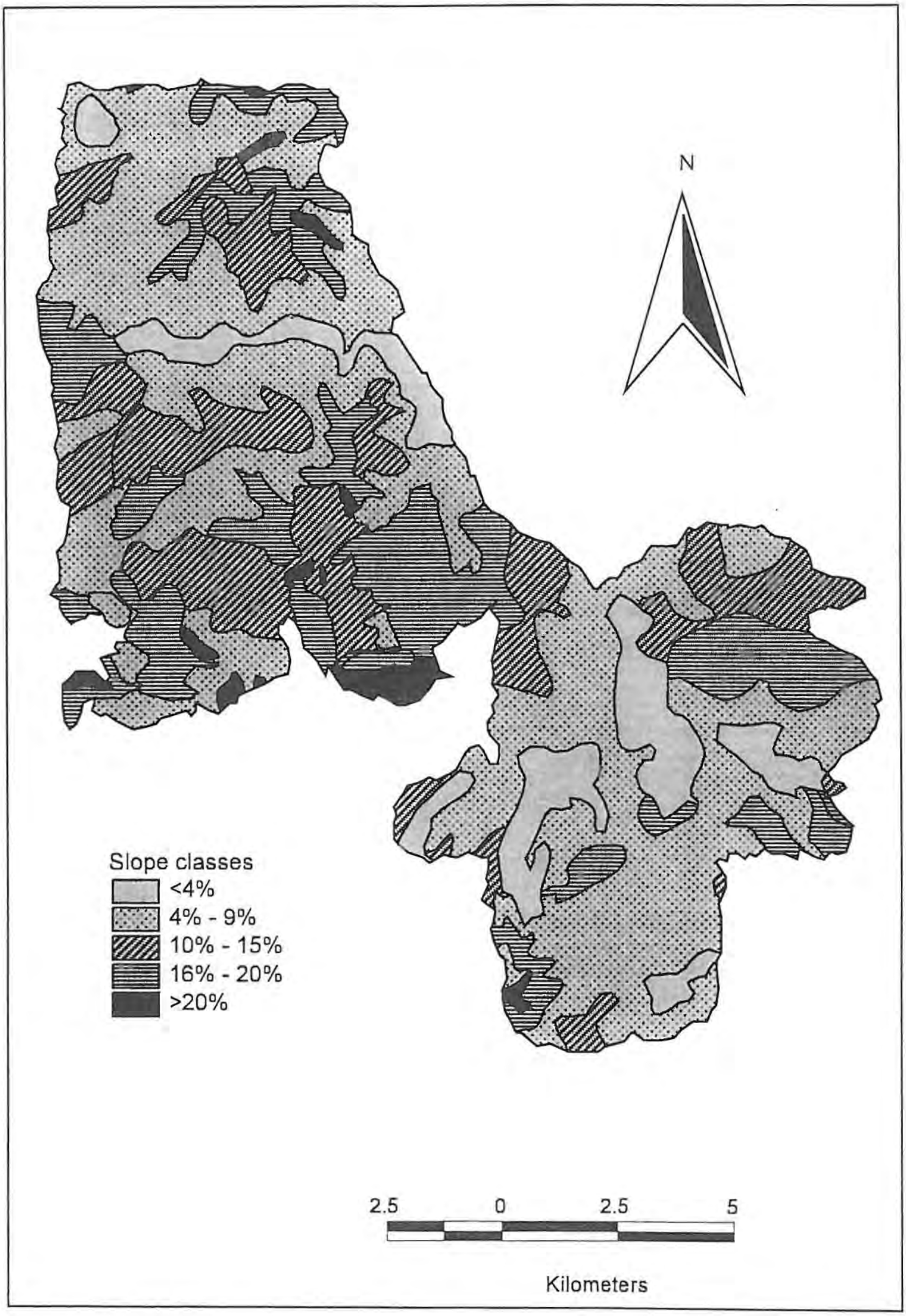

Figure 3.4 Slope distribution map of the study area

3.3 Geology

The study area is predominantly underlain by Sandstone, Shale and red Mudstone of the Beaufort and Ecca groups of the Karoo Supergroup deposited in the Triassic and Permian periods respectively (Table 3.1). According to Lewis (1995), the Dwyka deposits laid down in the Karoo basin in the Carboniferous Period form the basal members of this sequence. He refers to Toerien and Hill (1989) who state that the Ecca group differs from the adjacent Beaufort group in that while the former were deposited in relatively deep water, the latter were laid down in a more terrestrial environment. The soils of the area are thus largely a derivation of these sedimentary rocks so deposited. A Dolerite sill that traverses the area in a south easterly direction is the only major igneous intrusion (Figure 3.5).

Table 3.1 Lithostratigraphic succession of the sedimentary rocks in the study area. (Modified from Lewis 1995 and Gunter, *Pers.comm.*)

SUPERGROUP	GROUP	FORMATION	LITHOLOGY	AGE
Karoo	Beaufort	Middleton	Grey Shale	Triassic
		Koonap	Sandstone	
			Red Mudstone	
Karoo	Ecca	Ripon	Black Shale	Permian
		Collingham	Grey Shale	
		White Hill	Sandstone	
		Prince Albert	Red Mudstone	
	No Group Name	Dwyka	Tillite, Shale	Carbon-iferous

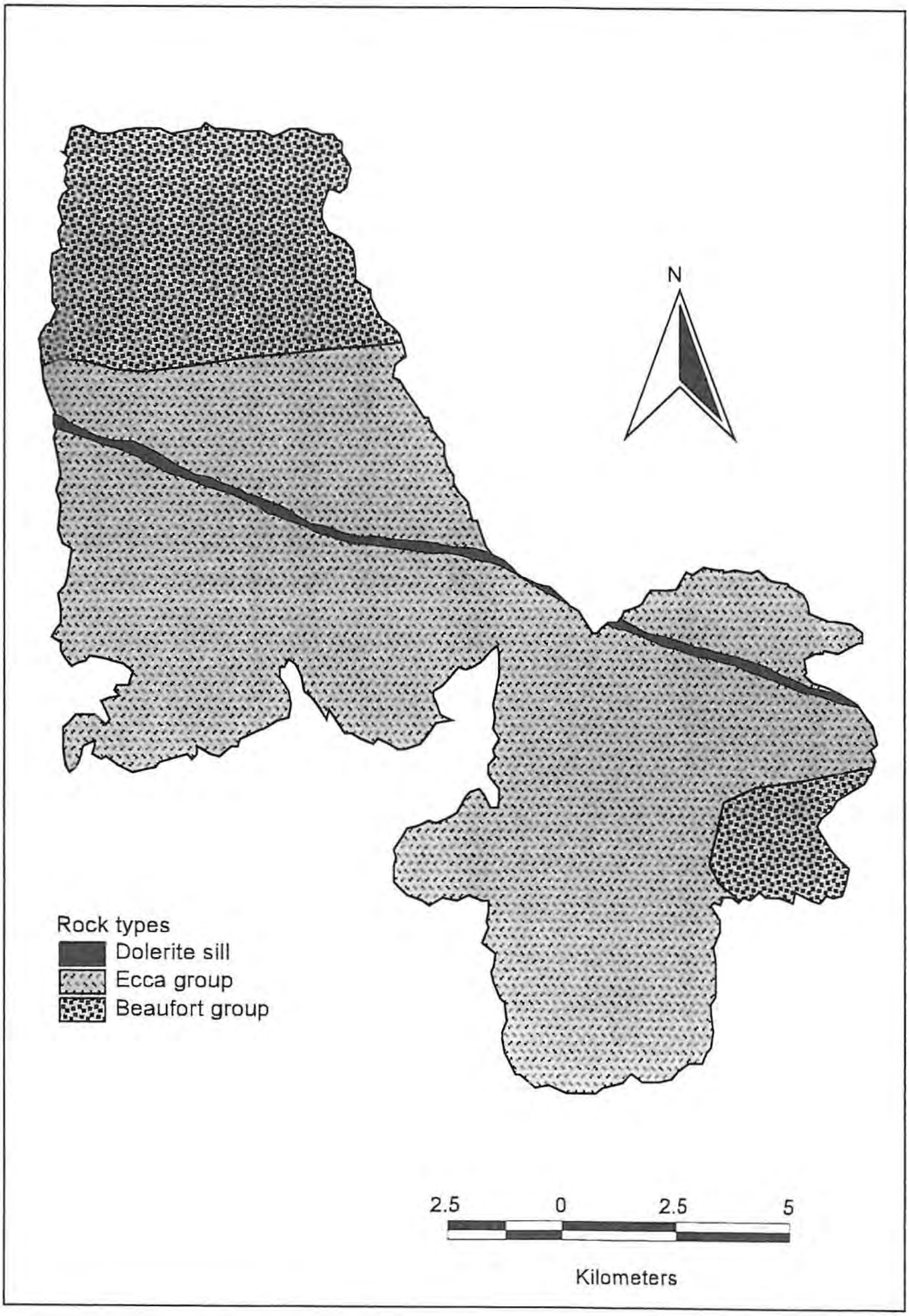

Figure 3.5 Geology of the study area

3.4 Geomorphological evolution

The geomorphic development of the Southern African subcontinent is a result of a period of tectonic uplift, which induced erosion to new base levels (Moon and Dardis 1988). The major uplift of the subcontinent which occurred in the Miocene and later in the Pliocene entailed the concentration of crustal movement along two major axes as identified by Partridge and Maud (1987) - the Griqualand-Transvaal and Ciskei-Swaziland axes. The uplift along the latter axis induced incision by high sinuosity east flowing rivers, most of whose valleys are structurally controlled. The drainage systems in the southeastern part of the subcontinent are thus degradational in character, with significant downcutting and reduced sediment storage in their channels (Dardis *et al* 1988).

The Great Fish river to the immediate south of the study area incises a deep sinuous canyon reminiscent of the aforementioned renewed downcutting and structural control. The steeply rising valley slopes characteristic of its tributaries that drain the south facing slopes of the area further attest this. Similar incision is displayed by the Keiskamma river and its tributaries to the north. The area's high drainage density alluded to earlier is an indicator of the catchment's high potential for geomorphic activity in terms of the operation of sub aerial processes. It is in such systems that extrinsically generated stresses may act as a catalyst to exceed a geomorphic threshold and trigger off a complex sequence of events. According to Dardis *et al* (1988), floods and drought on the one hand and overgrazing on the other are examples of infrequent large-scale and frequent small-scale events that may lead to such a scenario.

3.5 Climate

The study area lies in the semi arid plateau of the Eastern Cape. The climate of the whole Eastern Cape region is influenced by a broad range of factors. Foremost among these are: the configuration of the coastline, the warm Agulhas Current and the advection of dry Karoo air into the the region. Jury and Diab (1990) point out that the convex orientation of the Eastern Cape Coastline implies that the strong alongshore winds characteristic of the area may diverge over the coastal plains. Subsident motions in the coastal zone linked to circulations over the Agulhas Current lead to reduction in rainfall in the region (Jury and Courtney 1991). A progressive eastward encroachment of subsident dry air from the Karoo basin has been noted (Jury and Levey 1993). These factors have interacted to make the region drought prone.

3.5.1 Rainfall

The rainfall data for the station of Peddie given in this section were obtained from the Computing Centre for Water Research (CCWR) in Petermaritzburg. The mean annual rainfall of the study area calculated over a period of 71 years is as low as 488mm. It is erratic in distribution and displays a well defined peak during the summer months - October to April. Winters are dry with annual rainfall totals ranging between 50 - 100mm. The coefficient of variation of the mean annual rainfall calculated over the same time period is 32%, indicating the highly variable nature of the area's rainfall. Its distribution is positively skewed, which implies that a larger proportion of years receives annual rainfall below the mean than those receiving that above it.

Figures 3.6 and 3.7 show the mean monthly rainfall and the annual rainfall chronology for Peddie between 1930 and 1991. The highly variable nature of rainfall from year to year is evident from the latter figure. Rainfall peaks at intervals of 12 and 19 years are noticeable, while a concentration of rainfall significantly above normal is evident in the early 1970s and mid 1980s. The former was a period of extensive floods as reported by Jury and Levey (1993). Such periods of rainfall concentration have significant implications in terms of runoff, erosion initiation and intensification.

No long term rainfall intensity data are available at the station in question. Data regarding rainfall erosivity are published by Weaver (1990) who plotted EI_{30} values on a 1:250 000 scale map of the former Ciskei. The study area lies within a region of an average annual EI_{30} value of 125. However, he cautions that these data should not be used to infer spatial variations in actual erosion, but rather for the potential for rainfall erosion.

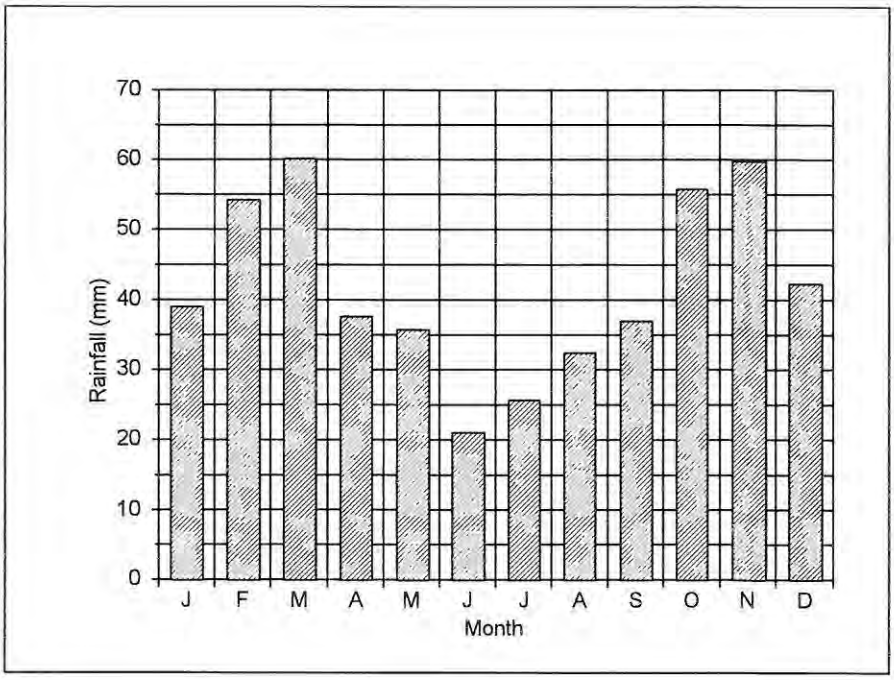

Figure 3.6 Mean monthly rainfall for Peddie.

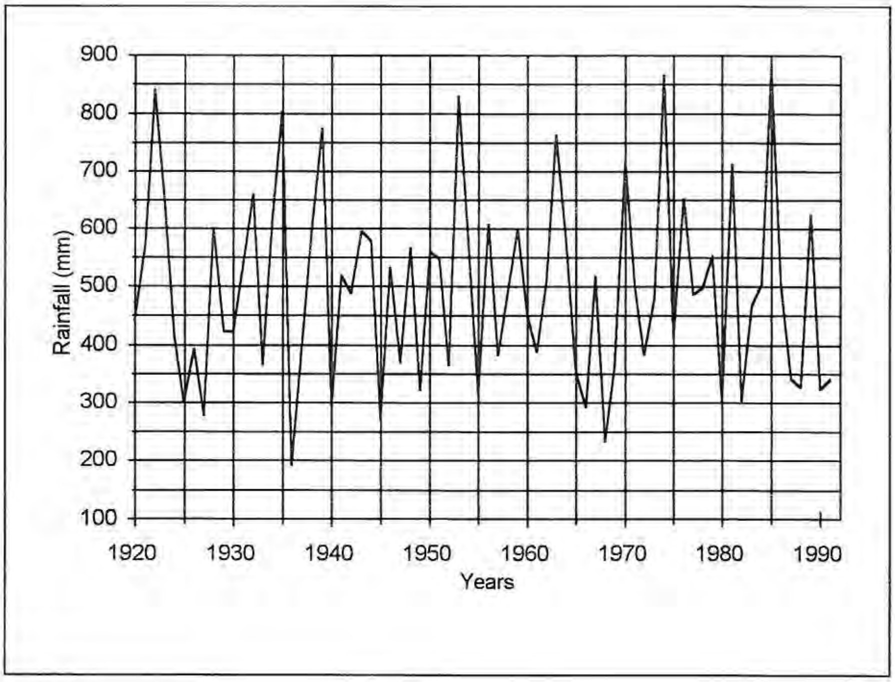

Figure 3.7 Annual rainfall chronology for Peddie (1920-1991).

3.5.2 Temperature

The area experiences hot summers, with the mean monthly maximum temperatures ranging from 29°C to 30°C for the period between December and February. Hot scorching berg winds cause extremes of temperatures of 44°C and 31°C in summer and winter respectively. Mild winter temperatures which range from 7°C to 9°C are recorded. The mean maximum, minimum and daily temperature data for Tyefu weather station located adjacent to the traditional villages of the Upper Tyefu location are given in Table 3.2. De Lange *et al* (1994) report abrupt temperature fluctuations in the area which they ascribe to two phenomena. On one hand, the on-shore flow of very cold air of Antarctica origin brought in by the passage of cold fronts and the ridging- in of the South Atlantic high pressure system causes abrupt cooling. On the other, off- shore Berg winds alluded to above cause sudden warming.

Table 3.2 Mean maximum (M1), minimum (M2) and daily (M3) temperatures for Tyefu weather station, 1977-1984 (after Loxton, Venn and Associates 1987).

	J	F	M	A	M	J	J	A	S	O	N	D
M1	29.3	30.1	28.9	27.0	24.6	21.8	22.5	22.7	24.0	25.1	26.8	29.2
M2	18.0	18.5	17.5	14.0	10.9	7.9	7.3	8.7	10.9	13.0	15.2	17.1
M3	23.7	24.3	23.2	20.5	17.7	14.9	14.7	15.7	17.5	19.0	21.0	23.2

3.6 Soils

Comprehensive soil surveys have been conducted in the Keiskamma and Great Fish river catchments by Loxton, Hunting and Associates (1979). According these surveys, the soils are Eutrophic greyish brown shallow litholic soils derived from Beaufort and Ecca sediments. Mispah soil form, characterised by stony or rocky phases, is the dominant type. The Glenrosa Form occupies a small portion of the south- eastern part of the study area around Peddie town (Figure 3.8). Colluvial and Alluvial soils have accumulated in some stream valleys. These consist of a mixture of Karoo sediments and dolerite (De Lange *et al* 1994). According to the erodibility rating by Crosby *et al* (1981) for selected South African soils, the Mispah and Glenrosa are rated high and medium respectively. The salient characteristics of the two soil forms are described in

Table 3.3

Table 3.3 Soil forms found in the study area and their characteristics (modified after MacVicar *et al* 1977).

FORM	DIAGNOSTIC HORIZONS	CHARACTERISTICS
Mispah	orthic A / hard rock, hardpan ferricrete, calcrete, silcrete or dorbank	very shallow (200-300mm), minimal weathering of underlying rock.
Glenrosa	orthic A / Lithocutanic B	shallow (300-400mm), weathering of underlying rock more advanced.

3.7 Vegetation

According to Acocks' (1975) classification of Veld types of South Africa, the present study area falls under the Eastern Province Thornveld, fringed by the Valley Bushveld of the Keiskamma and Great Fish river valleys to the north and south respectively. The climax vegetation for this veld type would be short and scrub forest, but it essentially remains thornveld dominated by *Acacia karoo* (Weaver 1988a). A long history of human occupance and overutilisation has drastically modified the original natural vegetation over considerable areas. The degree of modification varies spatially with a close correlation with land tenure system.

In the rangelands of the traditional villages and betterment areas, this modification is manifested by a drastic reduction in palatable species and a shift towards single dominance by unpalatable ones (Palmer and Avis 1994). Karroid dwarf shrubs, particularly *Pteronia incana,* which are indicative of vegetation degradation and leaf succulents, for instance *Aloes,* typify the area. The dominant indigenous grass species, namely *Themeda triandra* and *Digitaria eriantha,* have gradually given way to the above mentioned invaders, probably due to overgrazing.

In the former commercial farmlands, there is no significant deviation of the veld condition from the normal. Invasion by karroid dwarf shrubs is also noticeable in these areas but not as widespread as is the case with the traditional and betterment villages. Indigenous species such as *Capparis sepiaria, Boscia oleoides, Phyllanthus verucossus* are well represented (Palmer and Avis (1994).

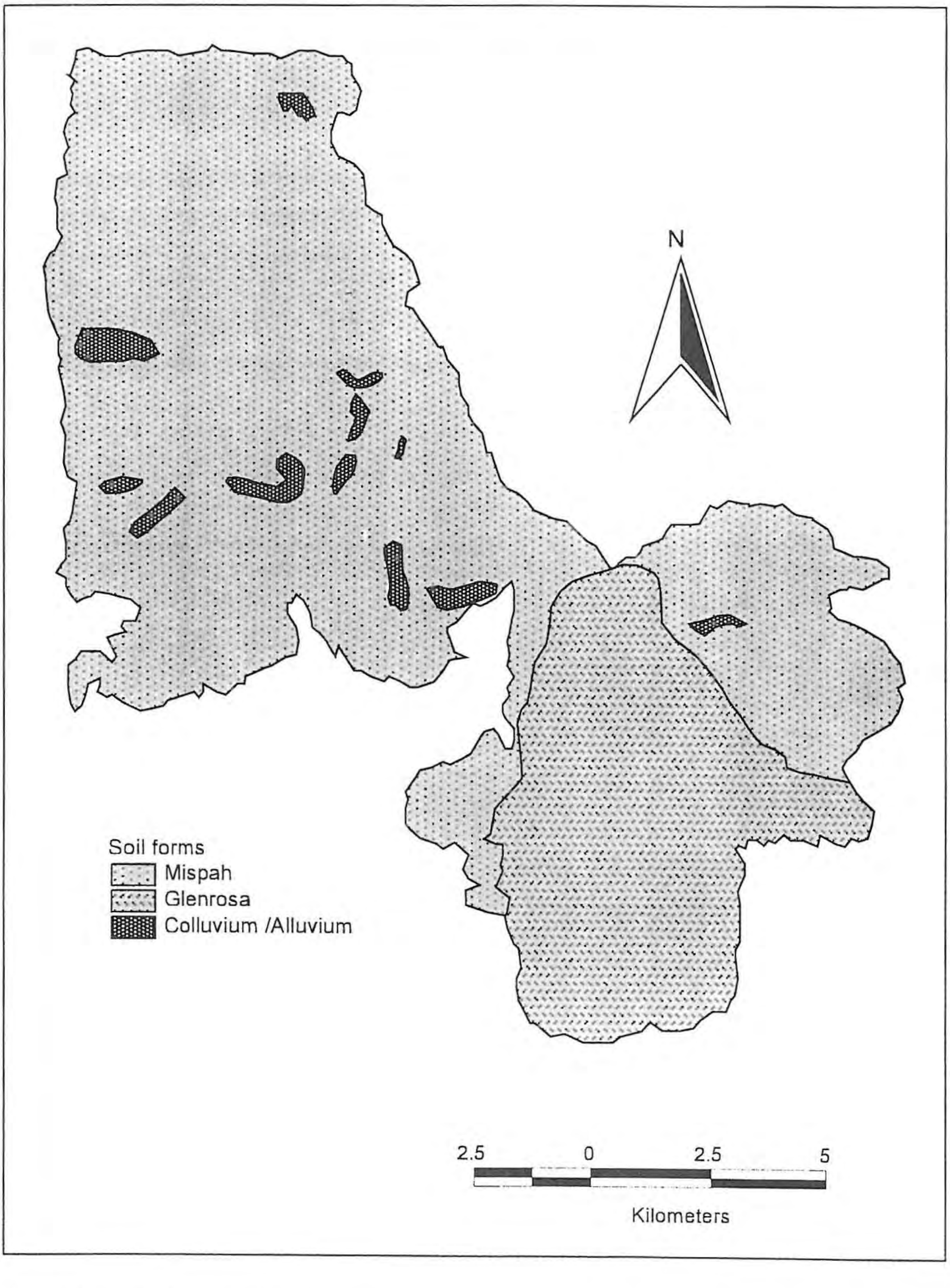

Figure 3.8 Distribution of soil types in the study area

3.8 An overview of land use history

The establishment of the Tyefu traditional villages is traced back to May 1835 when the Cape Colonial Government placed 16 000 of the Fingo people in present day Peddie district. They had migrated south from Natal as a result the Tshaka wars (Mfecane) that were in progress then. The rationale behind this placement was to serve as a bufferstate between the Cape Colony and the Xhosa people (De Jager 1971). Chief Joseph Mphahla and his followers established the Zulu location in 1835. At the request of the community, this was later renamed Tyefu Tribal Authority in 1968 after chief Tyefu Msutu. The White commercial farms had been established earlier during the 1820s and 30s by the 1820 Settlers and their descendants (De Lange *et al* 1994). These farms were expropriated in early 1980s on the eve of the creation of the former Ciskei 'homeland'. The latter area was re-incorporated into the Republic of South Africa in April 1994.

Evidence from the earliest aerial photographs taken in 1938 indicates that, by the turn of the century, the study area had already been demarcated into distinct land tenure units -African traditional villages and white farmlands. The stream valley slopes of the traditional villages were already intensively cultivated. The white farmlands were predominantly used for animal grazing with just a small acreage under crop cultivation.

The phenomenon of "betterment" was introduced in the in the early 1960s to arrest what was perceived to be deteriorating soil conditions in the traditional villages. This would ideally entail the consolidation and reorganisation of the unevenly distributed arable land and homesteads which were the characteristic feature of traditional African villages. The allocation of "economic farming units" to African farmers would be the cornerstone of this system (Childs 1989). The implementation of this programme was only partially carried out in the area as it was stiffly resisted by the communities of the Upper Tyefu location. As to whether the system ever achieved its desired goals in the areas where it was implemented is one of the aspects of investigation of this study.

4. Methodology

In a study of this nature, the scale of assessment and purpose are the cardinal determinants of the appropriateness of the data collection methods. At the present scale, a three pronged approach was adopted in the collection of data relevant to the study. This entailed:

- The mapping and quantification of the spatial distribution and variation of land use, vegetation type and cover and soil erosion at different dates.

- Field surveys to assess the present status of the degradation process and to ascertain the salient characteristics of the natural physical and anthropogenic landscape of the catchment.

- Consulting secondary data sources regarding, for instance, long term climatic records, local geology and soils, whose interaction with the progressive change in the degradation process was considered crucial.

In each of the three instances, the specific techniques applied in data collection are outlined in sections 4.1, 4.2 and 4.3 below.

4.1 Mapping and quantification of variables

4.1.1 Aerial photograph interpretation

Sequential black and white panchromatic aerial photographs of the area were analysed using a mirror stereoscope with x3 magnification lenses. With such magnification capacity, the characteristics of the variables required for the study could be depicted at different dates with precision. This technique has successfully and reliably been used in several studies elsewhere (Keech 1969, Stromquist *et al* 1985, Marker 1988, Ntsaba 1989, Rowntree *et al* 1991, Garg and Harrison 1992, Whitlow 1994b, Rowntree and Dollar 1995 and 1996, Watson 1995 and 1996). The dates of sequential aerial photographs analysed in the present study are: 1938, 1954, 1965, 1975 and 1988. The criterion for the choice of these dates was availability.

The analysis of the spatial variability of certain phenomena, for example vegetation on aerial photographs at different dates, must be done with caution since their response to rainfall is a dramatic one. The observation made by Rowntree (1988), cited in section 2.4, Chapter 2, about vegetation variations on photographs taken in wet and dry years, is relevant here. Hence there is a need to take cognisance of the time of the year at which an area was flown and correlate that with the available climatic data. The scales of the sequential aerial photographs taken at the dates mentioned above, are given in Table 4.1 below. The rainfall status of the period of the year in which they were taken is also indicated.

Table 4.1 Dates and scales of sequential aerial photographs.

Year	Month	Scale	R/f Status
1938	December	1:25000	Fairly wet
1954	April	1:36000	Fairly wet
1965	April	1:36000	Dry
1975	August	1:15000	Dry
1988	April	1:15000	Wet

Alternative techniques, for instance the use of satellite imagery, could be used in the present study. However, given the scale and purpose of the study, the technique used remains the most appropriate. There is a considerable trade-off in precision when satellite imagery is used to map the relevant variables for such a study, for example erosion types. It becomes very difficult to relate measurements in the field, even to 'SPOT panchromatic', the best commonly available satellite resolution (Koh 1995). Besides, satellite imagery does not cover such long time span as aerial photography. The level of resolution of aerial photographs of the scale used in the present study makes it possible to map erosion types. Hence, aerial photographs remain valuable when it comes to identifying, mapping and quantitatively recording different erosion types (Weaver 1988a).

Different layers of data regarding land use, soil erosion, vegetation type and cover at each date were initially mapped from the aerial photographs. The details of the mapping process for each data layer are described under the sub-headings below.

Land use, land tenure, population

Distinct boundaries of the three land tenure units that constitute the study area were identified. Land use patterns, for instance that of homesteads, and fence lines, were the main criteria used to distinguish between traditional villages, betterment areas and commercial farmlands. Different categories of land use namely: cultivation plots, grazing land and settlements, were mapped from the photographs.

Conspicuous changes in land use, notably the abandonment of cultivation fields and increase in settlements, were recorded. Individual dwelling units in the traditional and betterment villages were counted at each date as surrogates for population increase. This technique could not apply to commercial farms where the tenure system is such that an extensive farmland may belong to one farmer. Hence, an increase in farm houses is irrelevant as an indicator of population increase. Apparently, farm labourers used to come from the nearby traditional villages, as no labour lines existed on these farms.

Soil erosion

The mapping of erosion types and intensities was based primarily on a classification system that has been designed specifically for erosion mapping in Southern Africa - the Southern African Regional Commission for the Conservation and Utilisation of Soil (SARCCUS) (1981). As noted in an earlier study by Weaver (1988a), such a standardised system of classification would enable one to compare findings of studies of a similar nature conducted in the region. A summary of the original SARCCUS classification scheme is given in Table 4.3.

The original scheme was modified to exclude wind erosion and mass movement types, for example, wind, landslides, terracettes and creep which are not investigated in the present study. Besides, potential overlaps between adjacent erosion classes in the original scheme - a problem pointed out as well by Weaver (1988a) - were excluded. The scheme was further modified to include the "degraded gully remnant" component of the model designed by Beckedahl *et al* (1988). Their model, in the main, describes the geomorphic effects of soil erosion with an emphasis on the role of surface and subsurface processes. The modified version indicating the major erosion types mapped in the study is given in Table 4.2. Plates 4.1-4.6 illustrate the erosion classes designated in Table 4.2

Table 4.2 Erosion classes (modified from SARCCUS 1981 and Beckedahl et al 1988).

EROSION CLASS	DESCRIPTION	SARCCUS (1981) CLASS
1	No apparent erosion	S1
2	Slight sheet erosion without rilling	S2
3	Severe sheet erosion with incipient rilling	S3R2
4	Severe rill and gully erosion	R3G2, S3R4G2
5	Intricate gully patterns and degraded gully remnants	G3, G4, G5,GR
6	River bank and footpath erosion	RB, FE

Table 4.3 The SARCCUS soil erosion classification system (Modified after Beckedahl *et al* 1988)

Type of erosion	Class of erosion	Symbol	Description and remarks
1. Erosion caused by water			
Sheet (surface) Uniform removal of surface soil	None apparent	S1	No visible signs of erosion on air-photo. Level of management appears to be high.
	Slight	S2	Areas of light-tone observed on air-photos. Erosion deduced from poor cover, sediment deposits and plant pedestals.
	Moderate	S3	Eroded areas obvious on aor-photos. Plant cover very poor and sediment deposits extensive. Associated with small rills.
	Severe V.severe	S4 S5	} Sheet erosion of such severity always associated with rills and gullies. much or all of the A-horizon has been removed.
Rill Removal of soil in large channels or rivulets, mainly on arable land	None apparent	R1	As for sheet erosion
	Slight	R2	Small, shallow (mainly <0,1 m) rills present but not readily observed on air-photos.
	Moderate	R3	Rills of considerable depth (mainly 0,1 to 0.3m) and intensity usually observed on air-photos.
	Severe	R4	An abundance of deep rills (less than 0,5 m) easily observed on air-photos. Subsoil may be exposed.
	V.severe	R5	Large well defined rills but may be crossed by farm machinery. Associated with gully erosion.
Gully (donga) Removal of soil in large channels or gullies by concentrated runoff from large catchment areas	None apparent	G1	As for erosion
	Slight	G2	Clearly observed on air-photo and usually up to 1m deep. Cannot be crossed by farm machinery.
	Moderate	G3	Intricate pattern of deep gullies (mainly 1 to 3m) exposing entire soil in places. Many 'islands' of topsoil remain.
	Severe	G4	Landscape dissected and truncate by large (3 to 5 m deep) gullies. 25%-50% of area unproductive.
	V.severe	G5	Large and deep (often > 5m) gullies have totally denuded over 505 of the area.
Streambank Undercutting and slumping in of stream and river banks		B	Occurs on outer curves of streams and Rivers where fast-flowing water undercuts the banks. may or may not be seen on air-photos.

Plate 4.1 Erosion class 1

Plate 4. 2 Erosion class 2

Plate 4.3 Erosion class 3

Plate 4.4 Erosion class 4

Plate 4.5 Erosion class 5

Plate 4.6 Erosion class 6

Plate 4.3 Erosion class 3

Plate 4.4 Erosion class 4

Vegetation type and cover

Four categories of vegetated surfaces were distinctly discernible from the different sets of aerial photographs analysed. These were specified as: open woodland, wooded grassland, moderate grass cover and scanty grass cover. Changes in their aerial extent and species composition were mapped at each date. Clear-cut variations in the density of riparian vegetation were another intriguing feature of vegetation cover in this area. Individual stream courses were analysed on all the five sets of photographs and differences in the density of vegetation along them were designated as: dense, moderate and scanty.

The aerial photograph analysis technique primarily served the purpose of accurately identifying the spatial variation of the variables outlined above. Their quantification was not possible using the same technique given the distortion in scale, especially towards the margins of individual photographs. This deficiency was overcome by using the orthophoto map technique described in section 4.1.2 .

4.1.2 Orthophoto map technique

The information extracted from aerial photographs at each date was transposed to transparent overlays, superimposed onto orthophoto maps. The latter were drawn at a uniform scale of 1:10 000, which served as a measure against scale distortion. The catchment spanned 12 orthophoto maps prepared in 1992 by the Aircraft Operating Company at a scale of 1:10 000. They were based on the 1988 aerial photography. Since orthophoto maps are prepared with specific longitude and latitude references indicated on their corners, they would then facilitate the capture of these data into the GIS - a technique described in section 4.1.3.

4.1.3 Data capture into the Geographic Information System (GIS)

Data were graphically captured from the orthophoto transparent overlays onto a GIS in 'PC ARC/ INFO' format. A GIS can be defined as a facility for preparing, presenting, and interpreting facts that pertain to the surface of the earth (Tomlin 1990). The common denominator of different definitions of the concept 'GIS' is its capability to integrate all forms of geographically referenced information. The main advantage of this technique, observed as well by ESRI (1992), is that it is not merely a computer system for making maps but an analytical tool as well. It allows one to identify spatial relationships between spatially oriented features.

A total of 180 coverages digitised were 'mapjoined' into 15 coverages, depicting the spatial distribution of land use and erosion types, and categories of vegetated surfaces at each date. These were projected into the 'Albers projection'. This projection was the most appropriate at this scale of study given its 'equal area' property. Other coverages created include: riparian vegetation density, slope, soil and rock type distribution. A map showing the three categories of riparian vegetation density described in section 4.1.1, was prepared from the 1992 orthophoto maps. The details of the preparation of the last three coverages (slope, soil and geology maps) are given in section 4.3. A reliable database thus created was then imported into 'Quattro-pro' computer package for statistical manipulation.

4.2 Field surveying

Field surveys of the entire study area were conducted to groundtruth observations and interpretations made on aerial photographs. However, it is noteworthy that observations made in the field are not a true reflection of the degradation status of the dates at which the aerial photographs were taken. As a result, it becomes difficult to detect and quantify morphologically inconspicuous erosion forms. Such erosion forms are easily concealed on aerial photographs by, for instance woody vegetation.

Vegetation degradation in terms of cover and changes in species composition and erosion classes as outlined in Table 4.3 were verified by means of this groundtruthing exercise. Specific aspects of the two land degradation forms were investigated in greater detail. On one hand, the geomorphic impact of the removal of riparian vegetation, particularly, on stream channel morphology was examined on selected stream courses. On the other, sites identified from both the aerial photographs and field surveys as most severely affected by soil erosion in form of intricate gully networks were investigated. The rationale behind this was to establish their salient characteristics. Their spatial relationship with slope characteristics and geological formations was further examined using the "overlay" facility in PC ARC/INFO GIS. The technique used in the channel vegetation survey is outlined in sub-section 4.2.1 below.

4.2.1 Comparative channel vegetation survey

The role of river bank vegetation as a control on river channel morphology has been documented (eg. Hooke 1979, Hickin 1984, Marlow *et al* 1987, Thorne 1990, Trimble 1994, Rowntree and Dollar 1996). The comparative survey described in this section is that of a scantily vegetated stream on one hand and a densely vegetated one on the other. This dichotomy arises as a result of differences in land management practices over the past 60 years in two adjacent land tenure units. Vegetation along streams in traditional villages was almost annihilated while it remains dense in former commercial farmlands. This is discernible even on the earliest aerial photographs (1938) analysed in this study. Such a scenario permits a comparative analysis of two stream segments located in one land unit, with other factors controlling channel form (eg. bank material properties, discharge and gradient) remaining constant.

The technique applied in this survey is that of comparing the morphology of the macro and active channel components of two adjacent second order streams bearing vegetation and locational characteristics described above. Ten sites at intervals of 200 metres were examined along the vegetated stream, while 7 were examined along the unvegetated one. The stream lengths in both cases were 2 kilometres and 1.4 kilometres respectively. This explains why fewer sites were examined in the latter case. At each site, channel morphology variables namely: width, minimum and maximum depth of both the macro and active channel were measured. The channel condition, whether eroding or aggrading was assessed.

4.3 Secondary data sources

Data relating to certain variables that were considered to have a direct bearing on trends in land degradation was obtained from different sources. Long term climatic data were obtained from the Computing Centre for Water Research (CCWR) in Petermaritzburg. Monthly and daily rainfall amounts were considered to be more relevant to the present study, given the catchment's high rainfall variability. Long term rainfall trends were analysed using the 'z-scores', which are standardised rainfall values (Whitlow 1994b). This made it possible to identify distinct dry and wet periods. Its computation is described in section 5.2 of the results chapter.

Long term daily rainfall data were not available for Peddie station. Daily rainfall records for Fort Hare, a station 35km away from the study area, were obtained from Uys (1983). He concludes from his analyses that rainfall characteristics at Fort Hare may be applicable within a radius of up to 50km. Such data would highlight the implications of long term rainfall variations on certain geomorphic thresholds.

Information regarding the physical characteristics of the area was acquired from a series of maps. The geology data of the area was obtained from the 1:125 000 map of geology of Grahamstown area (Department of Mines, Geology and Survey, 1946). Despite its date, this map was found to be the most accurate representation of the area's micro-geology as compared to the most recent ones. Its details tallied quite accurately with the field survey findings. Some geological details were noted to be missing on the later maps.

Spatial variations in the percentage of slope were determined by analysing contours of the 1982, 1:50 000 topographical map of the area. A slope map was prepared on the basis of such analysis. A soils map was also prepared using the details of the soil surveys of the area conducted by Loxton, Hunting and associates (1979). The details of the physical characteristics thus obtained were digitised in PC ARC/INFO GIS. This would ensure the drawing of reliable inferences with regard to relationships between physical characteristics and land degradation forms. Besides, statistical analyses were carried out in order to establish the significance of these relationships. The Chi-squared test, the T-test and Pearson's Product Moment Correlation Coefficient were employed. The results of the study are presented in the subsequent chapter.

5. Results

The results obtained using the methodology described in the preceding chapter are presented in the current chapter. As pointed out in Chapter 3 section 3.1, this study entails a comparative analysis between three land tenure units - the former commercial farmlands, traditional and betterment villages. Their areal extent is 56.6 Km^2, 84.7 Km^2 and 32.1 Km^2 respectively. The analysis was carried out in two stages. Firstly, the homogeneity of the three areas was tested in terms of physical characteristics namely; slope, geology and soils distribution and drainage density. Secondly, spatial variations in degradation forms were analysed against this background of the areas' physical attributes.

5.1 Distribution of physical characteristics

5.1.1 Slope distribution

The frequency and spatial distribution of the designated slope classes are depicted in Figures 3.2 and 3.3, Chapter 3 section 3.2, respectively. In order to verify whether there is a significant variation in slope distribution, a Chi- squared test was conducted. A Chi value of 57.56 was obtained, which is highly significant at all levels. This implies lack of homogeneity in terms of slope distribution in the study area.

The distribution of slope classes between the respective land tenure units is presented in Table 5.1 and Figure 5.1. It can be observed from Table 5.1 that the percentage of the land area steeper than 9% in the former commercial farmlands, betterment and traditional villages is 29%, 42% and 53% respectively. By implication, there is a tendency for the slopes in the traditional areas to be steeper than those in the other tenure units. This further confirms the highly variable nature of slope distribution in the area.

Table 5.1 Slope distribution between land tenure units.

Tenure area	Slope distribution (Km^2) and frequency (%)									
	<4%		4-9%		10-15%		16-20%		>20%	
	Km^2	%	Km^2	%	Km^2	%	Km^2	%	Km^2	%
Traditional	5.6	6.6	34.2	40.4	19.9	23.5	21.9	25.9	3.0	3.5
Betterment	6.3	19.6	12.1	37.7	5.6	17.4	8.1	25.2	0	0
Commercial	6.5	11.5	33.5	59.2	9.2	16.3	6.5	11.5	0.7	1.2

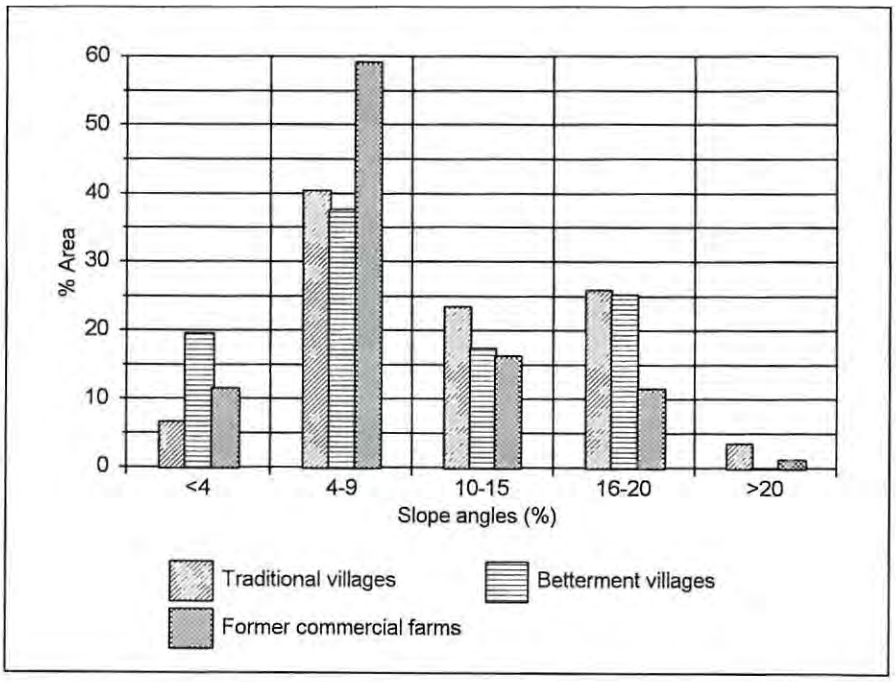

Figure 5.1 Slope distribution between land tenure units.

5.1.2 Soil type distribution

The distribution of the main soil types of the study area is presented in Figure 5.2. As already pointed out in Chapter 3 section 3.6, Mispah is the dominant soil form, covering 72% of the total land area and spanning the three main land tenure units. Thus there is homogeneity in soil distribution. Glenrosa form which is a derivation of Mispah, by way of weathering to greater depths, occupies only 24.7%. Pockets of colluvial and alluvial material accumulation in stream valleys cover 2.5%.

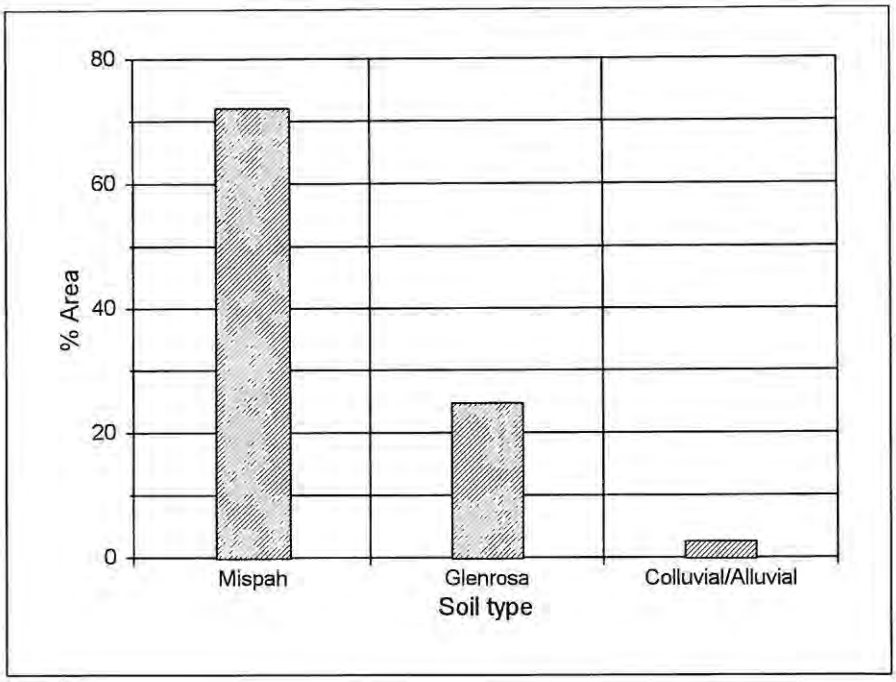

Figure 5.2 Distribution of the main soil types.

5.1.3 Rock type distribution

Table 5.2 and Figure 5.3 show the distribution of rock types between the respective tenure units. It is noticeable from the data presented that whilst the traditional and betterment villages are predominantly covered by the Ecca group of rocks, both the Beaufort and Ecca groups are adequately represented on the commercial farms. Most of the 2.6 Km^2 dolerite sill that traverses the study area is located in the traditional and betterment villages. A very small section of it lies on the commercial farms. Despite the uneven distribution of the two main rock types, uniformity in terms of the soils derived from them has been noted in section 5.2 above. It is noteworthy, however, that similarity in terms of soil classification does not translate to soil properties (Rowntree *pers. comm.*). The implications of such distribution on land degradation will be investigated in section 5.5.5.

Table 5.2 Distribution of rock types between land tenure units.

Tenure area	Rock type distribution (Km^2) and Frequency (%)					
	Ecca		Beaufort		Dolerite	
	Km^2	%	Km^2	%	Km^2	%
Traditional	81.3	95.9	1.4	1.7	1.8	2.1
Betterment	24.8	77.3	6.5	20.2	0.8	2.4
Commercial	25.3	44.7	31.2	55.1	0.1	0.2

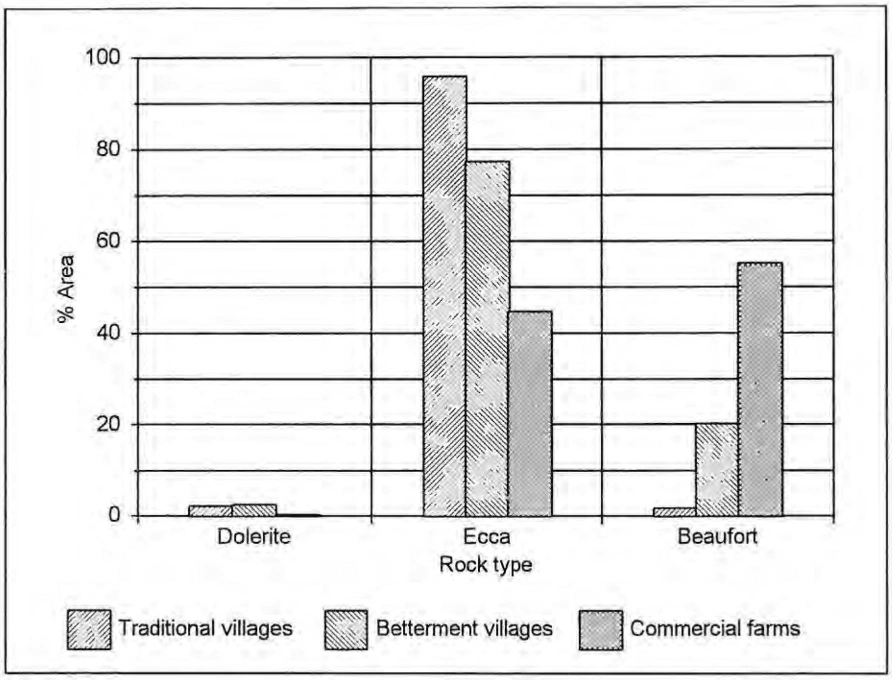

Figure 5.3 Distribution of rock types between land tenure units.

5.1.4 Drainage density

The drainage density for each of the three tenure units is presented in Table 5.3. By this measure, it is noticeable that the entire study area is evenly dissected by stream valleys. Given that, drainage density is affected by, *inter alia*, geology and the nature of the terrain as the cardinal factors, its uniformity in all the three units denotes the study area's physiographic homogeneity.

Table 5.3 Drainage density in the respective tenure units.

Tenure unit	Area	Stream length	Drainage density
Traditional	84.7	135.4	1.59
Betterment	32.1	51.3	1.59
Commercial	56.6	86.9	1.53

5.2 Rainfall trends

Long term rainfall variations for the study area were examined to determine the succession of wet and dry phases and episodes of extreme rainfall events. Annual, monthly and daily rainfall data series were analysed. Their relevance to vegetation and erosion changes was investigated in sections 5.4 and 5.5. It is notable from the annual rainfall chronology for Peddie (Figure 3.5 Chapter 3) that rainfall is highly variable and no consistent trend can be observed - a characteristic feature of the annual rainfall series of Southern Africa (Tyson 1986, Preston-Whyte and Tyson 1988, Rowntree and Dollar 1995). Peaks are discernible at intervals of 12 and 19 years.

Figure 5.4 shows the long term filtered annual rainfall trends for Peddie obtained using the "z" score, computed as follows:

$$z = \frac{\text{raw value - mean rainfall of station (1920-1991)}}{\text{Standard deviation of rainfall (1920-1991)}} \quad \text{.................(4)}$$

Distinct wet and dry phases were identified using a five year running mean of the z-scores (Figure 5.4). The average "z" score for each phase was determined as a surrogate for the rainfall status (Table 5.4) - a method adapted from Whitlow (1994b).

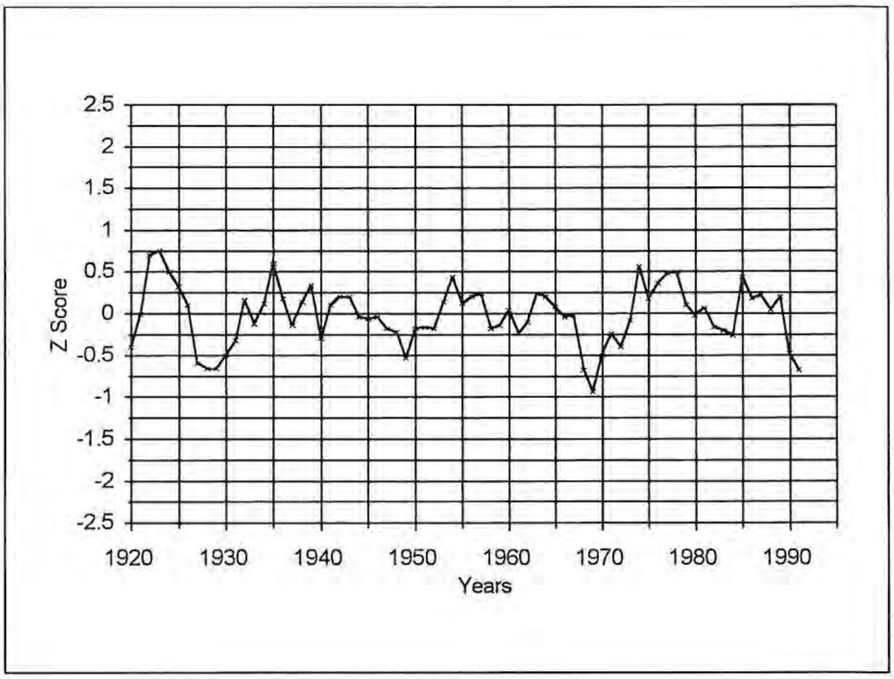

Figure 5.4 Long term filtered annual rainfall trends for Peddie using a five year running mean (1920-1991).

Table 5.4 Identified phases and their rainfall status.

Period	Rainfall status (z-score)
1922-1926	wet phase, z-score = 0.1
1927-1931	dry phase, z-score = -0.3
1932-1943	wet phase, z-score = 0.1
1947-1952	dry phase, z-score = -0.3
1953-1965	wet phase, z-score = 0.1
1968-1973	very dry phase, z-score = -0.4
1974-1989	wet phase, z-score = 0.2
1990-1991	very dry phase, z-score = -1.1

Figure 5.5 shows the maximum monthly rainfall trends for the same time period. Extreme monthly rainfall peaks in 1922, 1953 and 1970 are distinct. They contributed 35.8%, 36.9% and 50.3% to the annual rainfall. Such peaks could be better indicators of episodes of intense rainfall than annual totals. The highest peak is noted to have occurred in the middle of a very dry period

(1968-1973). August, the month during which the peak occurred, is towards the end of winter, when vegetation cover is supposedly low. Besides, the peak is also noted to follow three consecutive dry years. The implications of this discrepancy for erosion are examined in section 5.5.2.

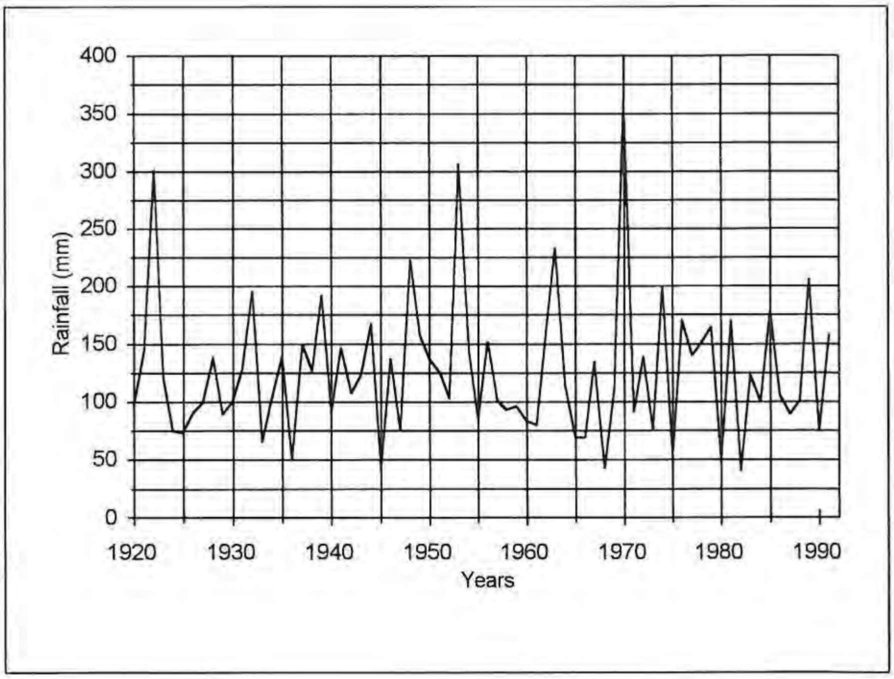

Figure 5.5 Maximum monthly rainfall chronology for Peddie (1920-1991).

Whilst daily rainfall data for Peddie station for the same time period are patchy, a complete record for the nearby Fort Hare station between 1970 and 1982 is obtainable from Uys (1983). Correlations were sought between the two stations for the annual and monthly rainfall series using Pearson's Product Moment Correlation Coefficient. Strong correlations of 0.79 and 0.86 respectively, significant at the 0.05 level, were found. Daily rainfall trends for Fort Hare station could, thus, be extrapolated to Peddie station.

In his analysis of the individual rainy days in each month for Fort Hare station between 1970 and 1982, Uys (1983) noted that a small proportion of the rainy days supply most of the monthly rainfall totals (Table 5.5). By implication, the daily rainfall distribution for the total period is highly negatively skewed. Undoubtedly, the same daily rainfall trends pertain to the study area.

Table 5.5 Average Monthly Rainfall (mm) and number of rainy days per month for Fort Hare and neighbouring stations (After Uys 1983).

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Av.
i.	52.1 7	65.2 7	74.1 8	43.4 5	29.0 4	15.5 3	16.7 3	19.7 3	39.3 5	49.6 6	55.0 7	53.0 7	42.7
ii.	64.0 9	67.1 10	76.2 11	44.9 8	35.9 6	21.1 4	23.0 4	22.6 5	41.3 5	52.6 9	64.9 9	61.8 10	47.9
iii.	60.6 7	63.4 7	81.4 9	46.0 6	33.4 4	20.1 3	24.6 3	23.0 3	41.3 5	50.5 7	64.9 7	63.1 7	47.7
iv.	49.6 4	58.0 8	75.6 4	35.5 3	25.6 2	16.4 2	19.7 2	16.6 2	37.6 3	47.0 5	61.1 5	45.6 3	40.7
v.	56.3 10	70.1 11	75.8 11	34.8 8	30.0 7	27.6 5	27.0 4	65.2 6	34.0 7	47.1 8	52.4 9	65.1 8	49.8

I. Fort Hare: 32^0 48' S26^0 50' E - 13 year period.
ii. Lovedale: 32^0 46' S26^0 50' E - 71 year period.
iii. Alice: 32^0 47' S26^0 50' E - 69 year period.
iv. Middledrift: 32^0 50' S26^0 59' E- 45 year period.
v. Fort Beaufort: 32^0 47' S26^0 18' E- 81 year period.

One extreme rainfall event can be singled out from the daily data series for Fort Hare between 1970 and 1982. A four day rainstorm of 254 mm, reckoned to be the most extreme since the turn of the century, was recorded in August 1970 (Table 5.6). At Peddie station, where reliable daily rainfall figures are not available for that period, 360mm of rain were recorded during the same month (Figure 5.5).

Table 5.6 Four day extreme rainstorm at Fort Hare (after Uys 1983).

Date	Rainfall (mm)
25/08/70	23
26/08/70	38
27/08/70	83
28/08/70	110
Total	254

This extreme rainstorm bears testimony to the highly skewed nature of the rainfall in the area, as it is only 5 days that supplied the rainfall total of 259mm recorded during that month. This confirms Tyson's (1986, p.3) observation that, "It is the frequency of occurrence of rainy spells of at least four consecutive days duration that distinguish a wet from a dry year". The implications of these rainfall data series on land degradation are examined in section 5.5.

5.3 Land use changes within tenure units

Changes in areal extent at each date of the three main land use categories, namely crop cultivation, grazing land and abandoned cultivation plots, are presented in Tables 5.7 to 5.9 for each land tenure unit. The rest of the land area in each land tenure unit occupied by, for instance, settlements, roads and streams is indicated as 'others' in the respective Tables. The areal extent of the three main land use types, expressed as a percentage of the tenure units, is presented in Figures 5.6, to 5.8.

Table 5.7 Changes in areal extent of land use types in traditional villages.
Note: *Ab = Abandoned in tables 5.7 to 5.9

Land use type	Year, Areal extent (Km^2) and %)									
	1938		1954		1965		1975		1988	
	Km^2	%	Km^2	%	Km^2	%	Km^2	%	Km^2	%
Cultivated land	26.1	30.9	26.4	31.2	18.7	22.1	21.3	25.1	10.7	12.6
Grazing land	26.5	31.3	25.8	30.5	25.4	30	19.2	22.7	18.7	22.1
*Ab. cultivation	0.2	0.2	0.6	0.7	8.6	10.2	12.1	14.3	23.2	27.4
Others	31.9	37.7	31.9	37.7	32.0	37.8	32.1	37.9	32.1	37.9

Table 5.8 Changes in areal extent of land use types in betterment villages.
* = Introduction of betterment

Land use type	Year, Areal extent (Km^2) and %									
	1938		1954		1965*		1975		1988	
	Km^2	%	Km^2	%	Km^2	%	Km^2	%	Km^2	%
Cultivated land	8.6	26.8	8.3	25.3	8.1	25.2	7.1	22.1	5.1	15.9
Grazing land	9.9	30.8	9.8	30.5	9.6	29.9	6.7	20.9	6.2	19.3
Ab. cultivation	0	0	0.2	0.6	0.5	1.6	4.5	14	7.1	22.1
Others	13.6	42.4	13.8	42.9	13.9	43.3	13.8	42.9	13.7	42.7

Table 5.9 Changes in areal extent of land use types on former commercial farms.

Land use type	Year, Areal extent (Km^2) and %									
	1938		1954		1965		1975		1988	
	Km^2	%	Km^2	%	Km^2	%	Km^2	%	Km^2	%
Cultivated land	2.6	4.6	2.6	4.6	2.4	4.2	1.2	2.1	0.7	1.2
Grazing land	41.9	74	41.9	74	41.7	73.7	42.1	74.4	42.4	74.9
Ab. cultivation	0	0	0	0	0.4	0.7	1.2	2.1	1.4	2.5
Others	12.1	21.4	12.1	21.4	12.1	21.4	12.1	21.4	12.1	21.4

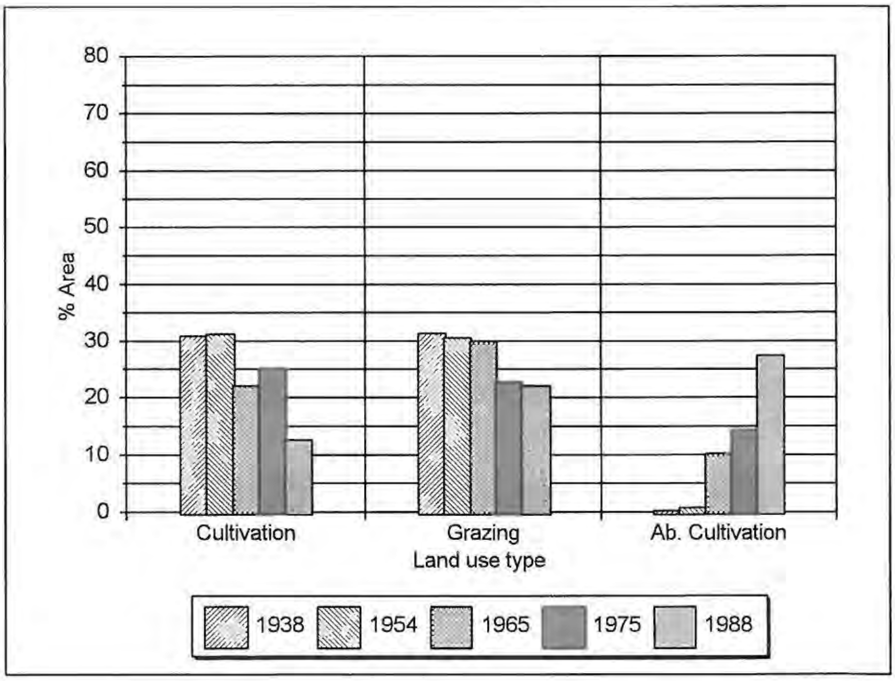

Figure 5.6 Land use changes in traditional villages.

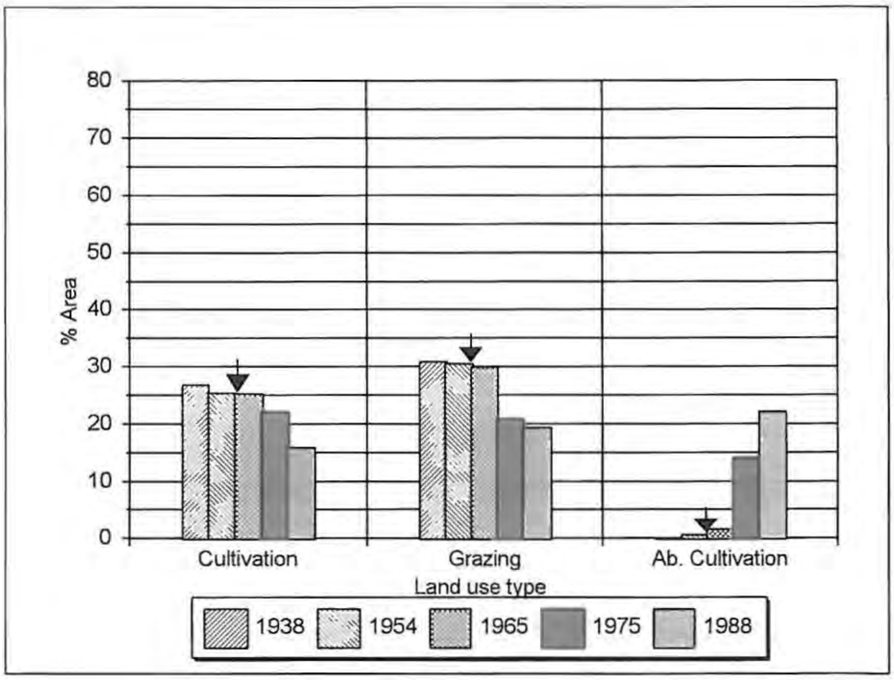

Figure 5.7 Land use changes in betterment villages. Arrows indicate the introduction of betterment.

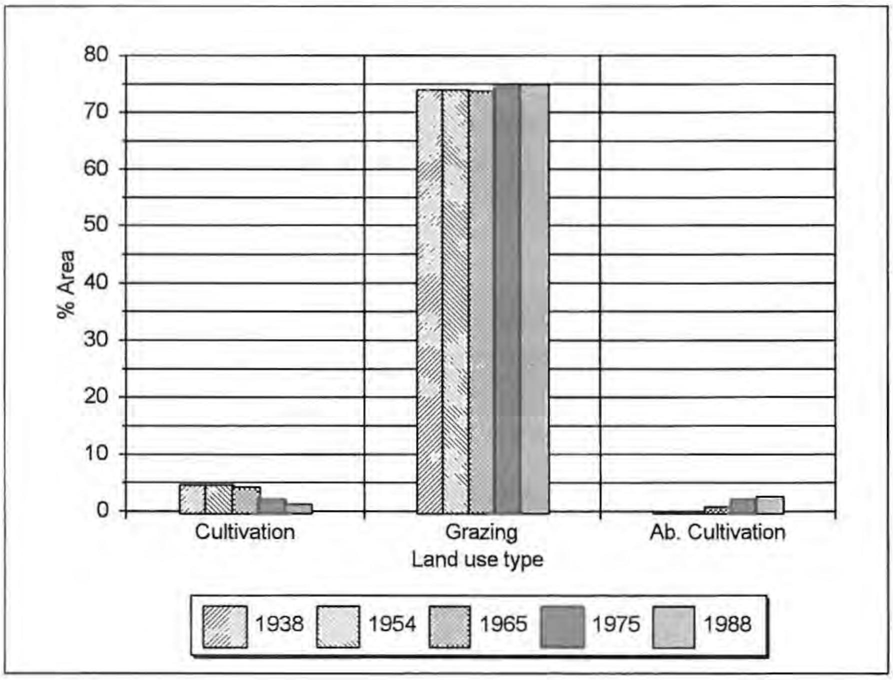

Figure 5.8 Land use changes on commercial farms.

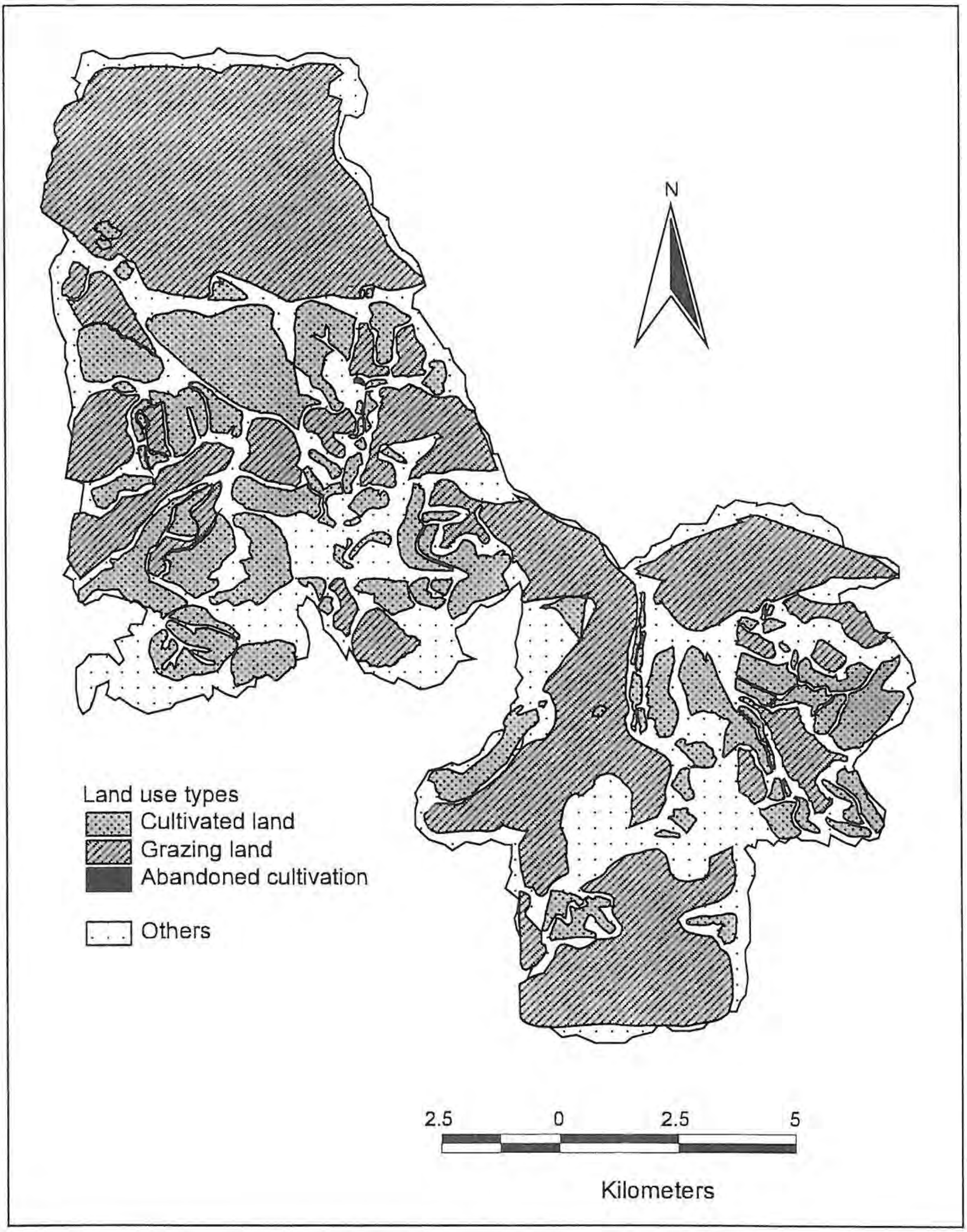

Figure 5.9 Land use distribution (1938)

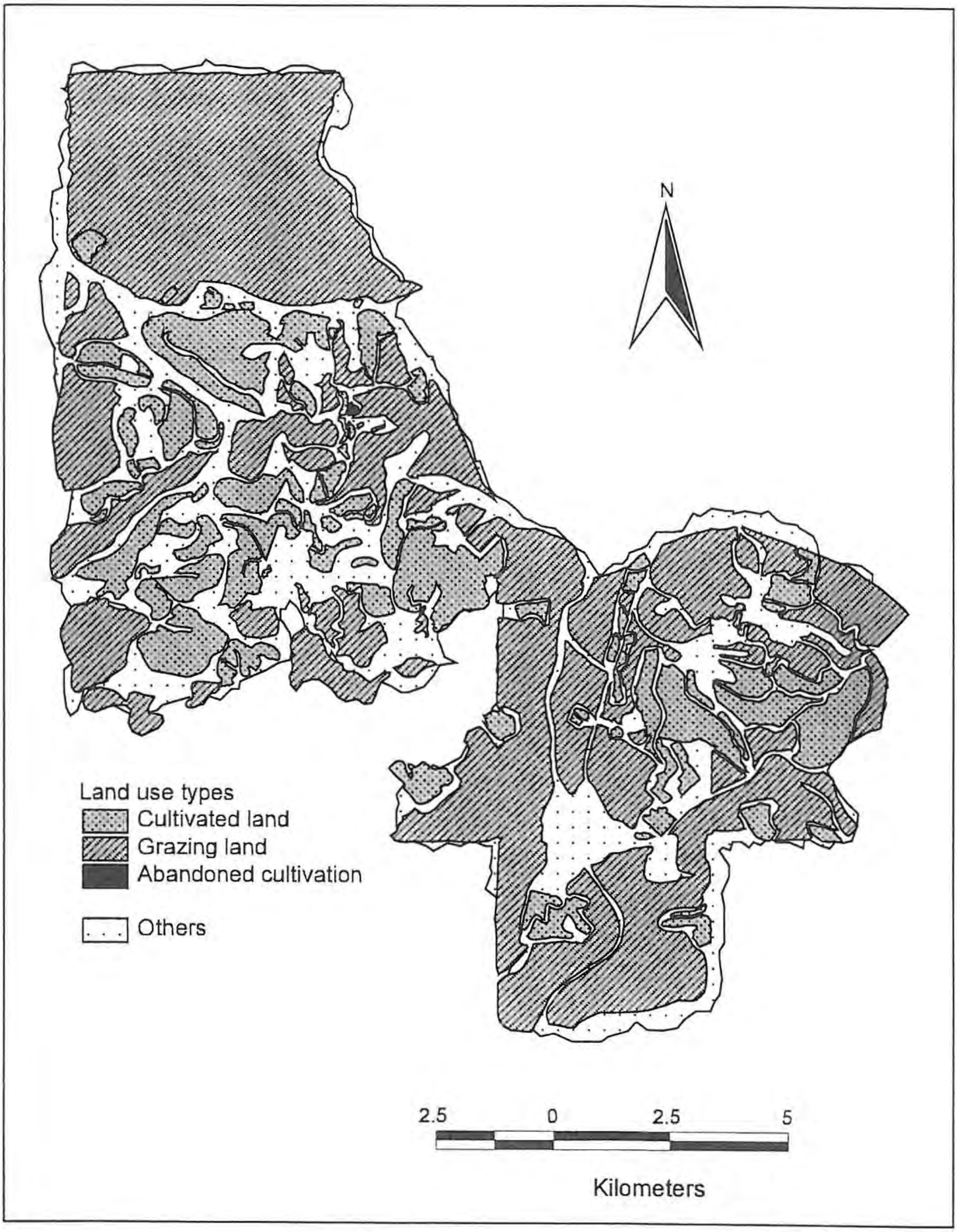

Figure 5.10 Land use distribution (1954)

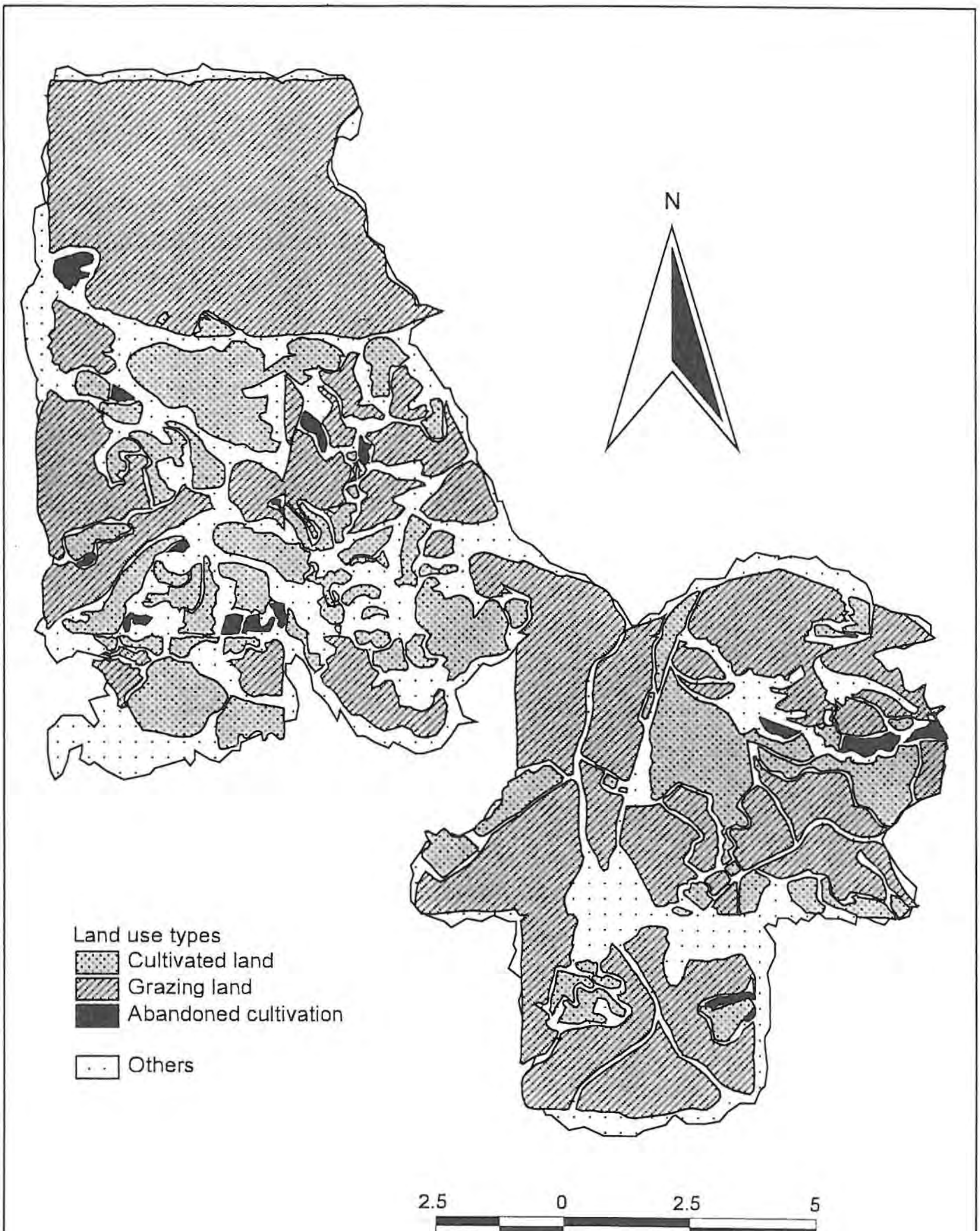

Figure 5.11 Land use distribution (1965)

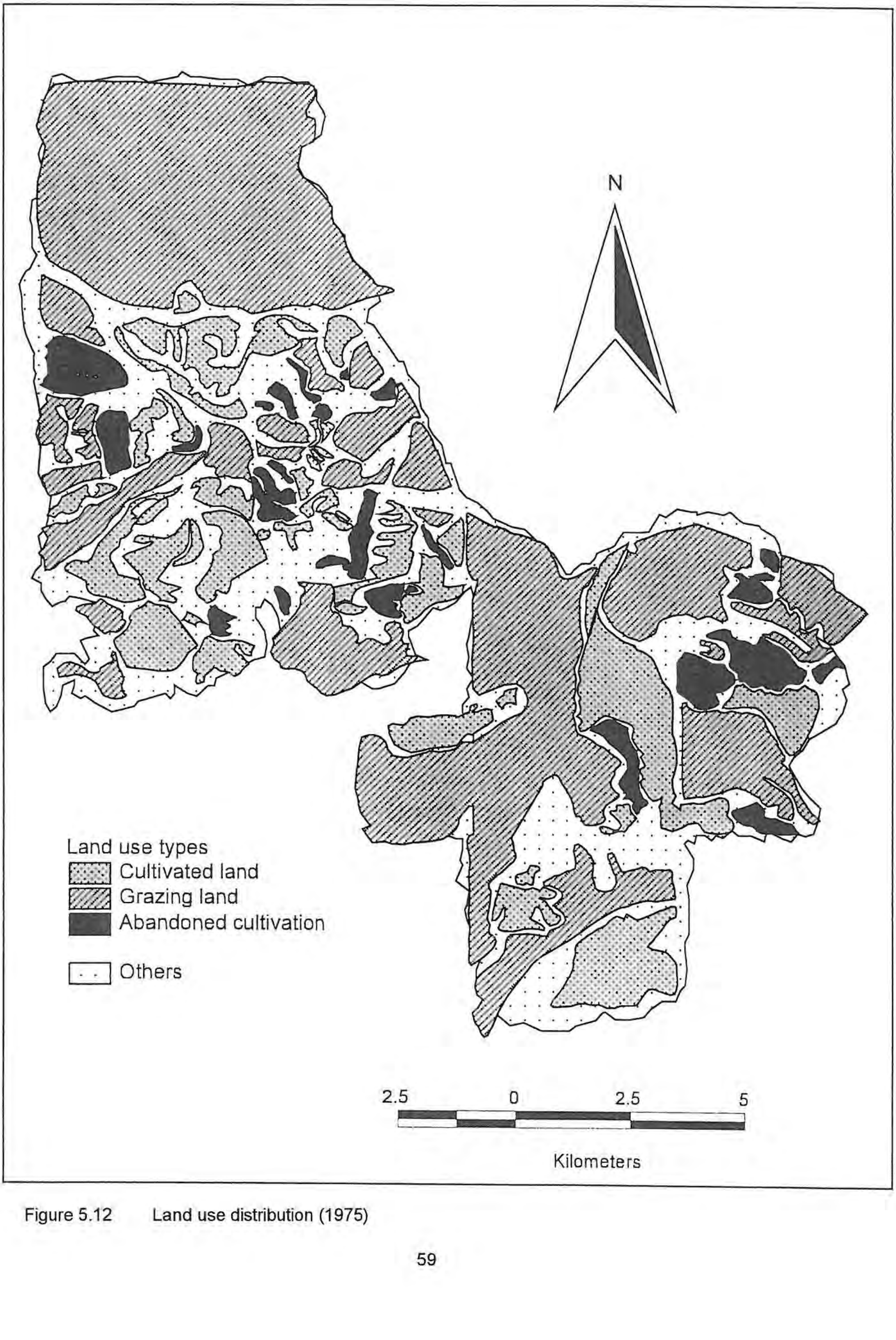

Figure 5.12 Land use distribution (1975)

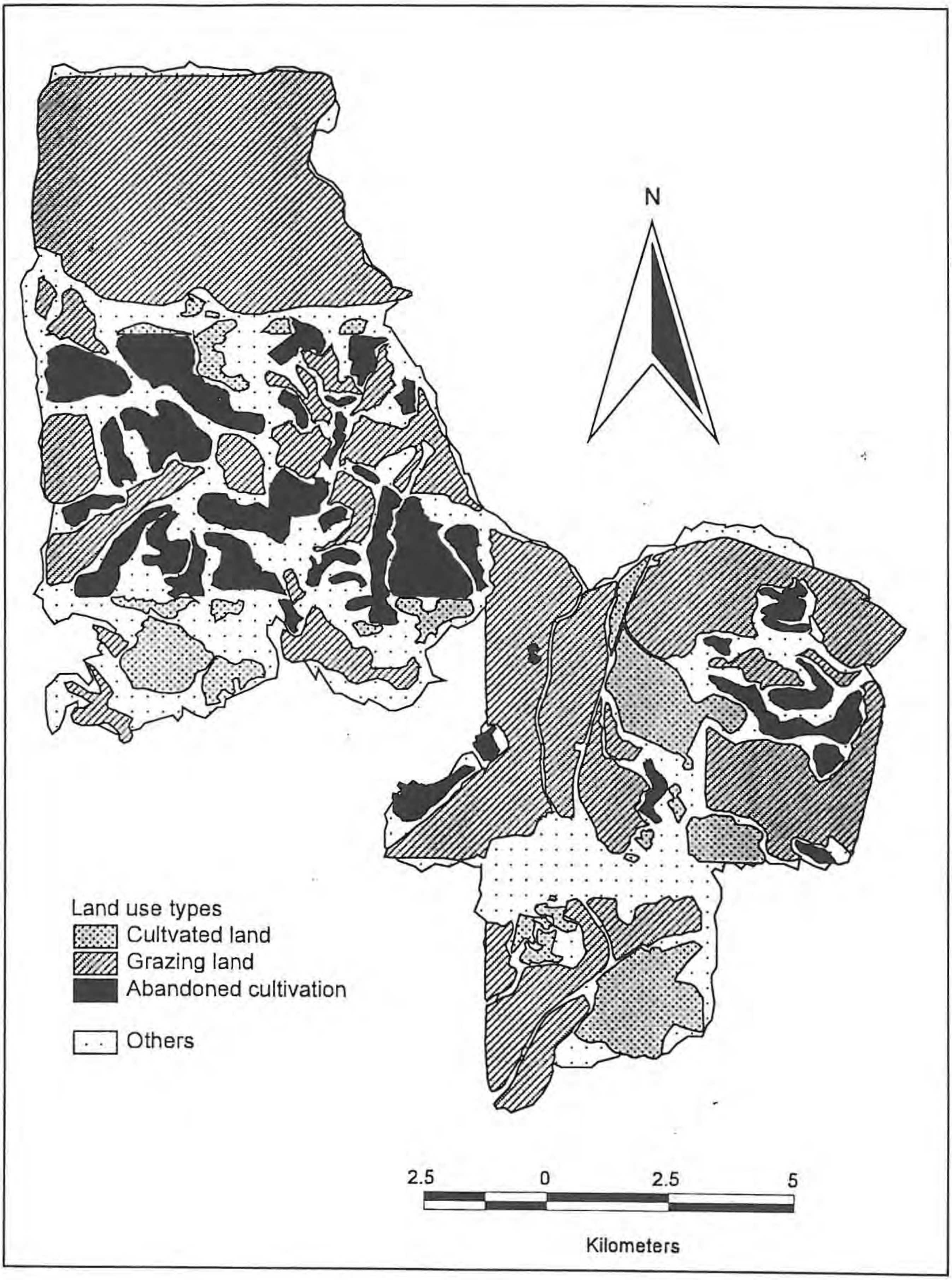

Figure 5.13 Land use distribution (1988)

Figure 5.13 Land use distribution (1988)

It is noticeable from the land use change data presented above that, between 1938 and 1954, the land area under crop cultivation in the traditional villages was almost equivalent to that under grazing. A progressive reduction in cultivated land on both the traditional and betterment villages, is the most significant trend for the remainder of the study period, despite the additional land taken up from grazing. On the other hand, grazing on the former commercial farms is noted as the consistently predominant land use type at each date, with an average areal extent of 42 Km^2. The small acreage under crop cultivation was, likewise, progressively abandoned notably from 1965. The distribution of the three land use types at each date is depicted in Figures 5.9 to 5.13.

Figures 5.14 and 5.15 show changes in the number of dwelling units in the betterment and traditional villages. A sharp rise after 1965 in the traditional villages and after 1954 in the betterment villages is discernible. In both instances, the magnitude of increase is four times the previous numbers. In the betterment villages, the increase is noted to coincide with the introduction of the betterment programme in the early 1960s. Contrary to the normal global trends, population increase in both tenure units is noted to be co-incident with the reduction in the areas of both grazing and cultivated land, and large increases in abandoned cultivated land. The socio-economic implications of such trend will be discussed in Chapter 6. The relationship between these land use changes and land degradation is examined in sections 5.4 and 5.5.

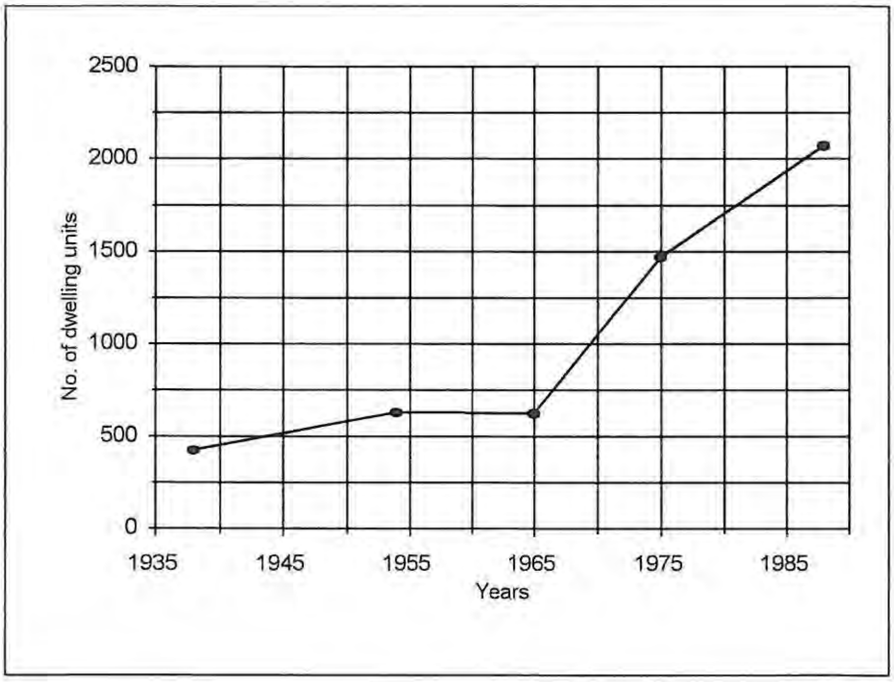

Figure 5.14 Number of dwelling units in traditional villages at each date.

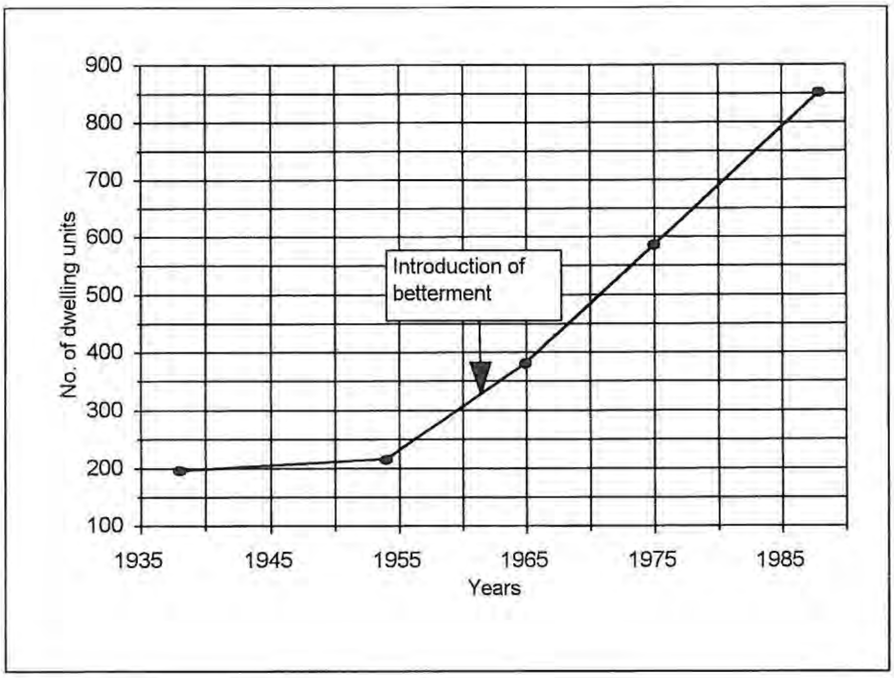

Figure 5.15 Number of dwelling units in the betterment villages at each date.

5.4 Vegetation changes

5.4.1 Changes in vegetated surfaces

Changes in the distribution of the four main vegetation categories described in Chapter 4, section 4.1.1, with respect to the respective tenure units, are presented in Tables 5.10 to 5.12. These categories were collectively designated as grazing land. The areal extent of each category, expressed as a percentage of the tenure units is presented in Figures 5.16 to 5.18. The distribution of the respective vegetation categories at each date is depicted in Figures 5.19 to 5.23.

Table 5.10 Changes in vegetated surfaces in traditional areas.

Year	Vegetation category, areal extent (Km^2) and %							
	Scanty cover		Moderate cover		Wooded grass		Open woodland	
	Km^2	%	Km^2	%	Km^2	%	Km^2	%
1938	16.5	19.5	2.2	2.6	7.8	9.2	0.0	0.0
1954	16.7	19.7	5.7	6.7	3.4	4.0	0.0	0.0
1965	18.1	21.4	3.9	4.6	3.4	4.0	0.0	0.0
1975	13.9	16.4	3.6	4.3	1.7	2.0	0.0	0.0
1988	15.1	17.8	3.9	4.6	0	0	0.0	0.0

Table 5.11 Changes in vegetated surfaces in betterment villages.

Year	Vegetation category, areal extent (Km^2) and %							
	Scanty cover		Moderate cover		Wooded grass		Open woodland	
	Km^2	%	Km^2	%	Km^2	%	Km^2	%
1938	9.0	28	0.2	0.6	0.7	2.2	0.0	0.0
1954	9.1	28.3	0.1	0.3	0.6	1.9	0.0	0.0
1965	8.6	26.8	0.3	0.9	0.7	2.2	0.0	0.0
1975	6.2	19.3	0.3	0.9	0.2	0.6	0.0	0.0
1988	3.7	11.5	2.2	6.9	0.3	0.9	0.0	0.0

Table 5.12 Changes in vegetated surfaces on commercial farms.

Year	Vegetation category, areal extent (Km^2) and %							
	Scanty cover		Moderate cover		Wooded grass		Open woodland	
	Km^2	%	Km^2	%	Km^2	%	Km^2	%
1938	0.4	0.7	0.0	0.0	14.5	25.6	27.0	47.7
1954	0.3	0.5	0.4	0.7	15.8	27.9	25.4	44.9
1965	0.1	0.2	0.3	0.5	12.1	21.4	29.2	51.6
1975	0.1	0.2	0.0	0.0	11.7	20.7	30.5	53.9
1988	0.2	0.4	1.0	1.8	5.6	9.9	35.6	62.9

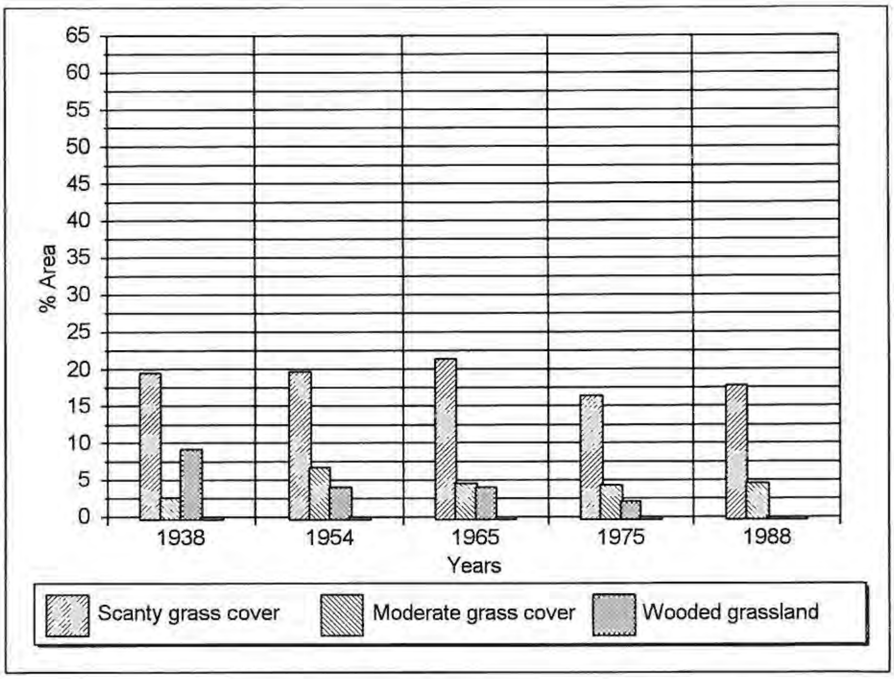

Figure 5.16 Changes in vegetated surfaces in traditional villages.

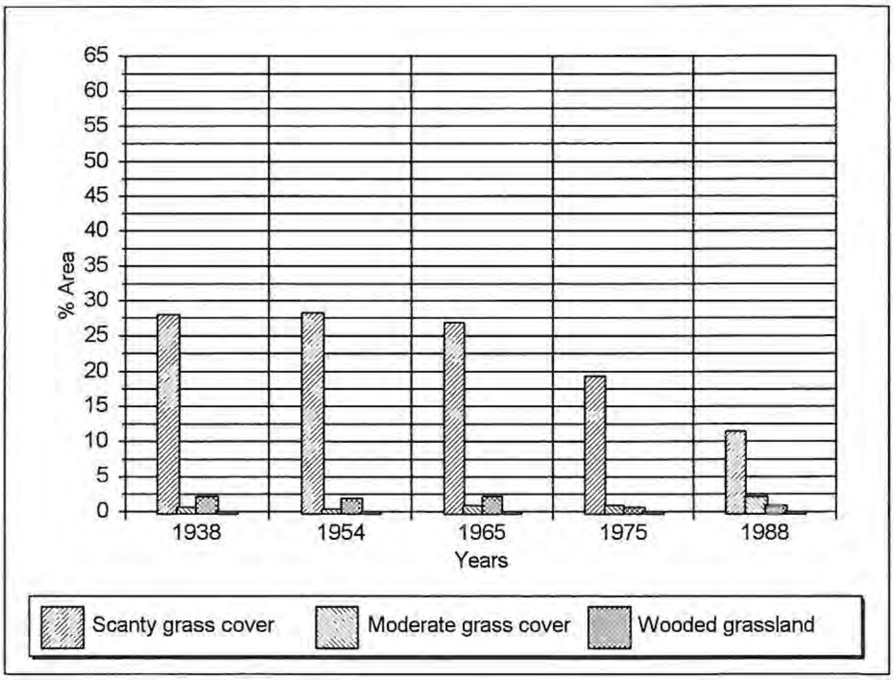

Figure 5.17 Changes in vegetated surfaces in betterment villages.

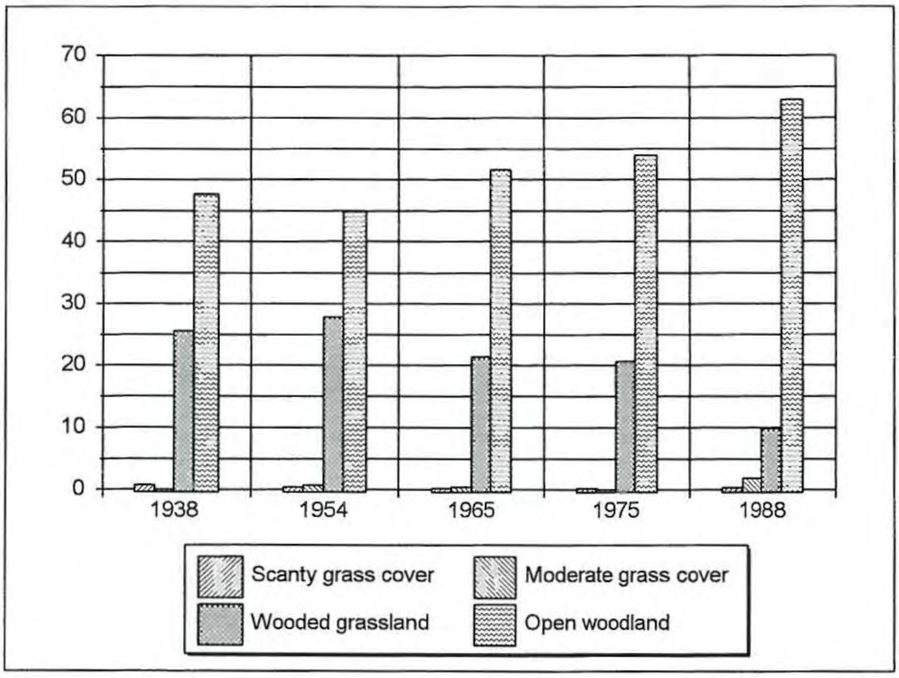

Figure 5.18 Changes in vegetated surfaces on former commercial farms.

Plate 5.1 Invasion by *Pteronia Incana* (Blue bush), an unpalatable Karroid dwarf shrub

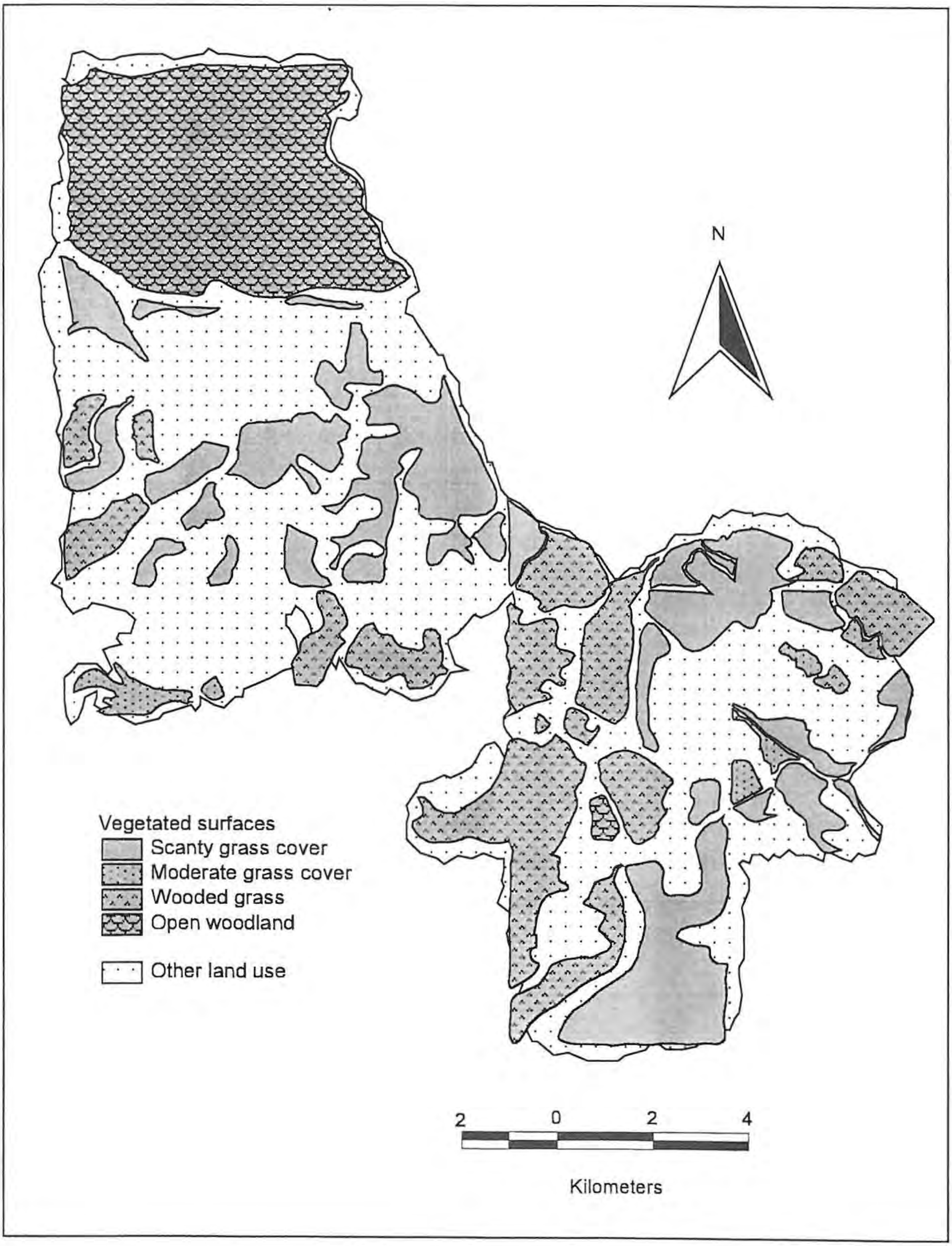

Figure 5.19 Distribution of vegetation categories (1938)

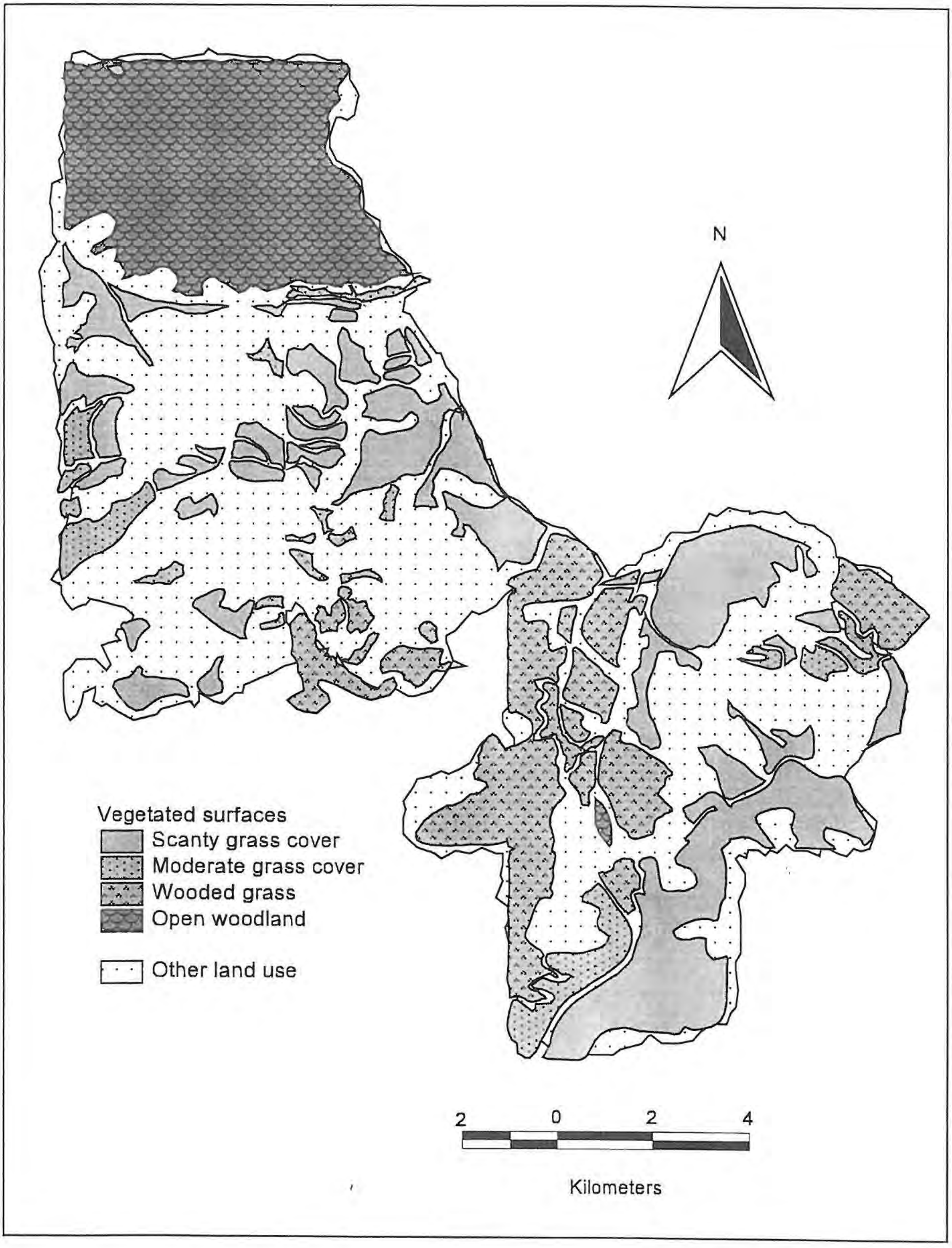

Figure 5.20 Distribution of vegetation categories (1954)

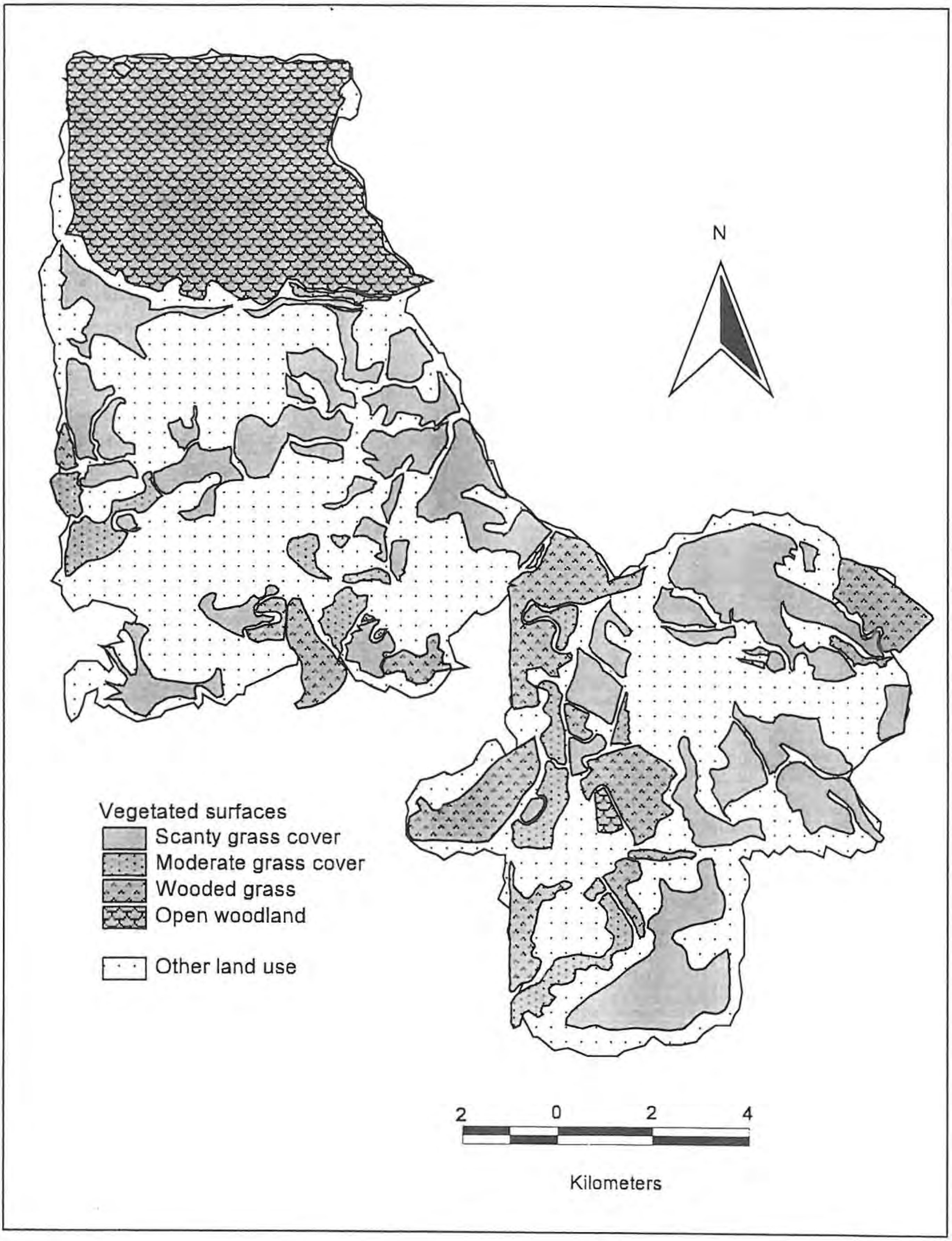

Figure 5.21 Distribution of vegetation categories (1965)

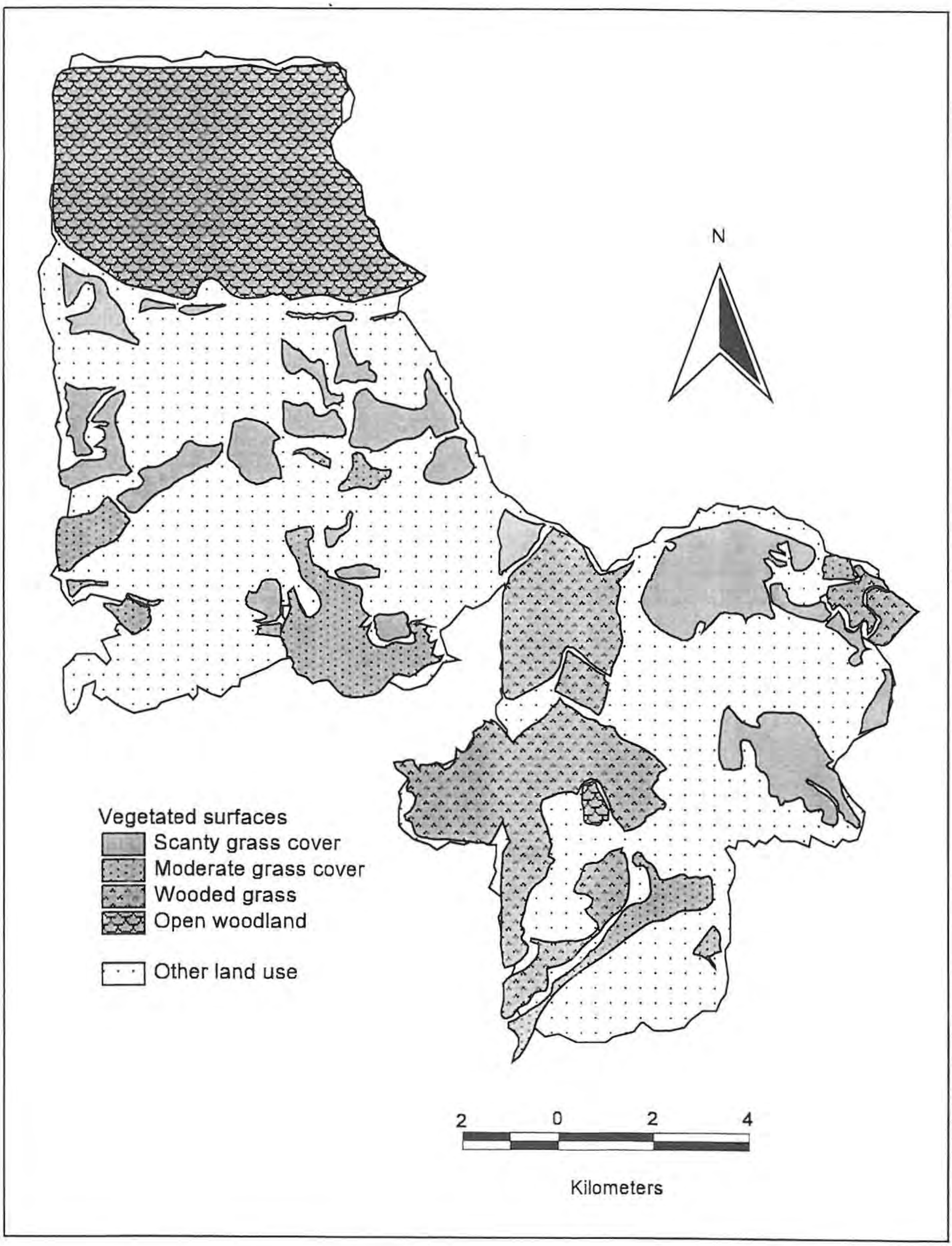

Figure 5.22 Distribution of vegetation categories (1975)

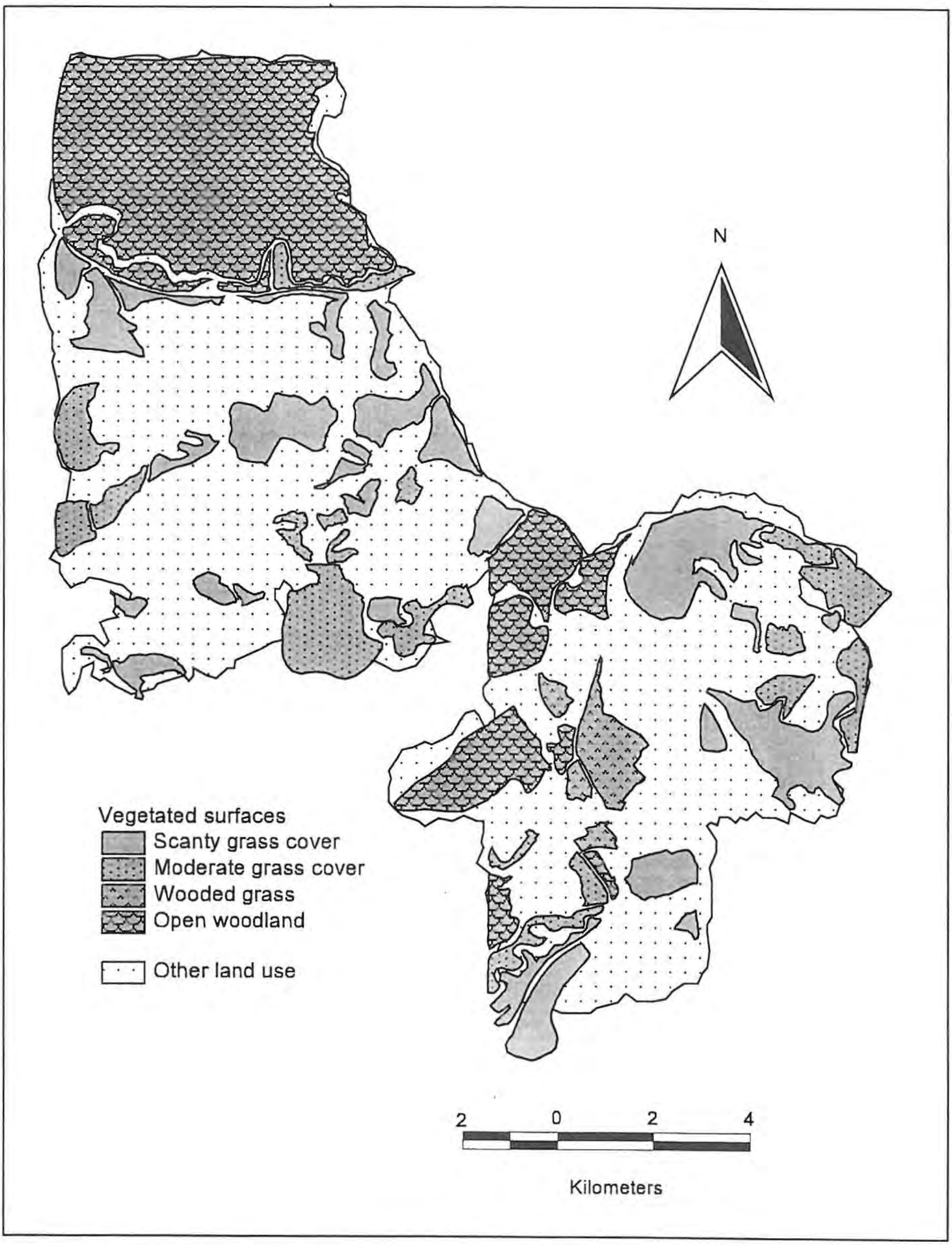

Figure 5.23 Distribution of vegetation categories (1988)

It is discernible that certain vegetation categories are confined to specific land tenure units. On average, 97.4% of the scanty grass vegetation category is observed on the traditional and betterment villages for the whole study period. It is consistently the dominant vegetated surface in both tenure units. The open woodland category is confined to the former commercial farmlands at each date. The wooded grassland category is more represented on the former commercial farms and its land area is fairly consistent between 1938 and 1975. Conversely, the small land area under the same category in the traditional and betterment villages diminishes gradually during the same period. Its shrinkage on the former commercial farms during the rest of the study period is noted to coincide with a 17% increase in the open woodland category.

While a gradual decrease in the total vegetated area in the traditional and betterment areas is noticeable, the reverse is true of the former commercial farms. In the latter case, the formerly cultivated land was later noted to have become vegetated, hence an increase in vegetated area. The additional land opened up for cultivation explains the decrease in the traditional and betterment areas. The abandoned cultivated land in both areas remained unvegetated. Besides, it was also observed from the sets of aerial photographs and field surveys that fence lines between tenure units mark the bounday between the dense woody vegetation on the one side and the scanty grass vegetation on the other. Another characteristic feature observed from field surveys is the widespread invasion of the traditional and betterment villages by *Pteronia incana* (Blue bush), an unpalatable Karroid dwarf shrub. Reminiscent of vegetation degradation, this shrub is spreading rapidly from the stream valley bottoms onto grazing lands and some of the abandoned cultivation fields (See Plate 5.1).

The rapidity with which vegetation responds to rainfall variations was alluded to earlier in Chapter 4, section 4.1.1. The rainfall condition of the periods during which the sets of aerial photographs were taken is indicated in Table 4.1. Despite the seasonal rainfall variations, the pattern of distribution of vegetated surfaces in the traditional and betterment villages, described above, remained consistent throughout the study period.

5.4.2 Variations in riparian vegetation density.

Spatial variations in the density of vegetation along stream courses are a prominent feature of the study area. Three categories of riparian vegetation density namely: Dense, Moderate and Scanty, are presented in Figure 5.24. The length of stream courses under each category mapped from the 1992 orthophoto maps based on the 1988 photography is given in Table 5.13.

Table 5.13 Categories of riparian vegetation density in tenure units (1988).

Tenure unit	Riparian vegetation category and Stream length (Km)		
	Dense	Moderate	Scanty
Traditional	0.0	15.5	119.9
Betterment	0.0	5.8	45.5
Commercial	86.9	0.0	0.0

It is noticeable from Table 5.13 and Figure 5.24 that the density varies with land tenure systems. Whereas stream courses in the former commercial farmlands have dense riparian vegetation along them, almost all stream courses in the traditional and betterment villages have had their vegetation removed. That this distributional pattern was observed even from the earliest set of photographs analysed, indicates that riparian vegetation removal from these villages began much earlier than 1938. Given such considerable length of streams under the scanty vegetation category, the geomorphic and environmental impact of vegetation removal, especially in terms of channel degradation, is pronounced. The results of the comparative channel vegetation survey, described in Chapter 4, section 4.2.1 are presented in Table 5.14.

It can be gathered from the channel survey results (Table 5.14) that, while there is some degree of progressive change in channel morphology downstream in well vegetated channels, the unvegetated ones show no systematic change. It is only sites 7 and 10 in vegetated channels that are noted to deviate from this trend. This is attributed to vegetation removal from these sites that occurred after the expropriation of the former commercial farms. Besides, reach 2 of the unvegetated stream channel was characterised by valley-fill. This was discerned to be a product of high sediment yields from the adjacent gullied abandoned cultivation fields. Widespread channel degradation was noted as a characteristic feature of most of the stream channels in the traditional and betterment villages. Exemplified by sites 4 and 5 in the traditional villages, this is a direct

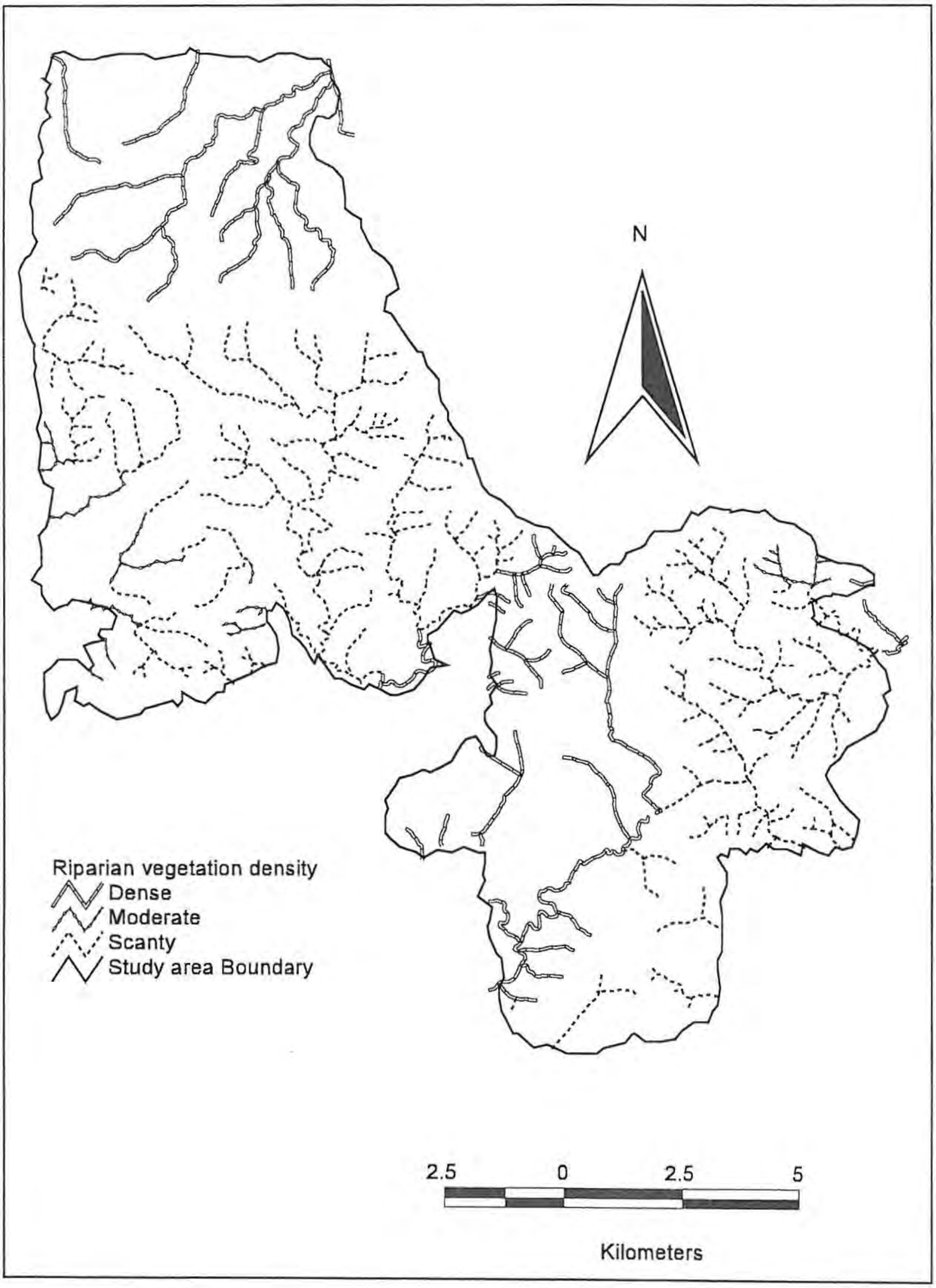

Figure 5.24 Variation in riparian vegetation density in the study area.

Table 5.14 Results of a comparative survey of the channel morphology of two adjacent streams (1996).

Vegetated Channel (Former commercial farmlands)								
Reach	Section	Macro channel			Active channel			Condition
		width (m)	max. depth (m)	capacity (m^2)	width (m)	average depth (m)	capacity (m^2)	
1	1	13.6	3.3	45.0	5.6	.56	3.1	eroding
1	2	9.8	c. 2.0	19.6	5.4	.63	3.4	aggrading
1	3	3.0	1.5	4.5	2.8	.71	2.0	stable
2	4	3.6	1.28	4.6	2.0	.49	1.0	aggrading
2	5	6.1	2.0	1.8	4.6	.59	2.7	eroding
2	6	3.6	.48	1.7	1.4	.50	0.2	stable eroding
2	7	5.5	1.8	9.9	0.7	.33	0.2	stable/eroding
2	8	1.9	1.13	2.1	1.5	.21	0.3	stable
2	9	2.2	1.6	3.5	1.7	.39	0.7	eroding
2	10	3.2	1.5	4.8	1.5	1.18	0.3	eroding
Unvegetated channel (Traditional villages)								
Reach	Section	Macro channel			Active channel			Condition
		width (m)	max. depth (m)	capacity (m^2)	width (m)	average depth (m)	capacity (m^2)	
1	1	4.1	1.48	6.1	2.4	0.39	0.9	eroding
1	2	4.9	1.44	7.1	2.8	0.17	0.5	eroding
1	3	5.6	1.53	8.6	3.1	0.27	0.8	eroding
1	4	side walls degraded			2.4	0.49	1.2	eroding
2	5	side walls degraded			8.2	0.17	1.4	aggrading
2	6	5.5	1.55	8.5	1.7	0.24	0.4	eroding
2	7	4.8	0.60	2.9	2.2	0.12	0.3	eroding

NB Reach 2 in the traditional villages was characterised by an incised valley fill.

result of riparian vegetation removal from these channels. The reverse is true of the densely vegetated stream courses in the former commercial farmlands.

5.4.3 Vegetation and land use change

As has been noted in section 5.4.1 above, the spatial distribution of vegetation categories varies with land tenure systems. The scanty grass cover category has, in particular, been noted as the predominant vegetated surface in the betterment and traditional villages at all the dates. A progressive decrease in the wooded grass category is noticeable in both tenure areas. An attempt is made here to link it to changes in the area's population and stocking rates.

Trends in change of the number of dwelling units in traditional and betterment villages have been presented in Figures 5.14 and 5.15. The predominance of the scanty vegetation cover at all dates cannot be ascribed to these trends, since that was the status quo even before the exponential population rise observed in both cases. Neither can the riparian vegetation removal, discussed above, be attributed to population trends. Evidence of this was deduced from the earliest set of aerial photographs analysed. Conversely, a progressive decrease in the wooded grass category with an increase in dwelling units in both tenure areas is conspicuous. The increased demand in wood fuel with population rise explains this. A historical perspective of the stocking rates in the area was obtained by way of participatory interviews with the elderly local residents. Notwithstanding the fact that these were not a primary component of the research design, information thus obtained indicates that stocking rates well above the veld carrying capacity have been maintained throughout the study period. The persistent dominance of the scanty vegetation category bears testimony to this. A reduction in livestock numbers from the 1950s is envisaged, as participants recalled large stock losses during the long and recurrent droughts that struck the area between 1950 and 1970. Brown (1971) reports a drastic reduction in stock numbers in the former Ciskei as a result of the 1968 acute drought. Efforts to obtain reliable livestock data for the study area were unsuccessful.

5.5 Soil erosion changes

5.5.1 Erosion changes in land tenure units

The spatial distribution of erosion classes at each date, designated according to Table 4.3 in Chapter 4, is presented in Figures 5.25 to 5.29. As can be discerned from these figures, all actual erosion classes (2-6) are confined to traditional and betterment villages at all dates. It is only class 1 (No erosion) that is prevalent on the former commercial farmlands. For this reason, the former commercial farms are left out from Tables 5.15 to 5.16 and Figures 5.30 and 5.33 showing the areal extent of erosion in tenure units.

Table 5.15 Erosion areal extent in traditional villages at each date.

Erosion class	Year and Erosion areal extent (Km^2) and (%)									
	1938		1954		1965		1975		1988	
	Km^2	%	Km^2	%	Km^2	%	Km^2	%	Km^2	%
1	69.5	82.1	67.5	79.7	62.7	74.0	63.0	74.4	63.0	74.4
2	13.5	15.9	12.6	14.9	11.6	13.7	9.2	10.9	2.4	2.8
3	1.4	1.7	3.0	3.5	7.7	9.1	2.1	2.5	11.6	13.7
4	0.2	0.2	1.5	1.8	2.4	2.8	8.3	9.8	5.3	6.3
5	0.1	0.1	0.1	0.1	0.3	0.4	2.0	2.4	2.3	2.7
6	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1

Table 5.16 Erosion areal extent in betterment villages at each date.
* = Introduction of betterment

Erosion class	Year and Erosion areal extent (Km^2) and (%)									
	1938		1954		1965*		1975		1988	
	Km^2	%	Km^2	%	Km^2	%	Km^2	%	Km^2	%
1	27.5	85.7	28.2	87.9	25.6	79.8	21.3	66.4	23.3	72.6
2	4.5	14	0.7	2.2	1.9	5.9	3.9	12.1	1.6	4.9
3	0.0	0.0	3.1	9.7	4.2	13.1	5.2	16.2	4.2	13.1
4	0.1	0.1	0.1	0.1	0.3	0.9	1.4	4.4	2.0	6.2
5	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.7	2.2
6	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.6	0.3	0.9

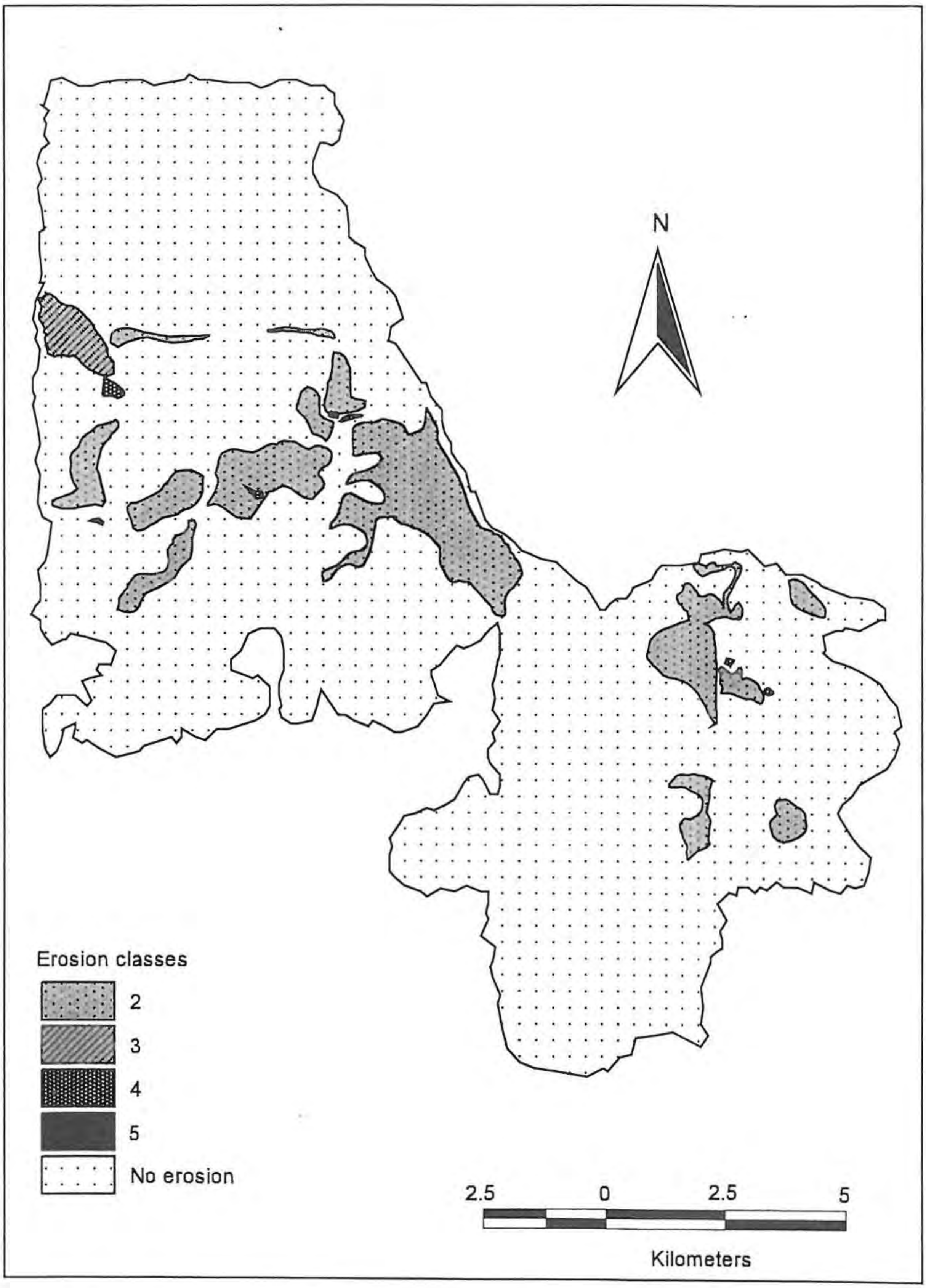

Figure 5.25 Erosion distribution (1938)

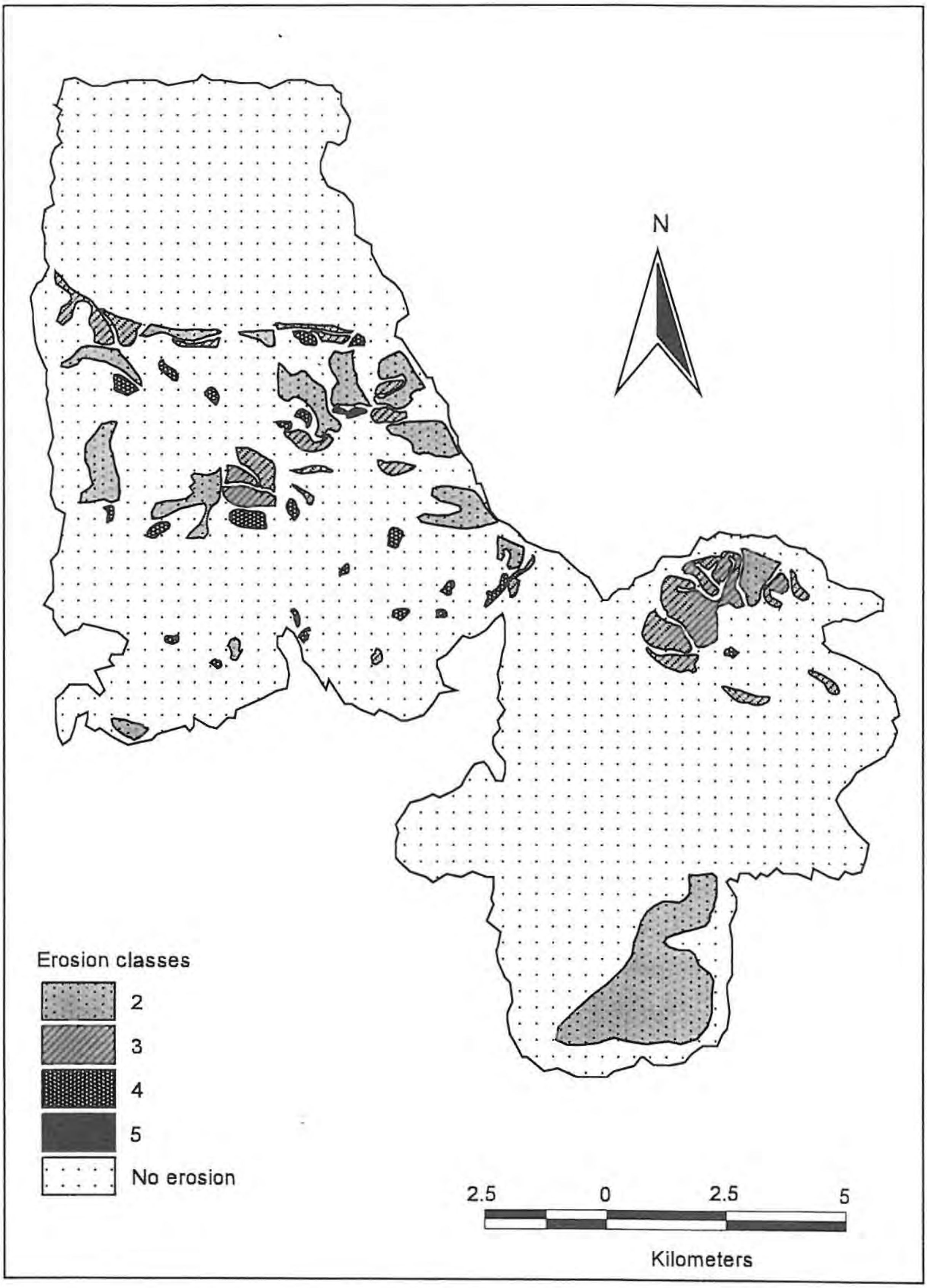

Figure 5.26 Erosion distribution (1954)

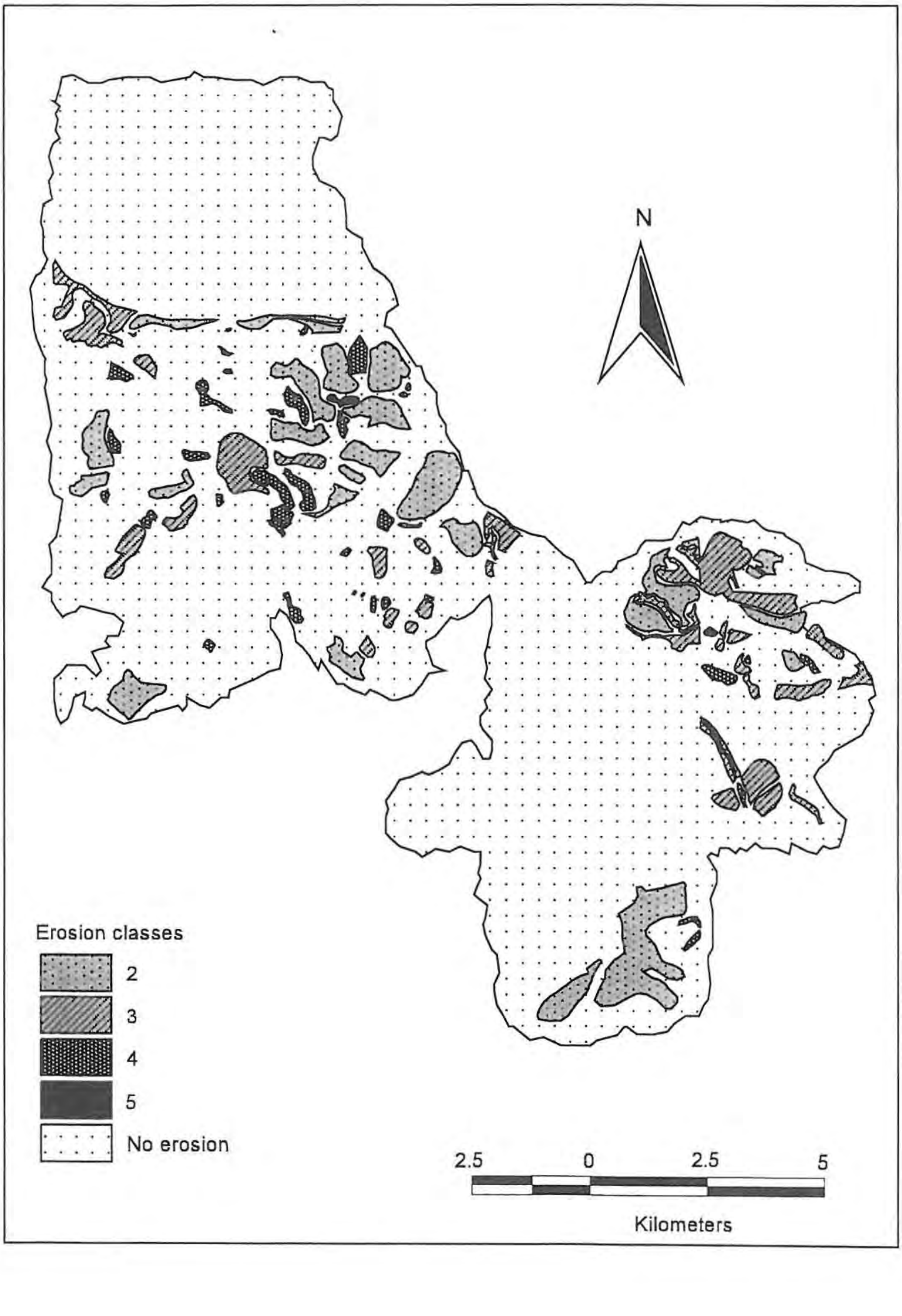

Figure 5.27 Erosion distribution (1965)

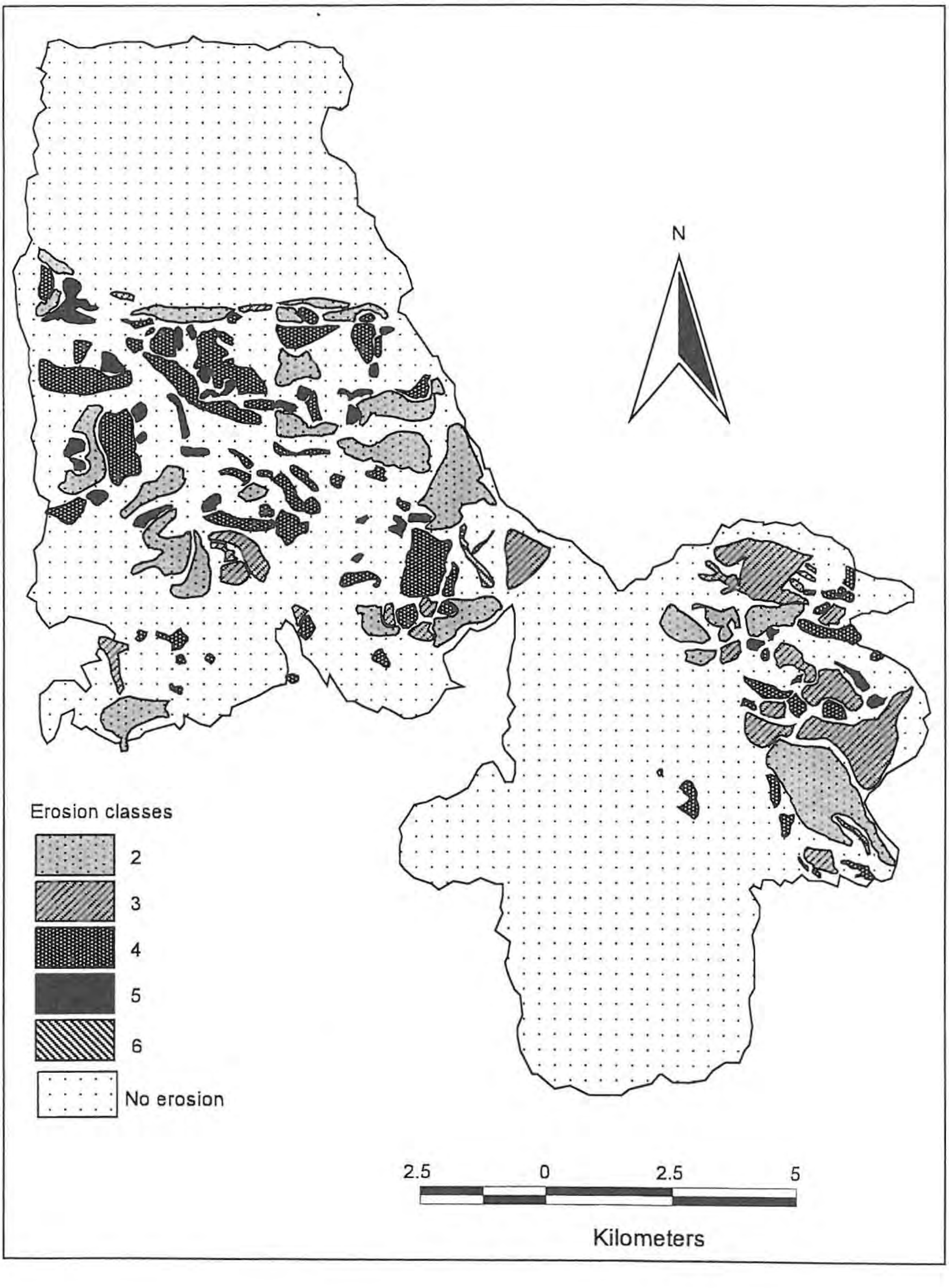

Figure 5.28 Erosion distribution (1975)

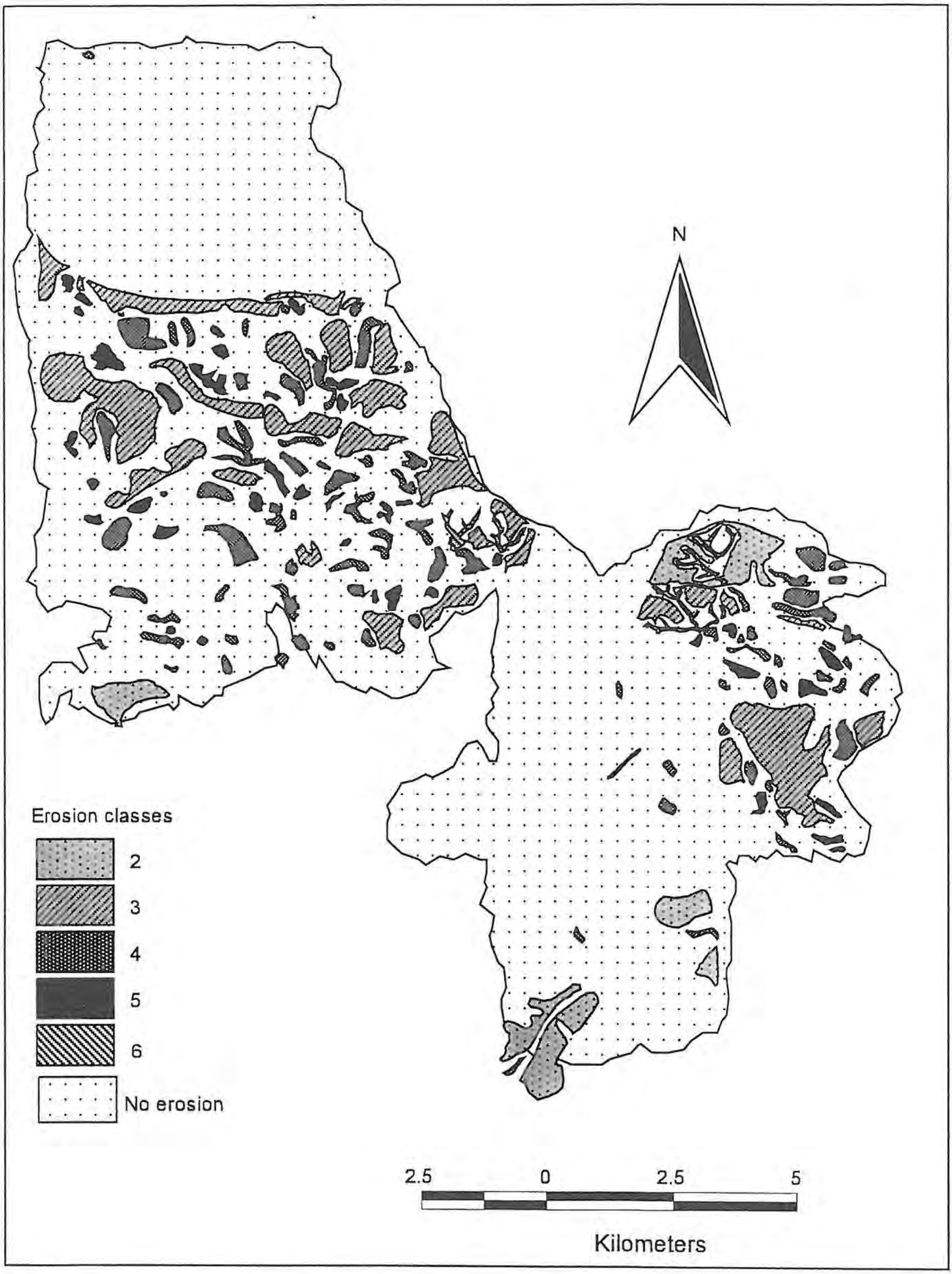

Figure 5.29 Erosion distribution (1988)

The total eroded and uneroded area in each tenure unit are depicted in Figures 5.30 and 5.31. For purposes of clear visual impression in the actual erosion classes (2 - 6), erosion class 1 (No erosion) is not indicated in Figures 5.32 and 5.33.

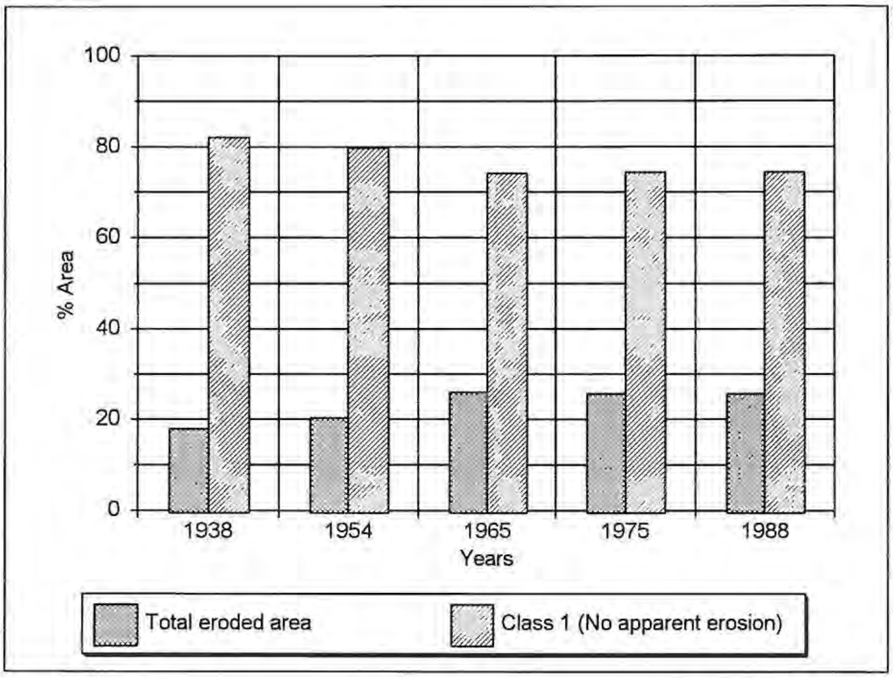

Figure 5.30 Areal extent of total eroded and uneroded land in traditional villages.

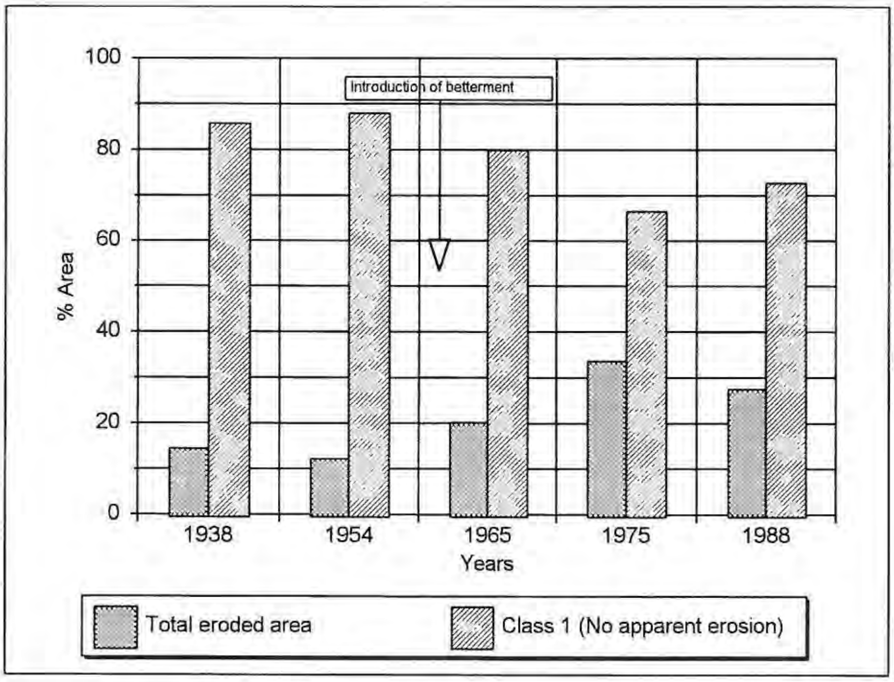

Figure 5.31 Areal extent of total eroded and uneroded land in betterment villages.

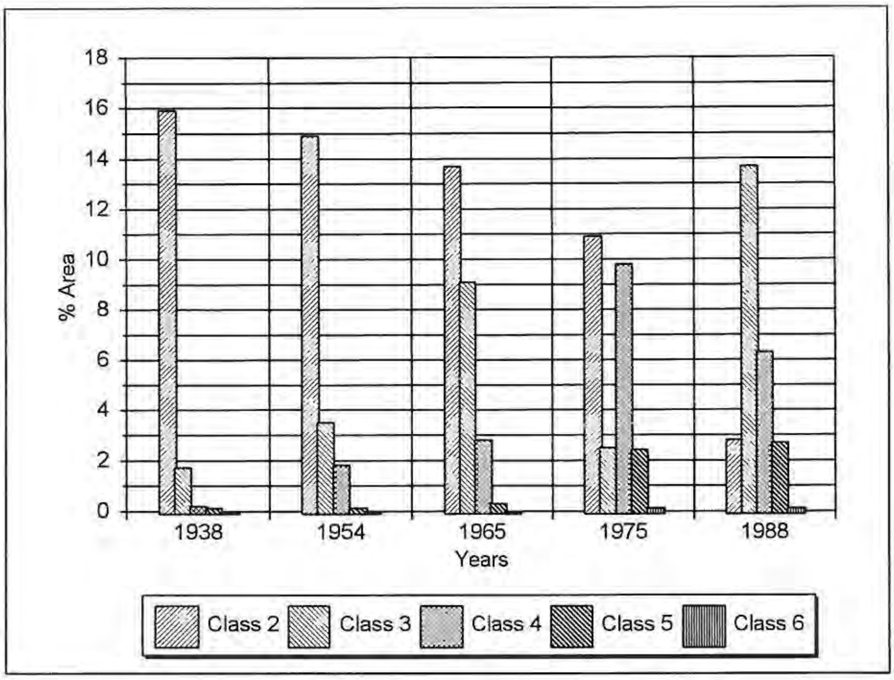

Figure 5.32 Erosion areal extent in traditional villages at each date.

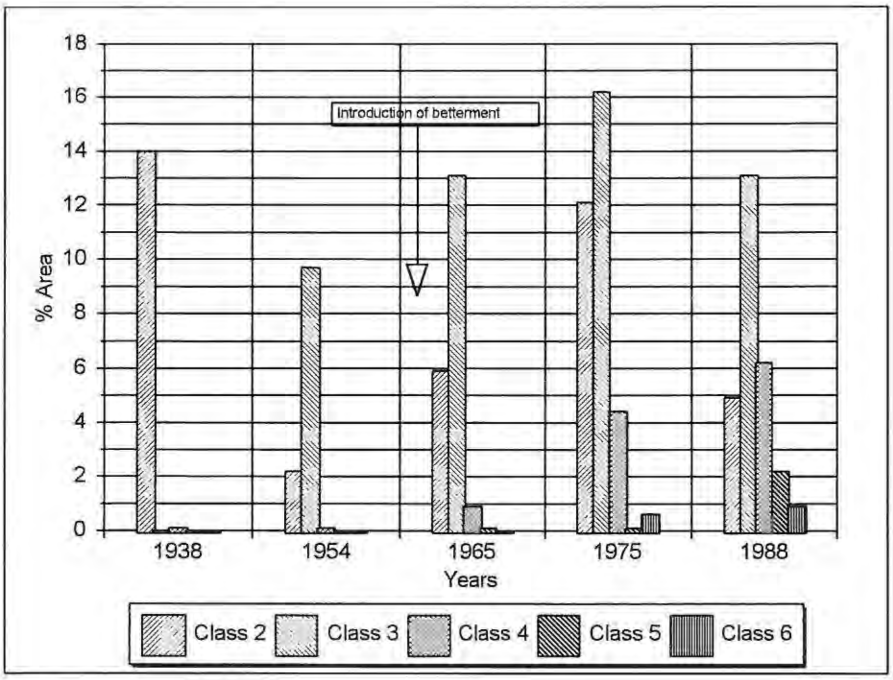

Figure 5.33 Erosion areal extent in betterment villages at each date.

Specific trends in erosion change in both traditional and betterment villages can be discerned from the data presented in the tables and figures above. A dramatic increase in the total eroded area of 134.7% between 1938 and 1975 was observed in the betterment villages as opposed to 44.7% in the traditional ones. A reduction of 18.5% and 1.4% respectively, was recorded for the remainder of the study period. The intensification of erosion into more severe forms with time in both tenure units is the more significant overall trend. An expansion in the areal extent of classes 4 and 5 of up to 5 and 2 times respectively was recorded in both tenure units. Erosion class 2 which is noted as the dominant erosion form by 1938 in both areas diminishes gradually in areal extent for the rest of the study period. The period between 1965 and 1975 is singled out as an episode characterised by a drastic increase in the morphologically conspicuous erosion forms. The combined areal extent of erosion classes 4 and 5 rose by 281.4% (from 2.7 Km^2 to 10.3 Km^2) and 275.0% (from 0.4 Km^2 to 1.5 Km^2) in the traditional and betterment areas respectively. The interplay of different variables that could lead to such a dramatic increase in erosion are investigated in the sections of this chapter that follow.

As already pointed out in Chapter 3 section 3.8, the rationale behind the establishment of the betterment villages in the study area was, *inter alia*, to curb the deteriorating soil conditions. From 1965, three years after the programme's implementation, severe erosion forms which were hitherto very limited in areal extent expanded considerably (See Table 5.16). Further expansion in them was noted during field surveys although this could not be reliably quantified. On the whole, a 25% increase in the total eroded area was observed in the betterment villages between 1965 and 1988, thus signifying the failure of the programme in this regard.

5.5.2 Erosion changes and rainfall variations

Relationships between trends in erosion change and rainfall variations are examined in this section. Distinct dry and wet phases and interludes of intense rainfall were identified by analysing the annual, monthly and daily rainfall data series. Minor increases in all erosion forms, except class 2, were observed during the 1938-54 and 1954-65 fairly wet phases. The period between 1965 and 1975 was established as an episode of dramatic increase in severe erosion forms. This increase is noted to coincide with a period of extreme rainfall events and extensive floods of the early 1970s. As can be noted from Table 5.4 and Figure 5.4, these events occured after an extremely dry period. By implication, erosion activity is highest when an extremely wet phase follows a dry one. The scenario described in section 5.2, in which the highest monthly rainfall peak occured in the middle of a dry season could have triggered off even higher erosion rates.

Such extreme rainfall events alone, however, might not fully explain the rapid increase in serious erosion forms observed. For instance, the extreme peaks of 1922 and 1953 did not appear to have caused significant erosion. It would require an interplay of different variables to reach such a threshold for increased erosion. The interaction between rainfall variations and other factors, notably, anthropogenic and physical ones and its implications on erosion increase is explored further in the subsequent sections.

5.5.3 Erosion and land use change

The areal extent of each erosion class on different land use types was determined by overlying land use, erosion, and tenure maps, using the 'overlay' technique in PC ARC/INFO GIS. The frequency of occurrence of erosion on specific land use types in both the traditional and betterment villages was expressed as a percentage of the total areal extent of each erosion class at each date. The relationship between different erosion forms and specific land use types could thus be established on the basis of the frequency of the former on the latter. The Tables 5.17 to 5.26 show the areal extent and frequency of each erosion class on different land use types in both traditional and betterment villages.

Table 5.17 Erosion frequency on different land use types in traditional villages (1938).

Erosion class	Land use type, Erosion areal extent (Km^2) and Frequency (%)							
	Cultivation		Grazing		*Ab. Cultivation		Others	
	(Km^2)	%	(Km^2)	%	(Km^2)	%	(Km^2)	%
2	0.3	2.2	12.2	90	0.0	0.0	1.0	7.4
3	0.1	7.1	1.3	92	0.0	0.0	0.0	0.0
4	0.0	0.0	0.1	50	0.1	50	0.0	0.0
5	0.0	0.0	0.0	0.0	0.1	100	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total (Km^2)	0.4		13.6		0.2		1.0	

Table 5.18 Erosion frequency on different land use types in traditional villages (1954).

Erosion class	Land use type, Erosion areal extent (Km^2) and Frequency (%)					
	Cultivation		Grazing		*Ab. Cultivation	
	(Km^2)	%	(Km^2)	%	(Km^2)	%
2	2.0	15.8	10.6	84.1	0.0	0.0
3	0.9	30	2.1	70.0	0.0	0.0
4	0.0	0.0	1.0	66.6	0.5	33.3
5	0.0	0.0	0.0	0.0	0.1	100
6	0.0	0.0	0.0	0.0	0.0	0.0
Total (Km^2)	3.0		13.9		0.6	

Table 5.19 Erosion frequency on different land use types in traditional villages (1965).

Erosion class	Land use type, Erosion areal extent (Km^2) and Frequency (%)							
	Cultivation		Grazing		*Ab. Cultivation		Others	
	(Km^2)	%	(Km^2)	%	(Km^2)	%	(Km^2)	%
2	0.5	6.9	9.5	81.9	0.4	3.4	1.2	10.3
3	0.4	5.2	5.1	66.2	1.4	18.1	0.8	10.4
4	0.0	0.0	1.0	41.7	1.4	58.3	0.0	0.0
5	0.0	0.0	0.1	33.3	0.2	66.7	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total (Km^2)	0.9		15.7		3.4		2.0	

Table 5.20 Erosion frequency on different land use types in traditional villages (1975).

Erosion class	Land use type, Erosion areal extent (Km^2) and Frequency (%)							
	Cultivation		Grazing		*Ab. Cultivation		Others	
	(Km^2)	%	(Km^2)	%	(Km^2)	%	(Km^2)	%
2	2.3	2.5	5.5	59.8	0.1	1.1	1.3	14.1
3	0.5	23.8	0.8	38.1	0.1	4.8	0.7	33.3
4	0.9	10.8	1.5	18.1	5.9	71.1	0.0	0.0
5	0.1	5.0	0.4	20.0	1.4	70.0	0.1	5.0
6	0.0	0.0	0.1	100	0.0	0.0	0.0	0.0
Total (Km^2)	3.8		8.3		7.5		2.1	

Table 5.21 Erosion frequency on different land use types in traditional villages (1988).

Erosion class	Land use type, Erosion areal extent (Km^2) and Frequency (%)							
	Cultivation		Grazing		*Ab. Cultivation		Others	
	(Km^2)	%	(Km^2)	%	(Km^2)	%	(Km^2)	%
2	0.0	0.0	1.9	79.2	0.0	0.0	0.5	20.8
3	0.7	6.0	6.8	58.6	2.2	19	1.9	16.4
4	0.9	17.0	1.2	22.6	3.2	60.4	0.0	0.0
5	0.1	4.3	0.3	13.4	1.9	82.6	0.0	0.0
6	0.0	0.0	0.1	100	0.0	0.0	0.0	0.0
Total (Km^2)	1.8		10.4		7.4		2.4	

Table 5.22 Erosion frequency on different land use types in betterment villages (1938).

Erosion class	Land use type, Erosion areal extent (Km^2) and Frequency (%)							
	Cultivation		Grazing		*Ab. Cultivation		Others	
	(Km^2)	%	(Km^2)	%	(Km^2)	%	(Km^2)	%
2	0.1	2.2	2.9	64	0.0	0.0	1.5	33.3
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.1	100	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total (Km^2)	0.1		2.9		0.1		1.5	

Table 5.23 Erosion frequency on different land use types in betterment villages (1954).

Erosion class	Land use type, Erosion areal extent (Km^2) and Frequency (%)							
	Cultivation		Grazing		*Ab. Cultivation		Others	
	(Km^2)	%	(Km^2)	%	(Km^2)	%	(Km^2)	%
2	0.0	0.0	0.5	71	0.0	0.0	0.2	28.6
3	0.0	0.0	2.0	64.5	0.0	0.0	1.1	35.5
4	0.0	0.0	0.0	0.0	0.1	100	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total (Km^2)	0.0		2.5		0.1		1.3	

Table 5.24 Erosion frequency on different land use types in betterment villages (1965).

Erosion class	Land use type, Erosion areal extent (Km^2) and Frequency (%)							
	Cultivation		Grazing		*Ab. Cultivation		Others	
	(Km^2)	%	(Km^2)	%	(Km^2)	%	(Km^2)	%
2	0.0	0.0	1.8	94.7	0.0	0.0	0.1	5.3
3	0.1	3.2	2.9	69	0.3	7.1	0.9	21.4
4	0.0	0.0	0.1	33	0.2	66.7	0.0	0.0
5	0.0	0.0	0.0	0.0	0.1	100	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total (Km^2)	0.1		4.8		0.6		1.0	

Table 5.25 Erosion frequency on different land use types in betterment villages (1975).

Erosion class	Land use type, Erosion areal extent (Km^2) and Frequency (%)							
	Cultivation		Grazing		*Ab. Cultivation		Others	
	(Km^2)	%	(Km^2)	%	(Km^2)	%	(Km^2)	%
2	0.0	0.0	3.7	94.8	0.1	2.6	0.1	2.6
3	1.5	28.8	1.7	32.7	1.6	30.8	0.4	7.7
4	0.1	7	0.4	28.6	0.7	50	0.2	14.3
5	0.0	0.0	0.0	0.0	0.1	100	0.0	0.0
6	0.0	0.0	0.2	100	0.0	0.0	0.0	0.0
Total (Km^2)	1.6		6.0		2.5		0.7	

Table 5.26 Erosion frequency on different land use types in betterment villages (1988).

Erosion class	Land use type, Erosion areal extent (Km^2) and Frequency (%)							
	Cultivation		Grazing		*Ab. Cultivation		Others	
	(Km^2)	%	(Km^2)	%	(Km^2)	%	(Km^2)	%
2	0.0	0.0	1.6	100	0.3	7.1	0.0	0.0
3	0.1	2.4	3.0	71	1.0	50	0.1	2.4
4	0.0	0.0	0.7	35	1.3	65	0.0	0.0
5	0.0	0.0	0.1	14.2	0.6	85.7	0.0	0.0
6	0.0	0.0	0.3	100	0.0	0.0	0.0	0.0
Total (Km^2)	0.1		5.7		3.2		0.1	

A similar pattern of distribution of erosion classes on the respective land use types, in both the traditional and betterment villages, is discernible from the data presented. Extremely high frequencies of erosion classes 2, 3, and 6 (riverbank and footpath erosion) can be noted on grazing land in both instances at all the dates. The same trend is noticeable with erosion classes 4 and 5 on abandoned cultivated land. Low to moderate frequencies of erosion in all classes are observed on cultivated land in both areas at each date. Such a pattern of erosion distribution might, to some extent, reflect the influence of specific land use types. Given such an analogous distribution pattern, erosion occurrence on each land use type in both tenure units was combined to produce Figures 5.34 to 5.36 showing erosion frequency.

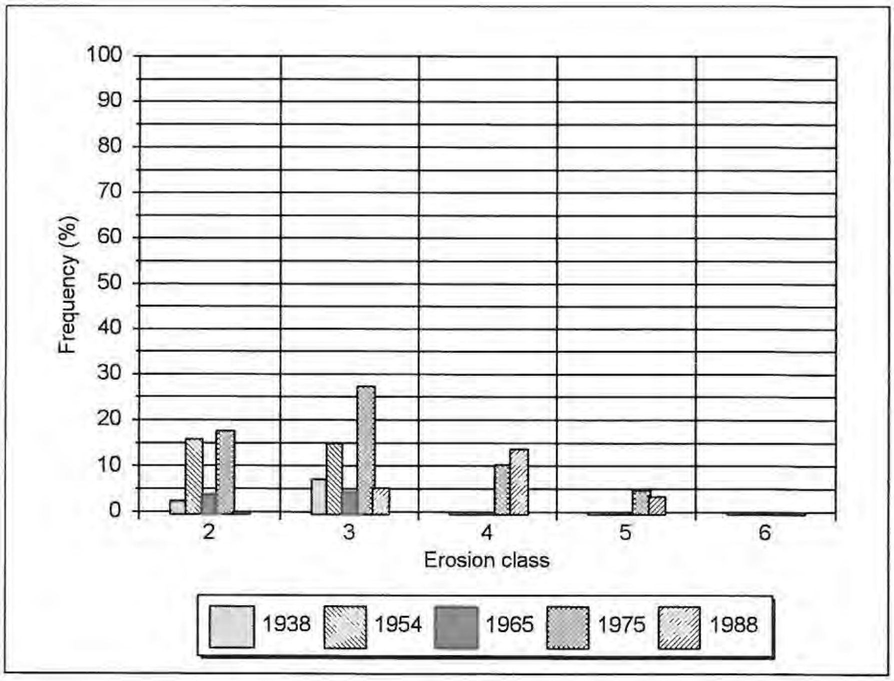

Figure 5.34 Erosion frequency on cultivated land.

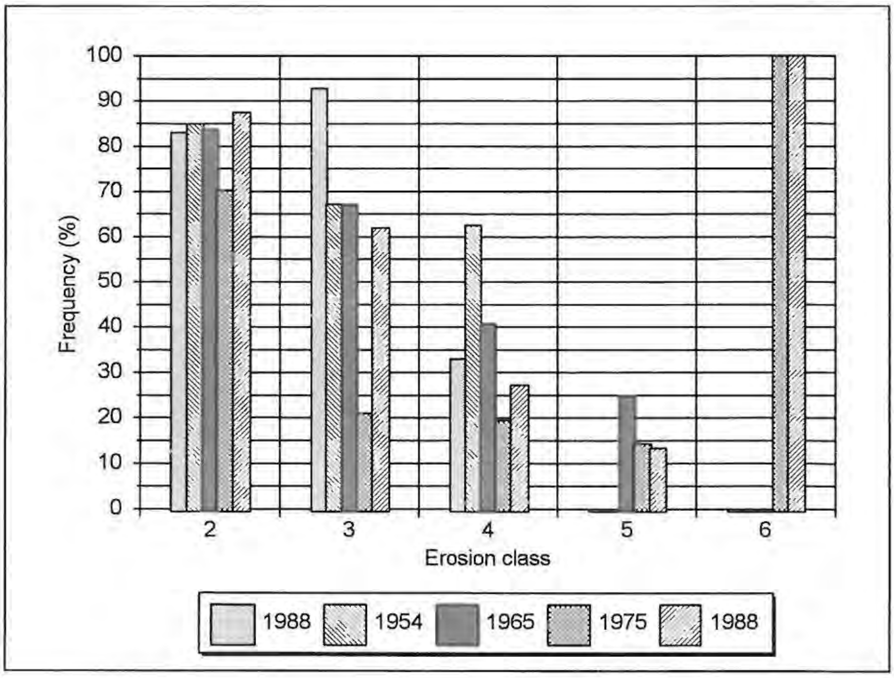

Figure 5.35 Erosion frequency on grazing land.

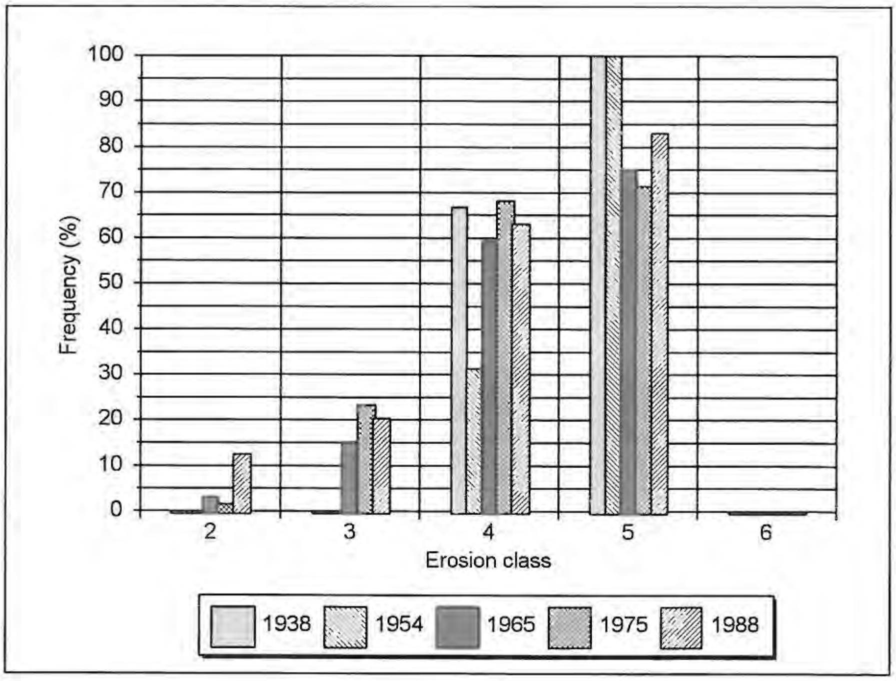

Figure 5.36 Erosion frequency on abandoned cultivated land

In order to verify whether differences in the observed frequencies of erosion on land use types occurred by chance or are significant enough to reflect the influence of specific land use types, a chi-squared test was conducted. In this instance, it is postulated that the expected frequencies of erosion should be proportional to the land area of each land use category. The erosion classes were grouped into two categories: moderate and severe forms. Classes 2 and 3 constituted the former, while 4 and 5, the latter group. Erosion class 6 was not included in this analysis since it is observed on no land use type other than grazing. The results of this statistical test on both erosion groups are presented in Tables 5.27 and 5.28. As a rule of thumb, the test does not work if the expected frequency in any of the categories is less than 5 (Gregory 1964). This explains why the test was not conducted, or conducted separately at the dates indicated in Tables 5.27 and 5.28 below.

Table 5.27 Significance of differences in the distribution of moderate erosion forms on land use types.

Year	X^2 value	Significant
1938	82.8	Yes
1954	30.6	Yes
1965	59.9*, 91.5*	Yes
1975	36.9	Yes
1988	72.6	Yes

*Test was done separately on cultivation and grazing, cultivation and abandoned cultivation, due to the expected frequency of less than 5 in the latter category.

Table 5.28 Significance of differences in the distribution of severe erosion forms on land use types.

Year	X^2 value	significant
1938	*	
1954	143.2	Yes
1965	65.8	Yes
1975	124.2	Yes
1988	25	Yes

* Test was not done due to the expected frequency of less than 5 in the abandoned cultivation category.

It can be deduced from the results of the chi- squared test that variations in erosion distribution on the respective land use types are highly significant at all dates. On the basis of these results, it can be inferred that the land use types on which high erosion frequencies are observed, influenced the intensity of occurrence. Erosion classes 2, 3 and 6 could be associated with grazing and class 4 and 5 with abandoned cultivation fields. There is, thus, a need for closer scrutiny of the factors that caused such variations. These will be discussed in Chapter 6.

5.5.4 Erosion distribution and physical factors

An identification of where different erosion classes occur in relation to physical factors such as slope position and geological structures may create a deeper understanding of the combined influence of the human and physical landscape on erosion. The relationship between the actual erosion classes (2 - 6), slope position and local geology in both the traditional and betterment areas is examined in this section.

For purposes of examining erosion occurrence with respect to slope position, the slope categories examined in section 5.1.1 were grouped into two: gentle upland slopes and the steep bottomland slopes. The former category consists of the <4% - 9% slope classes while the latter consists of 10% - >20% classes (See figures 3.2 and 3.3). By overlaying erosion maps at each date with the slope map, erosion distribution in each class at different slope positions was quantified. The results are presented in Tables 5.29 to 5.33.

Table 5.29 Erosion distribution with respect to slope position (1938).

Slope position	Erosion class areal extent (Km^2)				
	2	3	4	5	6
Gentle uplands	8.9	0.3	0.1	0.0	0.0
Steep bottomlands	9.0	1.2	0.2	0.1	0 .0

Table 5.30 Erosion distribution with respect to slope position (1954).

Slope position	Erosion class areal extent (Km^2)				
	2	3	4	5	6
Gentle uplands	11.1	2.9	0.8	0.0	0.0
Steep bottomlands	2.1	3.2	0.8	0.1	0.0

Table 5.31 Erosion distribution with respect to slope position (1965).

Slope position	Erosion class areal extent (Km^2)				
	2	3	4	5	6
Gentle uplands	8.7	5.6	1.3	0.1	0.0
Steep bottomlands	4.8	6.3	1.4	0.3	0.0

Table 5.32 Erosion distribution with respect to slope position (1975).

Slope position	Erosion class areal extent (Km^2)				
	2	3	4	5	6
Gentle uplands	7.2	3.0	3.5	0.7	0.0
Steep bottomlands	5.9	4.2	6.8	1.3	0.3

Table 5.33 Erosion distribution with respect to slope position (1988).

Slope position	Erosion class areal extent (Km^2)				
	2	3	4	5	6
Gentle uplands	3.4	9.4	2.9	0.7	0.0
Steep bottomlands	0.5	6.4	4.4	2.6	0.4

Variations in the distribution of erosion classes, except class 6, are discernible on both slope groups. Whereas no specific trend in the distribution of erosion classes 2, 3, and 4 is noticeable, class 5 appears to be better represented on the bottomland slopes. The significance of the differences in erosion class distribution between the gentle upland and steep bottomland slopes at all dates was assessed using the F-test . The results of this test are given in Table 5.34.

Table 5.34 Significance of differences in erosion distribution per class between the gentle upland and steep bottomland slopes.

Erosion class	F value	*Significant
2	1.35	No
3	2.46	No
4	3.81	No
5	8.68	Yes

*Significance determined at 0.05 level. Critical value = 5.32

The results of the F-test indicate that there is no significant functional relationship between slope position and erosion classes 2, 3 and 4. Conversely, there is a clear-cut influence of slope position on the occurrence of erosion class 5 (intricate gullies and gully remnants) which is significantly associated with the steep bottomland slopes. Despite the fact that the soils of the catchment are predominantly of the shallow Mispah form, erosion sites with gullies as deep as 6 m were observed on the steep bottomland slopes during field surveys. All of these sites were identified from aerial photographic evidence as abandoned cultivation plots. It was confirmed during field surveys that evidence of earlier gully development such as stone lines, artefacts and aggradational phases are non-existent at these sites. By implication, these gully sites do not predate anthropogenic influence.

An overlay in PC ARC/INFO of the erosion distribution map of 1988 and the soil map of the study area indicated that 84.4% of the pockets of colluvium accumulation are truncated by intricate gullies and gully remnants. These pockets were established as the location of the deep gully sites cited above. A chain of events that commenced, most likely, from the beginning of this century, triggered off a rapid and unprecedented incision of gullies into the unconsolidated colluvium. This chain entailed the removal from the erosion sites of protective vegetation cover for cultivation, subsequent abandonment probably during the dry period and augmentation of geomorphic activity during the wet period which followed. Threshold values were thus reached and exceeded as a culmination of the latter event.

The progressive development of three of these gully sites, in particular, was monitored as a time sequence from the aerial photographs. Their erosion and land use status at each date were recorded from the date they were morphologically conspicuous. This is presented in Table 5.35.

Table 5.35 Progressive development of gullies at three chosen gully sites.

Site	Date	Erosion status	Land use
1	1938	Sheet and slight rill(S2&R1)	Cultivation
	1954	Slight rill (R1)	Cultivation
	1965	Severe rill (R4)	Ab. cultivation
	1975	Intricate Gullies (G5)	Ab. cultivation
	1988	Gully remnants (GR)	Ab.cultivation
2	1938	Moderate rill (R2)	Ab.cultivation
	1954	Moderate rill (R2)	Ab cultivation
	1965	Severe rill (R4)	Ab. cultivation
	1975	Intricate Gullies (G5)	Ab. cultivation
	1988	Intricate Gullies (G5)	Ab. cultivation
3	1938	Slight rill (R1)	Cultivation
	1954	Slight rill (R1)	Cultivation
	1965	Severe rill (R4)	Ab. cultivation
	1975	Intricate gullies (G5)	Ab. cultivation
	1988	Gully remnants	Ab.cultivation

The influence of the study area's local geology on erosion distribution is another aspect examined in this section. The Ecca and Beaufort groups, as already noted, are the major rock types in terms of areal expanse. Figure 5.37 shows erosion occurrence on them, expressed as a percentage of the total eroded area at each date.

As can be gathered from Figure 5.37, on average 90% of the total eroded area at each date is prevalent on the Ecca group. The traditional and betterment areas to which erosion is confined happen to lie, predominantly on this group of rocks (See Table 5.2). Notwithstanding the differences in land management, the increased area of the erosion-prone Ecca group must have impacted on the high prevalence of erosion in these areas. The implications of geology on erosion are discussed in section 6.2 of the discussion chapter.

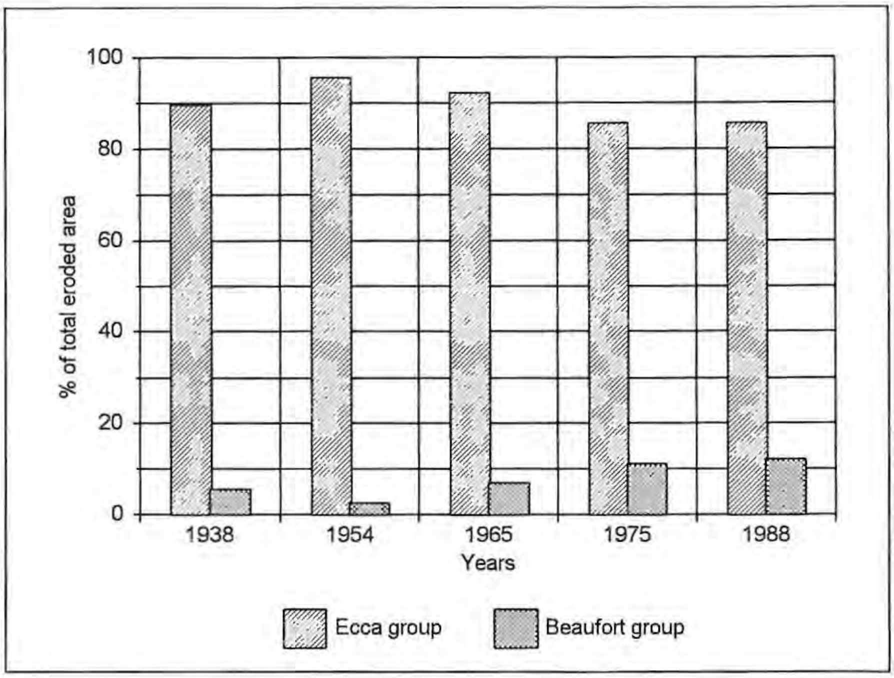

Figure 5.37 Erosion frequency on rock groups

The location of intricate gullies and gully remnants in relation to the dolerite sill referred to in section 3.3 is another intriguing feature. Using the "ARC/INFO buffer" facility, the deep gully erosion sites alluded to earlier in this section were noted to lie on the downslope edge of the dolerite sill and are incised in colluvium. This was also verified during groundtruthing exercises. This sill was extrapolated in the field as the upslope limit of these erosion sites.

It was discerned in the field that the transverse dolerite sill marks a break in the slopes on which these gully erosion sites are situated. Given the relationship explained above, it is suggested that the downslope boundary of the sill forms the zone of both colluvium accumulation and gully initiation. Figure 5.38, which is a profile of one of the slopes on which these gully sites are located, illustrates this.

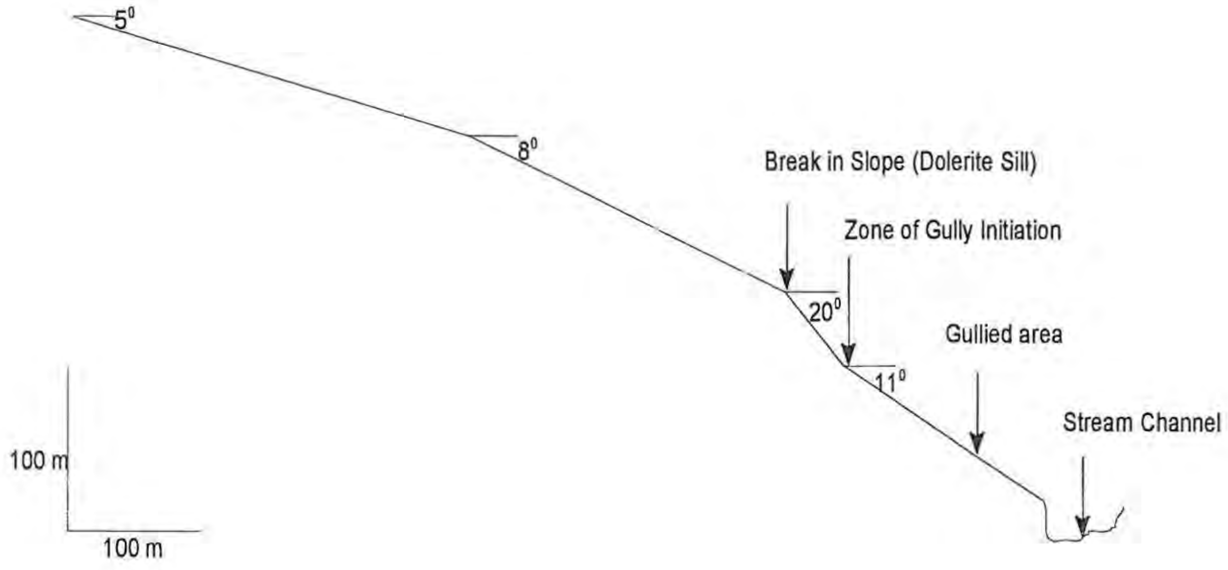

Figure 5.38 Slope profile for one of the gully sites described in section 5.5.4

5.5.5 Erosion distribution on vegetated surfaces

Erosion occurrence on the respective categories of vegetated surfaces at each date is presented in Tables 5.36 to 5.40. The open woodland category is not included in these categories, since it was observed to be non-existent in the traditional and betterment areas throughout the period of study. The frequency of erosion was expressed as a percentage of the total areal extent of each erosion class at each date.

Table 5.36 Erosion frequency on vegetated surfaces* (1938).

Erosion class	Vegetation category , Erosion areal extent and Frequency (%)							
	Scanty cover		Moderate cover		Wooded grass		Other land uses	
	(Km^2)	%	(Km^2)	%	(Km^2)	%	(Km^2)	%
2	14.6	81.1	0.0	0.0	0.3	1.7	3.1	17.2
3	1.3	92.9	0.0	0.0	0.0	0.0	0.1	7.1
4	0.1	33.3	0.0	0.0	0.0	0.0	0.2	66.7
5	0.0	0.0	0.0	0.0	0.0	0.0	0.1	100.0
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

* All vegetated surfaces were categorised as grazing land.

Table 5.37 Erosion frequency on vegetated surfaces (1954).

Erosion class	Vegetation category , Erosion areal extent and Frequency (%)							
	Scanty cover		Moderate cover		Wooded grass		Other land uses	
	(Km^2)	%	(Km^2)	%	(Km^2)	%	(Km^2)	%
2	11.1	83.5	0.1	0.8	0.0	0.0	2.1	15.8
3	5.4	88.5	0.1	1.6	0.0	0.0	0.6	9.8
4	1.0	62.5	0.0	0.0	0.0	0.0	0.6	37.5
5	0.0	0.0	0.0	0.0	0.0	0.0	0.1	100.0
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 5.38 Erosion frequency on vegetated surfaces (1965).

Erosion class	Vegetation category , Erosion areal extent and Frequency (%)							
	Scanty cover		Moderate cover		Wooded grass		Other land uses	
	(Km^2)	%	(Km^2)	%	(Km^2)	%	(Km^2)	%
2	12.0	88.9	0.0	0.0	0.0	0.0	1.5	11.1
3	8.0	67	0.0	0.0	0.0	0.0	3.9	32.8
4	1.0	37.0	0.0	0.0	0.0	0.0	1.7	63.0
5	0.1	25.0	0.0	0.0	0.0	0.0	0.3	75
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 5.39 Erosion frequency on vegetated surfaces (1975).

Erosion class	Vegetation category , Erosion areal extent and Frequency (%)							
	Scanty cover		Moderate cover		Wooded grass		Other land uses	
	(Km^2)	%	(Km^2)	%	(Km^2)	%	(Km^2)	%
2	8.9	67.9	0.0	0.0	0.1	0.8	4.1	31.3
3	4.1	56.2	0.0	0.0	0.0	0.0	3.2	43.8
4	1.9	19.6	0.02	0.2	0.03	0.3	7.75	79.9
5	0.4	19.0	0.0	0.0	0.0	0.0	1.7	81.0
6	0.3	100.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 5.40 Erosion frequency on vegetated surfaces (1988).

Erosion class	Vegetation category , Erosion areal extent and Frequency (%)							
	Scanty cover		Moderate cover		Wooded grass		Other land uses	
	(Km^2)	%	(Km^2)	%	(Km^2)	%	(Km^2)	%
2	4	100	0.0	0.0	0.0	0.0	0.0	0.0
3	9.3	58.9	0.5	3.2	0.0	0.0	6.0	37.9
4	1.4	19.2	0.4	5.5	0.0	0.0	5.5	75.3
5	0.3	10.0	0.1	3.3	0.0	0.0	2.6	86.7
6	0.4	100.0	0.0	0.0	0.0	0.0	0.0	0.0

It is evident from the data presented above that erosion occurrence on vegetated surfaces, particularly class 2, is largely restricted to the scanty vegetation category. The reverse is true of the wooded grass and open woodland categories. This further confirms the vulnerability of less vegetated surfaces to high erosion rates. Notwithstanding this, the possibility of an increased cover concealing erosion, especially class 2 must not be overlooked. This may, to some extent account for the lack of recorded erosion on the commercial farms. As pointed out by Trimble (1990), vegetative cover is the variable controlling erosional activity which is most subject to human manipulation. The role of man in the vegetation- erosion interaction will be examined further in the discussion Chapter 6.

The results presented in this chapter portray a sequence of events that led to the present degradation status of the study area. An interplay of different factors resulting in degradation inducement has been examined. A discussion of the results is made in the subsequent chapter.

6. Discussion

In the discussion chapter, an attempt is made to elucidate the trends in change of land degradation presented in Chapter 5. The interaction between physical and human factors is scrutinised, using the relationships established between them in the results chapter as a point of departure. It is on the basis of this scrutiny that recommendations with regard to remedial measures are made. Conclusions from the study are drawn in Chapter 7.

6.1 Physiographic homogeneity

The physiographic homogeneity of the study area was established in some respects, after analysing its physical characteristics in the results chapter. However, marked variations in their response to human and geomorphic activity have been identified. This is in conformity with the observation by Amerman (1965), quoted by Gregory and Walling (1973, p.299) that, "Any catchment larger than 1.2 to 2.0 hectares must be viewed as physically complex, containing a number of units, each exhibiting a different response." "The magnitude and nature of any variation is most conveniently assessed by consideration of catchment dynamics which are surrogates for the pattern of operation of the catchment" (Gregory and Walling 1973, p.298).

The results have displayed that the magnitude and nature of variation of land degradation is a consequence of a complex interaction between physical and anthropogenic variables. Subjected to different forms of land management, inherent physical attributes such as slope gradient, geology and soils come out clearly as controls to the spatial and temporal contrasts of such phenomena as land degradation. Differences in land tenure systems, however, emerge as the overriding factor that has determined the rate at which intrinsic characteristics respond to land degradation. The influence of physical characteristics on erosion distribution is discussed below.

6.2 Soil erosion changes

6.2.1 Erosion distribution and physical factors

The distribution of some erosion types was noted to reflect the effect of slope position on erosion. This was verified by the statistically significant relationship between the steep bottomlands and erosion class 5. This implies that there is adequate accumulation of colluvial and alluvial material in the bottomlands for deep gullies to develop, as opposed to the uplands. Hence, gully depth at the sites referred to in section 5.4.4 of the results chapter is a function of sediment accumulation. This is in keeping with the findings of Cobban and Weaver (1993). They noted that the restriction of gullies to alluvial fans in Tsolwana game reserve, former Ciskei, was due to the storage of sediments of up to 6 metres deep in the fans.

The interaction chain is complicated further by the sediment characteristics of some areas of the steep bottomlands. The association between intricate gullies and the unconsolidated colluvium and alluvium accumulation in these areas was identified, using the "overlay facility" in PC ARC/INFO, as the dominant factor that influenced the rapid development of intricate gullies at specific sites. The potential erodibility of colluvium has been substantiated (Oudtshoorn 1988). The removal of vegetation for cultivation from these highly susceptible sites triggered off unprecedented erosion rates. The three gully sites described in section 5.5.5 demonstrate the rapidity with which threshold values for gully development in such material are reached. Field observations indicate that these gully sites are still actively eroding. Thus, gullying at these sites is a response to both intrinsic and extrinsic thresholds.

The higher prevalence of erosion on the soils derived from the Ecca group of rocks than those of Beaufort group, indicates the bearing geology has on erosion distribution. This confirms the observation by Johnstone (1981) regarding the highly dispersive nature, susceptibility to compaction and erosion of the soils derived from the Ecca group. Given such inherent vulnerability to erosion, the predominance of the Ecca group in the traditional and betterment villages is an additional factor that promoted erosion.

The spatial relationship between the gully sites and a dolerite sill illustrates further the influence of geology on erosion. It is discernible from field surveys that the dolerite sill marks the boundary of a zone of colluvium and alluvium accumulation and gully initiation. The break in slope formed by this feature (Figure 5.38), to an extent acted as a knickpoint at which incision into the unvegetated and unconsolidated colluvium commenced. The implications of this relationship to erosion remedial measures and future land management strategies are crucial. This being an erosion-prone zone, sediment stabilisation must be a priority as an erosion remedial measure. For purposes of land management, elaborate conservation measures have to be applied. These are discussed in the recommendations, section 6.5.

6.2.2 Erosion changes and rainfall variations

The analysis of annual, monthly and daily rainfall series for the study area revealed intriguing rainfall trends. Marked rainfall fluctuations in the form of wet and dry phases were identified. Tyson (1986) describes extremely wet years as those with rainfall exceeding 125 per cent of the normal. By this threshold, none of the years examined in the annual rainfall chronology for the study area can be categorised as extremely wet. For instance, taking 868mm, the highest total annual rainfall ever recorded for that time period, it exceeds the average rainfall of the area by 77%. This confirms the observation that maximum monthly rainfall peaks are better indicators of periods of intense rainfall than annual ones. That the monthly rainfall distribution is typified by a small proportion of rainy days supplying most of the rainfall, was established.

Such skewed rainfall distribution highlights the importance of understanding its implications in terms of land use planning and eliciting geomorphic activity. Extreme rainfall events have been noted as a characteristic feature of this distribution. Cognisance must, therefore, be taken of the return period of such events, as they may invoke pronounced geomorphic responses. In the present study, 24 years has been identified as the return period of such events.

As already noted in the results chapter, a progressive increase in severe erosion forms is the most noticeable trend of erosion change. The culmination of this trend manifests itself in the drastic increase in gully erosion particularly during the 1965-75 period. A coincidence was established between widespread gully initiation and intensification in the early 1970s, and an extremely wet phase preceded by an extremely dry one. As pointed out by Verstappen (1983), rain falling on dry soil at the beginning of the rainy season is of special significance with regard to erosion initiation. Thus, it can be inferred that erosion activity appears to be most effective after an acute dry spell. The impact of the highest monthly rainfall peak examined in section 5.2 must have had a considerable impact in terms of initiating and intensifying erosion.

Having examined the daily rainfall trends pertaining to the study area, it is highly probable that the drastic increase in severe erosion forms observed was a product of a sequence of extreme rainfall events occurring over a few, presumably consecutive days of the month. Weaver (1990), who studied rainfall erosivity in the former Ciskei, acknowledges the importance of extreme rainfall events in terms of inducing soil erosion. However, it was pointed out in section 5.5.2 of the results chapter that rainfall peaks in 1922 and 1953 did not appear to have induced significant erosion. Given the close spatial correlation between severe erosion forms and abandoned cultivated lands, the observed erosion increase was therefore a result of the interaction between rainfall variations and land use changes. "A rare, extreme meteorological event may trigger off accelerated erosion once a critical situation has been created by man" (Verstappen 1983, p.374).

The findings of this study in this regard, tally with those of similar studies conducted in some parts of Southern Africa. Stromquist *et al* (1985) highlight the significance of the wet spell after a long dry spell in terms of inducing rapid gully erosion. They point out that, coupled with increased land use, it is possible that the combination of an extremely dry number of years followed by an extremely wet period is necessary to reach the threshold for an increased erosion. In a similar study, Whitlow (1994b) found rainfall to be a key factor accounting for differences in gully activity, with wet phases characterised by active erosion and vice versa during dry phases. A study by Thornes (1976),quoted by Morgan (1986a), where extensive changes to a hillside and channel forms during a three day storm of 196 mm, was alluded to in Chapter 2, section 2.5.

Conversely, some studies in the same region have associated wet spells and above average rainfall conditions with a decrease in erosion. Watson (1996) noted that the eroded area in the Mfolozi catchment, KwaZulu-Natal, contracted during the 1970s wet spell. Neither did it lead to a change in gully dimensions. Marker (1988) found no relationship between erosion incidence and rainfall fluctuations in a catchment near Alice. The former finding in KwaZulu-Natal verifies Zachar's (1982) view that soil erosion does not always occur where erosivity is highest, but where ecoclimatic conditions are unfavourable.

As opposed to the catchment in KwaZulu-Natal, the study area is very drought prone, as typified by the rainfall trends in section 5.2. The protective effect of vegetation cover in such areas gets significantly suppressed during dry phases. Besides, the land use history of the two areas, which undoubtedly has a significant bearing on degradation dynamics, is not analogous. Unlike the case with the present study area, whose settlement history by native peasants dates as far back as 1835, it was not until 1958 that Zulu peasants were settled in Watson's (1996) study area in the Mfolozi catchment. An earlier observation that dominant variables controlling the spatial and temporal variation of degradation forms differ with scale of analysis (Morgan 1986a), is relevant in the instance of Marker's (1988) study in the Mavuso catchment near Alice. Perhaps, for a catchment 3.6 Km^2 in area, a distinct correlation between erosion changes and rainfall fluctuations could not be identified as the dominant controlling variable. Measures to halt erosion, for example, dam building at the gully heads could also have altered the trends of gully development. She points out, however, that it is possible that run-off associated with flooding in 1976 and 1979 caused renewed gully incision.

6.2.3 Erosion change in land tenure units

The confinement of all erosion forms to traditional and betterment villages, at all dates, further signifies how pivotal a bearing land management differences have on erosion initiation and distribution. Its prevalence in these areas even at dates when they were scantily settled augments this observation. Erosion intensification into severe forms with time, particularly the drastic increase during the 1965-1975 period is, plausibly, a product of the interaction of a whole range of variables, from climatic and human to physical ones. This interaction is reviewed in the relevant sections below, where relationships between these variables are examined.

The observation that erosion exacerbation rather than control prevailed in the betterment areas after the introduction of the betterment programme is in keeping with the findings of Watson (1996) in Mfolozi catchment, KwaZulu-Natal. She concludes that land use changes associated with restitution and redistribution will inevitably rapidly increase soil erosion. In part this might connote that such "top-bottom" programmes introduced by the government of the day acted as a disincentive to land users to adopt any conservation strategies, thus aggravating the land degradation problem. This emphasises the need for full involvement of the land managers if measures to inhibit land degradation are to succeed.

6.2.4 Erosion and land use changes

Trends in land use change are described in sub section 5.1.2 of the results chapter. A progressive increase in abandoned cultivation fields over the study period and an exponential rise in the number of dwelling units during specific periods, in traditional and betterment villages, are the two most significant land use changes observed. Population changes and erosion are discussed in section 6.4. Of particular interest are the underlying reasons for the abandonment of cultivated land.

Divergent explanations regarding the issue have been obtained. Elderly local residents talked to during field surveys ascribe this phenomenon to the long and recurrent droughts that struck the area between the early 1940s and 1970. Besides the adverse effects of droughts, most of the ploughing was done using ox-drawn ploughs, which oxen were lost during acute drought spells. This hindered the resumption of cultivation even during the short rainy spells that punctuated the drought periods.

Socio-economic considerations, for instance, the pension system in the early 1960s are alternative reasons given for cultivation abandonment. Pension payments to the rural elderly were increased in the early 1960s to match those of their urban counterparts (Fox, *pers. commun.*). This provided an ample source of livelihood to them, hence cultivation abandonment. The migrant labour phenomenon targeted the young and energetic, leaving nobody to work the land. Presumably, a combination of drought effects and socio-economic factors led to cultivation abandonment. Unlike on the former cultivation farms, abandoned cultivation fields did not revert to grazing land in both the traditional and betterment villages. They remained distinctly discernible as bare and, in most instances, eroded surfaces.

It was confirmed via the chi-square test conducted in sub section 5.5.3 of the results chapter that the observed differences in the distribution of erosion classes on the respective land use types are significant enough to exhibit the influence of specific land use types. Erosion classes 4 and 5 (severe rill, gully, intricate gullies and gully remnants) on one hand and classes 2 and 3 (slight and severe sheet, with incipient rilling) on the other were, consequently, associated with abandoned cultivated land and grazing land respectively. Closer scrutiny of the factors leading to this association is made here.

The close spatial correlation between abandoned cultivated land and erosion classes 4 and 5 elicits, *inter alia,* pertinent questions namely: Did erosion on the cultivation fields occur before or after their abandonment? If the former is true, could erosion be one of the causes for abandonment? That erosion occurs even when land is actively under cultivation, especially in the absence of sound conservation measures, is true. The capability of cultivation to conceal erosion has been documented (Ntsaba 1988). Erosion forms that are morphologically inconspicuous are easily obliterated when tillage activities are still in progress at a given site. Erosion escalation from mild to severe forms, is likely to occur when tillage activities at the site cease unless it reverts to bush. This is in conformity with Watson's (1996) observation that soil erosion processes are more sensitive to land use change than its intensification. This applies to the present study, where, the gully development is predominantly observed on abandoned cultivation plots.

Many of the abandoned cultivated fields in the traditional and betterment villages remained unvegetated, as noted earlier. The biophysical attributes of the soil probably became impaired with time, especially during the drought periods, hence rendering it vulnerable to severe erosion when the wet period begins. Thus exposed, the soil becomes baked, followed by reduction of its infiltration capacity, and promotion of run-off. Soil crusting is another deterioration characteristic that soil is likely to undergo when cultivation activities cease. A thin humic layer that protects soil from crusting is destroyed by tillage, rendering it susceptible to erosion (McKenzie 1994). Destruction of microaggregation has also been linked to cultivation. Flanzluebbers and Arshad (1996) cite a 25-50% reduction in microaggregation resulting from cultivation of native grassland soils.

Most researchers examining soil deterioration resultant from its recent history have focused on the effects of organic material (Trimble 1990). Organic matter losses of 40- 50 percent during periods of 35-60 years have been reported in some studies (Morgan 1986a). A linear relation between organic matter and soil erodibility has been documented (Trimble 1990). Such a chain of soil deterioration phases, as outlined above, must have unfolded even more rapidly in the abandoned cultivated fields of the study area, especially in the absence of sound conservation measures.

The location of some of the abandoned cultivated fields with regard to physical characteristics is another factor that explains the observed correlation with severe erosion classes. According to evidence from aerial photographs and field observations, most of these fields are located in the bottomlands, along stream channels. Understandably, these were the attractive, fertile alluvial and colluvial soils. The association between these soils and erosion is discussed in section 6.5.5.

Evident from field observations is the fact that many of the formerly cultivated fields in the bottomlands lie on slope angles between 10^0 - 14^0. Notwithstanding the fact that the threshold slope for arable farming differs with soil type (D'Huyvetter 1985, D'Huyvetter and Laker 1985), 9^0 is, generally accepted, with sound conservation measures (Rowntree *pers. comm*). There is no indication from aerial photographs that any conservation measures were put in place to curb erosion on such critical angles of slope. Accelerated erosion on these fields was, consequently inevitable, especially after their abandonment.

The observed spatial correlation between grazing land and erosion classes 2, 3 and 6, at all dates, indicates a functional relationship between the two. The detrimental effect of communal grazing systems, overstocking and the resultant overgrazing on vegetation has already been alluded to. The concomitant reduction in vegetation cover, greater soil compaction and crusting and lowering of the infiltration capacity (Morgan 1986a) will promote run-off and, consequently, erosion.

The development of severe erosion classes on grazing land is noted to be a gradual process, coincident with a gradual reduction in the areal extent of classes 2 and 3. This suggests long term non- recovery of the overgrazed veld, hence, the intensification of these erosion types with time, from sheet to gully erosion. The confinement of erosion class 6 (footpath and riverbank erosion) to grazing land, illustrates the same positive feedback mechanism as explained in the preceding paragraph. This entails the reduction of vegetation cover through overgrazing, trampling effects along human footpaths and cattle tracks, soil compaction, reduced infiltration rates, enhanced runoff and erosion.

Field surveys indicated that footpath erosion is even more widespread than could be gathered from aerial photographs. The expropriation of the former commercial farms in the early 1980s appears to have facilitated the establishment of easy access routes through these farms to the only shopping centre in the area, Peddie town. The user-intensity of the footpaths is noticeably high, as evidenced by the rapid development of a series of parallel gullies along them. These gullies are in advanced and nascent stages in the traditional villages and former commercial farms respectively. Regarding the latter case, the footpath gullies were non existent during the period of study (1938-1988). Relationships between footpath user-intensity and erosion have been established (Sumner 1995). As is always the case, when the depth of footpaths increases, there is a tendency by users to abandon it, resulting in multiple footpaths. This explains the formation of the parallel gullies observed in field surveys.

The spatial correlation between stream channel erosion and grazing activities indicates the influence of the latter on the former. Due to the unlimited access animals have to streams, they contribute to the decline in riparian community by removing protective vegetation during grazing and increasing bank instability by trampling. Unstable banks lead to accelerated channel erosion and higher instream sediment loads (Marlow *et al* 1987). The widespread channel degradation observed in the study area is, thus, a combined effect of both removal of the woody riparian vegetation discussed in section 6.4.2 and grazing activities.

6.3 Vegetation changes

6.3.1 Changes in vegetated surfaces

The time series analysis of vegetation condition reveals a marked change in vegetation gradient from the traditional and betterment villages to the former commercial farms, at all dates. To some extent, the vegetation condition in the former commercial farmlands provides a benchmark against which deviation from the normal can be determined. The converse is true of the traditional and betterment villages. The persistence of 'scanty grass cover' as the dominant vegetated surface and absence of 'open woodland' category in the two tenure units, at each date, indicate that the detrimental impact on vegetation is not a recent phenomenon. By implication, the dominance of scanty grass cover at each date is indicative of permanent damage to vegetation. That below average or poor performance of vegetation during good rainfall years indicates long term damage (Dube 1995), thus, pertains to these tenure units. No improvement in vegetation condition was observed in these areas even during the wet phases. Analysed from aerial photographs, some vegetated surfaces may create an impression of a healthy cover, yet they are inferior and unpalatable species. The widespread invasion by such species observed from field surveys indicates the critical levels which vegetation degradation has reached.

In contrast, the former commercial farms are noted to be plagued with the problem of bush encroachment during the latter part of the study period. Hitherto, no significant change in vegetation condition was discerned. A considerable increase in woody species observed between 1975 and 1988, has led to a reduction in the grass ones. It is suggested that this increase, which coincided with a decrease in wooded grassland, is a reciprocal response which displays a vegetation succession process, augmented by tenure changes. Grazing activities on these farmlands ceased from the early 1980s when the former white owners had to vacate them on the eve of the creation of Ciskei "homeland". This gave the woody shrubs a competitive advantage over grass species.

6.3.2 Riparian vegetation density variations

Riparian vegetation density was also observed to vary with land tenure units at each date. The time period for which stream courses in the traditional and betterment villages have been scantily vegetated implies considerable geomorphic effects on stream channels. These effects are manifested in a substantial reduction in bank stability and the resultant widespread channel degradation. Observations from the comparative channel survey indicate that the system is complicated further by the high sediment yields from the adjacent, unvegetated, formerly cultivated hillsides. As pointed out by Trimble (1990), when vegetative cover is poor and upland erosion supplies streams with more sediment than they can transport, sediment is stored as colluvium and alluvium. In the present study, the valley fill, so derived, has led to a shift towards a more semi-arid type system. The absorption of flood run-off, its re-emergence as baseflow, forming small active channels down stream, are characteristic features of this system (Rowntree, *pers. comm.*).

6.3.3 Vegetation and land use changes

It is evident that the temporal and spatial vegetation variability, discussed in section 6.4.2 above, is human induced. The change in vegetation gradient with tenure units, at each date, reflects the impact on land of the differences in its management. Apart from the gradual decrease in the wooded grass category, the observed vegetation status in the traditional and betterment villages cannot be attributed to trends in land use change. Evidence for vegetation diminution, for instance, the depletion of the open woodland category and the widespread scanty vegetation, was noticeable as from 1938. This denotes that vegetation in the two tenure units was, possibly, subjected to injudicious use right from the turn of this century. Vegetation changes and population increase are discussed in section 6.4.

6.3.4 Vegetation-erosion interaction

The observed distribution of erosion on vegetated surfaces in Tables 5.37 to 5.41 reflects the influence of the density of ground cover on erosion. The confinement of most of the erosion to the scanty grass category demonstrates the role of low ground cover density in promoting erosion. It is also in keeping with the literature cited in section 2.4 of Chapter 2. As noted earlier, the long term impact of unfavourable farming practices, coupled with recurrent droughts, contributed to the non-recovery of the veld in this vegetation category. In his study of the interaction of erosional and vegetational dynamics in land degradation, Thornes (1990) noted that organic matter loss through erosion was the sole constraint on vegetation growth. Vegetation cover is kept in check by erosion and an increase in erosion will result in a complete loss of vegetation cover. This explains the non-recovery of the veld in the present study which consequently enhanced the intensification of erosion from mild forms to severe ones with time.

6.4 Population changes and land degradation

The drastic rise in population in the traditional villages between 1965 and 1975 is a trend not unique to the study area. It conforms to the general trend in the Eastern Cape, where the population curve for the whole province displays an exponential rise in population during the same period (Fox, *pers. comm.*). In the betterment villages, such increase is noted to coincide with the introduction of villagisation in the early 1960s. The reallocation of land and consolidation of scattered homesteads, which measures the programme entailed, could, possibly, have attracted more people from the nearby traditional villages. A slight reduction in dwelling units in the traditional villages during the same period might be an indication of this.

The distinctive relationships between erosion and land use types, described in section 6.2.4, provide the basis upon which erosion and population increase could be linked. Both the moderate and severe erosion forms are noted to occur where the land use categories examined had, for long, been prevalent. An intensification in these land use types is not observed even after the drastic rise in population, save cultivation abandonment. For instance, severe erosion forms are associated with abandoned cultivation fields, which fields were in existence long before the observed exponential rise in population. The same is true of the mild erosion forms on grazing lands. Indicative of overgrazing, scanty vegetation cover, which promoted these erosion forms, is a dominant characteristic feature throughout the entire study period. Erosion increase is, thus, more a result of shifts in the pre-existing land use types, especially cultivation abandonment, than the drastic rise in population that was noted to occur in the middle and latter part of the study period in the betterment and traditional villages respectively.

More often than not, the decimation of resources, for instance vegetation, have been attributed to population growth (Brinkcate and Hanvey 1996), especially in communally utilised land. In the present study, it has been verified that the observed vegetation diminution is more a product of earlier injudicious use than increase in population. Apart from the gradual decrease in the small land area under wooded grass category, open woodland is noted to be absent even from the earliest set of photographs analysed. The predominance of scanty grass category at all dates has already been referred to. That communally owned land is utilised with due disregard for conservation measures has been documented (e.g. Blaikie 1985, Blaikie and Brookfield 1987, Gregory and Walling 1987, Abel and Blaikie 1988). Such land is used by everyone but cared for by a few or none. It could be argued, and indeed truly, that access to more land could ease the pressure on it and ameliorate the degradation problem. However, against the background of the present study's findings, unless decisions to alter land management practices are made, even with increased access to land, a perpetuation of the observed scenario will prevail.

The coincidence of the rise in population with a reduction in cultivated land has crucial socio-economic implications. It is a manifestation of a total transformation in the socio-economic set -up of the area, characterised by drastically reduced dependence on land as a source of livelihood. There is a need to unravel this shift in land use systems in order to provide a better understanding of the current land-population dynamics in the area.

6.5 Recommendations

Suggestions regarding remedial measures and future land management strategies, based on the findings of this study, are outlined below:

- One of the priority areas should be gully control. The worst eroded areas being those of sediment accumulation, there is a need to stabilise sediments. Stabilization barriers should be built along the point of incision, which was identified at many of the sites as a dolerite sill. The design of stabilisation structures for large gullies is described in Morgan (1979). Having stabilised sediments, trees of an appropriate height should be planted in the gullies. Appropriate height is in the sense that, tall trees will instead exacerbate erosion, as was the case in Mondoro, Zimbabwe, cited by Stocking (1988). Gully control being an expensive undertaking, it should not be left to the community alone, given their meagre resources. Government should play a major role in this regard.

- Owing to the crisis levels vegetation degradation has reached, grazing activities should cease, especially in the traditional villages. This would improve the competitiveness of the desired plant species and gradually enable them to recover. This would also be an effective control measure to less severe erosion forms, which were mainly associated with the overgrazed veld. As explained by Trollope (1995), grasses depend on periodical defoliations to remain vigorous and competitive. Plants become moribund when no defoliation takes place. By implication, the desired species will have a competitive advantage over the widespread unpalatable Karroid shrub, *Pteronia incana*, already referred to. It is suggested that farmers in traditional villages should be allocated grazing land on the former commercial farmlands. These have remained state land since their expropriation from white farmers and their use to date remains undefined. Realistic stocking rates, commensurate with the veld carrying capacity, should be adhered to in order to avoid a repeat of the appalling situation in the traditional villages. The "multi-camp"and "high production grazing" systems which are veld rehabilitation strategies devised by the Department of agronomy, and explained fully by Trollope (1995), should be adopted. He points out that the latter system would assist in overcoming the effects of species selective grazing and deterioration of grass botanical composition. Periodic controlled burning of the undesired plant species is another alternative. Bush management trials, aimed at getting the vegetation to recover should also be embarked on.

- Besides the findings of this study, the communal tenure system has been held responsible for land degradation by many a researcher. A modification of this system should be encouraged, with due sensitivity to the perceptions and values of the local community. The editorial opinion on the subject, of the Daily Dispatch newspaper of 04/10/96 that, the rural people should be allowed to hold title to the land in their own name, is echoed here. Probably, with a sense of property ownership, this might lead to an improvement in the utilization of land resources.

- There is an urgent need to halt the widespread channel degradation in the traditional and betterment villages. This can be achieved by re-establishing suitable riparian vegetation along the upper banks of stream channels. This will promote deposition of massive amounts of sediment from the abandoned cultivation fields, enhance bank accretion and colonisation of berms by volunteer species. A detailed explanation of measures for bank protection and stabilization is given by Thorne (1990).

  Contouring that has been introduced as an erosion control measure on some cultivated land should be supplemented by contour farming. According to Morgan (1986a), the latter technique is more effective in protection against the erosivity of extreme rainfall events.

7. Conclusion

The current and final chapter is divided into two parts. Firstly, a review of the findings of the study is made within the context of the objective and specific aims of the study as spelt out in Chapter 1. Secondly, identified directions for future research are highlighted.

This study has unravelled the uncertainty surrounding the origins and causes of land degradation in the study area. It has been verified that, whereas land degradation is not a recent phenomenon, its temporal and spatial variation is a complex interplay of anthropogenic and physical variables. Distinct spatial contrasts in degradation with land tenure systems were observed throughout the period of study. These are typified by confinement of erosion to the traditional and betterment villages and a sharp change in vegetation gradient from the same areas to the former commercial farms. The dismal failure of 'betterment' is portrayed by the dramatic increase in erosion after its introduction. Such contrasts vividly portray the extent to which differences in land tenure systems are a controlling factor to land degradation variations. That they emerge as the cardinal determinants of the pattern and levels of degradation forms was established.

The rate of response of geomorphic activity to extrinsic thresholds is denoted by the close spatial correlation observed between specific land use types and degradation forms. Cultivation activities for several decades were linked to phases of soil deterioration outlined in section 6.2.4, Chapter 6. The predominance of scanty vegetation cover in the traditional and betterment areas was discerned to be a manifestation of permanent damage to vegetation, resulting from injudicious grazing activities. Widespread sheet erosion observed on this vegetation category for the period of study signifies the detrimental impact of erosion on vegetation recovery. Erosion intensification into severe forms was closely correlated with abandoned cultivation fields. According to Stocking (1981), gullying is more a response to intrinsic than extrinsic thresholds. However, the present study has verified that extrinsic variables are a precursor to the augmentation of the rate at which renewed geomorphic activity responds to intrinsic variables. The observed intensification of erosion is mainly a response to land use change. Hence, a reconstruction of land use history is a requisite to understanding the rate and trend of change of geomorphic activity and ultimately, land degradation.

The study has also demonstrated that the present status of land degradation can not be justified by the simplistic explanation of the rapid rise in population. Different forms of land degradation, for instance the depletion of the open woodland category and riparian vegetation removal, were observed as early as 1938, when the area was still sparsely settled. An increase in the intensity of land use as a reciprocal response to population rise was not observed either.

Rainfall variations have been found to be important indicators of periods of renewed geomorphic activity. This is illustrated by a drastic increase in gully erosion, coincident with an extremely wet phase, preceded by a three year acute dry spell. An examination of the rainfall trends of the study area verifies that monthly peaks are more reliable surrogates for episodes of intense rainfall than annual ones. The highly negatively skewed nature of the daily rainfall distribution was established. Against the background of the coincidence cited above, it can be inferred that the propensity of periods of intense rainfall to elicit geomorphic activity is considerable. In conformity with the observation by (Verstappen 1983), this is most effective where a critical situation has been put in place by land use activities, such as cultivation abandonment in the present study. It is noteworthy, however that such a scenario is likely to occur where, as noted in 6.2.2, Chapter 6, the eco-climatic conditions are unfavourable.

The role of physical characteristics as controls of the magnitude and variation of land degradation is evidenced by, *inter-alia*, the high prevalence of erosion on a specific group of rocks and the site-specific nature of erosion severity in the study area. That 90% of the total eroded area is prevalent on the Ecca group of rocks denotes the relevance of geology on erosion variation. Notwithstanding the fact that the inherently vulnerable nature to erosion of soils derived from the Ecca group must have enhanced erosion, the finding is not very conclusive. The traditional and betterment villages to which erosion is confined happen to lie, predominantly, on this group of rocks. The adjacent Beaufort group of rocks lie largely on the former commercial farms. Since the two groups of rocks were not subjected to the same land use history, a favourable ground for comparison does not exist.

A chain of interaction between land use history, slope position, geology, sediment characteristics and erosion explains the site-specific nature of the worst eroded sites in the study area. Vegetation removal for cultivation from sites on the steep bottomlands and their abandonment, exposed the highly susceptible unconsolidated colluvial and alluvial material to erosion. The potential for rapid gully development in colluvium was established. Besides, a break in slope formed by a dolerite sill, which also marks the upslope boundary of sediment accumulation at some sites, augmented rapid incision into the unconsolidated sediments. Such an interaction chain vividly portrays the observation made earlier, that extrinsic variables may act as a precursor to strengthening of the rate at which inherent physical attributes respond to geomorphic activity.

7.1 Directions for future research

A number of important questions that arise from this research constitute directions for future research. These are singled out below:

- The reasons surrounding the abandonment of cultivated land emerge as a major question from this study. These need to be probed into. Besides, the physical processes operating on abandoned land that lead to increased erosion should also be fully investigated.

- The socio-economic implications of the coincidence observed between population increase and cultivation abandonment are also yet to be unravelled. This is a direct challenge to human geographers and other social scientists, which apparently is not unique to the study area, but a ubiquitous phenomenon, especially in the former 'homelands'.

- It was beyond the scope of this study to examine the nature of erosional processes, for instance, surface erosion *vis-a- vis* sub-surface erosion. Further research in that area would provide a more in-depth understanding of erosion process dynamics and their interaction with vegetation.

- There is a need to have a deeper understanding of the impact of the enormous sediment yields from this area and similarly degraded ones within the framework of the wider drainage system. This may, *inter-alia* entail the quantification of sediment storage within stream channels, reservoirs and possibly outlets into the sea. This would act as an indicator to erosion rates and drainage system shifts.

The suggestions above do not exhaust all the avenues for related future research. The paucity of data regarding the present trends and present status of degradation at a wider scale highlights the need to embark on similar studies under different eco-climatic conditions. The assessment of vegetation condition, in particular, at such scale can be undertaken more effectively using satellite imagery and GIS packages, such as 'IDRISI', which can be used to extract standard vegetation condition indices.

The forms of land degradation examined have been found to be largely man induced. However, their magnitude and variation are determined by a combination of dynamic geomorphological factors and inherent physical attributes of the land. The findings of this study fulfil its sole objective as stated in Chapter 1. They are crucial with regard to land restoration and conservation policy directions.

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Appendix I

Table I Coverages created for the study and information depicted

Number of coverages digitised from transparent overlays	Mapjoined coverage	Information depicted
12	luse38	Distribution of land use types (1938)
12	luse54	Distribution of land use types (1954)
12	luse65	Distribution of land use types (1965)
12	luse75	Distribution of land use types (1975)
12	luse88	Distribution of land use types (1988)
12	eros38	Distribution of erosion classes (1938)
12	eros54	Distribution of erosion classes (1954)
12	eros65	Distribution of erosion classes (1965)
12	eros75	Distribution of erosion classes (1975)
12	eros88	Distribution of erosion classes (1988)
12	vegc38	Distribution of vegetated surfaces (1938)
12	vegc54	Distribution of vegetated surfaces (1954)
12	vegc65	Distribution of vegetated surfaces (1965)
12	vegc75	Distribution of vegetated surfaces (1975)
12	vegc88	Distribution of vegetated surfaces (1988)

Table II 'overlay' coverages derived from 'mapjoined' coverages

Input coverage	Union coverage	Output coverage	Information depicted
luse38	eros38	erouse38	Erosion distribution on land use types (1938)
luse54	eros54	erouse54	Erosion distribution on land use types (1954)
luse65	eros65	erouse65	Erosion distribution on land use types (1965)
luse75	eros75	erouse75	Erosion distribution on land use types (1975)
luse88	eros88	erouse88	Erosion distribution on land use types (1988)
eros38	tenure	tenero38	Erosion distribution in tenure units (1938)
eros54	tenure	tenero54	Erosion distribution in tenure units (1954)
eros65	tenure	tenero65	Erosion distribution in tenure units (1965)
eros75	tenure	tenero75	Erosion distribution in tenure units (1975)
eros88	tenure	tenero88	Erosion distribution in tenure units (1988)
luse38	tenure	tenuse38	Land use distribution in tenure units (1938)
luse54	tenure	tenuse54	Land use distribution in tenure units (1954)
luse65	tenure	tenuse65	Land use distribution in tenure units (1965)
luse75	tenure	tenuse75	Land use distribution in tenure units (1975)
luse88	tenure	tenuse88	Land use distribution in tenure units (1988)
vegc38	tenure	tenveg38	Vegetation* distribution in tenure units (1938)
vegc54	tenure	tenveg54	Vegetation* distribution in tenure units (1954)
vegc65	tenure	tenveg65	Vegetation* distribution in tenure units (1965)
vegc75	tenure	tenveg75	Vegetation* distribution in tenure units (1975)
vegc88	tenure	tenveg88	Vegetation* distribution in tenure units (1988)
eros38	slope	slpero38	Erosion distribution on slope classes (1938)
eros54	slope	slpero54	Erosion distribution on slope classes (1954)
eros65	slope	slpero65	Erosion distribution on slope classes (1965)
eros75	slope	slpero75	Erosion distribution on slope classes (1975)
eros88	slope	slpero88	Erosion distribution on slope classes (1988)
eros38	geol	geoero38	Erosion distribution on rock groups (1938)
eros54	geol	geoero54	Erosion distribution on rock groups (1954)
eros65	geol	geoero65	Erosion distribution on rock groups (1965)
eros75	geol	geoero75	Erosion distribution on rock groups (1975)
eros88	geol	geoero88	Erosion distribution on rock groups (1988)
eros38	vegc38	vegero38	Erosion types on vegetated surfaces (1938)

Input coverage	Union coverage	Output coverage	Information depicted
eros54	vegc54	vegero54	Erosion types on vegetated surfaces
eros65	vegc65	vegero65	Erosion types on vegetated surfaces
eros75	vegc75	vegero75	Erosion types on vegetated surfaces
eros88	vegc88	vegero88	Erosion types on vegetated surfaces
eros88	soiltype	soileros	Erosion distribution on soil types

* Categories of vegetated surfaces

Table III Other coverages created

Coverage	Information depicted
ripveg	Distribution of categories of riparian vegetation density
sillbuff	Buffer Zone for gully sites within 200 metres of the dolerite sill

Appendix II

Table IV Sources of materials and information

Materials / Information	Source
Aerial photographs for 1938, 1954, 1965	The Chief Surveyor General, Department of Regional and Land Affairs, P.B. X10 MOWBRAY
Aerial photographs for 1975, 1988 and orthophoto Maps for 1992	Aircraft Operating Company, Aircraft House, 23 Rogers Street, Selby, Johannesburg.
Rainfall Data for the study area (1920 - 1991)	Computing Centre for Water Research (CCWR), University of Natal, Petermaritzburg