# AN EROSION HAZARD ASSESSMENT TECHNIQUE FOR CISKEI

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## ABSTRACT

The study examines the relationship between the spatial variation in soil erosion and various natural and anthropogenic attributes of the region between the coastal plateau and the Winterberg escarpment of Ciskei. A raster - based geographical information system is derived for four separate study catchments and data on soil erosion and various soil erosion hazard indices are read into a computerised data matrix. The independent variables (soil erosion hazard indices) used in the study are selected on the basis of a review of the literature and on the availability of data in the Ciskei region. Multivariate analyses of the relationship between soil erosion and the various independent variables reveals that the primary variables affecting the spatial variation in soil erosion are land use, dominant soil type, geology, veld type and mean annual precipitation. All of these variables are readily quantifiable at the regional scale for large areas of Ciskei. An erosion hazard assessment model for use in central Ciskei is developed based on the results of the statistical analyses. The model is tested in separate study areas and is shown to provide an efficient method of identifying areas of differing susceptibility to soil erosion. The derived model is simple to operate and has input requirements which are easily met. It can be applied without the aid of computers, or where large areas are to be mapped it is well suited to computerisation.

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# CHAPTER ONE

## INTRODUCTION

Soil erosion is a natural phenomenon which has occurred throughout geological time and will continue to do so in the future. Soil erosion occurs when the forces tending to entrain and transport materials exceed those tending to resist removal (Thornes, 1980). The rate at which soil erosion occurs varies both temporally and spatially according to the balance between the forces of entrainment and those of resistance. Soil erosion only becomes a problem when the rate at which soil is being eroded from the land exceeds the rate at which the soil is being formed (Kirkby, 1980). A number of factors can upset the state of quasi-equilibrium that generally exists between soil erosion and soil formation. Although these factors are often related to the activities of man, they can also be due to natural processes such as climatic change. This study is concerned with spatial variations in the nature and extent of soil erosion in Ciskei, a Xhosa state granted political independence by South Africa in 1981. More specifically, the study will attempt to identify the natural and anthropogenic attributes of the environment which control spatial variations in erosion in Ciskei.

There are a number of reasons for, and approaches to, the study of soil erosion. The ultimate aim of all soil erosion research is to be able to suggest suitable conservation measures (Morgan,1986). Soil erosion hazard assessment is the branch of soil erosion research with which this thesis is concerned. Soil erosion hazard assessment represents a technique whereby the spatial and/or temporal variation in soil erosion and the factors governing soil erosion are identified. The main reason for developing soil erosion hazard assessment techniques is to identify areas with a high soil erosion hazard potential so that the soil conservationist can concentrate both capital and effort in these regions. Approaches to the development of soil erosion hazard assessment techniques differ widely. Differences occur according to the scale at which the techniques are applicable, varying from the global scale to individual cultivated fields. The level of detail with which erosion hazard can be described varies from a qualitative expression of relative risk to actual soil loss figures expressed quantitatively. Important differences in approach also exist between the techniques that concentrate on prediction and those that concentrate on explanation.

Various authors have made pleas for increased research into physically-based models which explain the erosion process (Quirk and Dudal,1980; Hudson,1981; Morgan,1986). However, the apparent lack of understanding of the erosion process and the pressing need for predictive models which provide immediate answers to erosion problems has meant that most available models are of the empirical, "black box" variety. These models are based on the identification of statistically significant relationships between soil erosion and soil erosion controlling factors (Morgan,1986). A major restraint to the application of most soil erosion hazard assessment techniques is the availability of input data for the development and testing of models (Hadley *et al.*, 1985). Stocking (1984a) points to the need for the development of methods which are both simple in design and practical in implementation yet encompass as wide a range of evidence as possible. The study reported here represents an attempt to develop a soil erosion hazard assessment technique applicable to Ciskei. It entails an investigation into the statistical relationship between various easily quantifiable environmental parameters and soil erosion.

It is generally accepted that soil is being lost from the southern African sub-continent at an alarming rate. Rooseboom (1975) estimates an annual loss to South African river systems of 120 million tonnes of soil. Murgatroyd (1979) estimates that soil erosion rates in the Tugela Basin (Natal, South Africa) are 28 times higher than the geologically normal rate. It has been stated by a number of writers that there is a danger that large parts of southern Africa will be rendered unsuitable for agricultural production within one lifetime if soil erosion continues at its present rate (Soil Loss Estimator for Southern Africa (SLEMSA), 1976; McPhee, Smithen *et al.*, 1983; Rooseboom,1983). Of particular concern is the fact that erosion rates in the semi-arid regions of southern Africa often exceed the rates at which soils are being replaced (Rooseboom, 1981). In spite of these observations, both Garland (1982) and Rooseboom (1983) point out that very little published work exists on the true nature and extent of the soil erosion problem in southern Africa. Most of the published work is site specific, and in many cases crop specific as well. It appears that this is a universal problem as de Ploey and Gabriels (1980) make the general observation that much of the completed erosion research is very specific with the vast majority viewing soil conservation as a purely technical problem.

The study of soil erosion in a spatial context fits well within the ambit of geography if one accepts that geography is "...the major discipline that is concerned with the identification, analysis and interpretation of spatial distributions as they occur on the surface of the earth" (Haring and Lounsbury, 1983, p5). The argument for a place for soil erosion hazard research in applied physical geography is strengthened when one considers Scheidegger's (1975) argument that one of the major contributions of geomorphology lies in the identification of sites that are free from geomorphic hazards. The multifaceted nature of the soil erosion problem makes its study particularly suited to geography which is often referred to as an integrating discipline (Hagget, 1972).

Further support for the selection of this particular study lies in the generally held belief that soil erosion in black occupied regions is occurring at unnaturally high rates. An anonymous report (Anon, 1980, p5) suggested that "...overgrazing and soil erosion in the black homelands, where some 33% of the country's population occupy 12% of the land area, has reduced the agricultural land conservation value of large areas". The Ciskei Commission (1980) reported that 47% of Ciskei is 'moderately' to 'severely' eroded. In a study of reservoir sedimentation in the Roxeni Basin in central Ciskei Weaver (1988) estimated erosion rates to be in excess of 100 $t.km.^{-2}.year^{-1}$. Other studies have produced evidence which suggest that soil erosion in areas where traditional agricultural techniques are practiced is lower than that in adjacent areas where technically advanced farming methods are employed (Stocking, 1983; Weaver, 1987).

There does, therefore, seem to be some controversy regarding both the nature and extent of soil erosion in black occupied areas. The report of the Commission of Enquiry into the Economic Development of the Republic of Ciskei estimated that 60% of the 1980 population was rural (Swart, 1983). This was already in excess of the estimated land carrying potential. The projected 2,4% population growth rate means that ever-increasing pressure will be placed on rural land resources. According to the South African department of statistics (1975), 73% of the population of Ciskei was not economically active in 1975. Of the remaining 27%, 53% were farm and forestry workers. Swart (1983, p28) summarizes the problems facing agriculture in Ciskei as follows: "...agriculture is hampered *inter alia*, by the extreme fragmentation of farmland into very small holdings on which only subsistence farming can be practiced. This has led to dereliction of land by absentee farmers who are seeking a living elsewhere. Overpopulation has on the other hand given rise to overgrazing which has caused serious loss of soil by erosion and the invasion of undesirable plants. Due to poverty, the remaining occupiers of land lack the capital for the necessary farming inputs; they are thus caught in a vicious circle of increasing poverty." There appears to be an urgent need for the identification of areas suitable for further rural development as well as areas where development should be restricted. One of the criteria recommended by the Commission for the selection of areas for rural settlement is soil carrying capacity (Swart, 1983). A key element in maintaining a high soil carrying capacity in the long-term is the minimisation of soil erosion to a rate lower than the rate of soil formation.

This chapter has provided a brief introduction to the soil erosion problem, the need for erosion hazard assessment techniques, the place of soil erosion studies in geography and the need for such studies in Ciskei. Chapter 2 discusses the available literature on soil erosion processes with specific reference to the quantification of the environmental factors which control the spatial variation in soil erosion. Chapter 3 considers methods available for the mapping of soil erosion and soil erosion hazard. A more detailed statement of the research aims and an outline of the proposed research procedure is presented in Chapter 4. A general discussion of the characteristics of the Ciskei environment (Chapter 5) forms the basis for the selection of areas for detailed study. Chapters 6 and 7 discuss the methods of data collection and analysis. The initial data analysis process is used to screen variables and to identify those most useful in an erosion hazard assessment model (Chapter 8). The multivariate analysis of the relationship between soil erosion and the various independent variables is described in Chapters 9 and 10. Chapter 11 presents the model and the results of model verification tests.

# CHAPTER TWO

## SOIL EROSION PROMOTING FACTORS

The prerequisites to any selection of a soil erosion hazard mapping procedure is the identification and an understanding of the various possible soil erosion promoting factors and the limitations of the available data with which to quantify these factors. Soil erosion promoting factors and their quantification for use in soil erosion hazard mapping will be discussed in this section. One of the major problems in any discussion of erosion promoting factors lies in determining which variables express the same relationship and which identify truly separate relationships with soil loss (Morgan, 1980). The factors which are commonly accepted as having an important influence on the rate of erosion are rainfall, runoff, wind, soil, slope, plant cover and the absence or presence of conservation measures (Morgan, 1980). These factors can be grouped under the general headings of energy, resistance and protection as shown in Figure 2.1. Hudson (1981) combines resistance and protection as one and describes erosion as being a function of erosivity (of the rain) and erodibility (of the soil), or:

Erosion = f (erosivity, erodibility).

Erosivity refers to the potential ability of the eroding agent (wind, rainfall or runoff) to cause erosion. Resistance and protection factors (Hudson's "erodibility") refer to the ability of the soil to resist erosion or the vulnerability of the soil to erosion. For given soil conditions, one event (rainfall, runoff or wind) can be compared with another and a numerical scale of erosivity can be obtained. Similarly, for given erosivity levels, soil conditions can be quantitatively compared with each other and a scale of values for erodibility can be defined (Hudson, 1981). Morgan and Keech (1976) point out that the apparent relative importance of factors affecting the spatial variation of soil erosion are dependent on the scale of analysis. Table 2.1 summarizes the available evidence on various factors affecting soil loss at different scales.

There is a strong degree of interdependence between the various soil erosion factors. For example, both rainfall erosivity and runoff erosivity are affected by slope angle (Hudson, 1981). For the sake of convenience the factors affecting soil erosion are dealt with independently in this chapter. The discussion will concentrate on factors which are quantifiable at the scale required for erosion hazard assessment by this study. These factors will be dealt with under five broad headings, namely climate, soil, relief, vegetation and man.

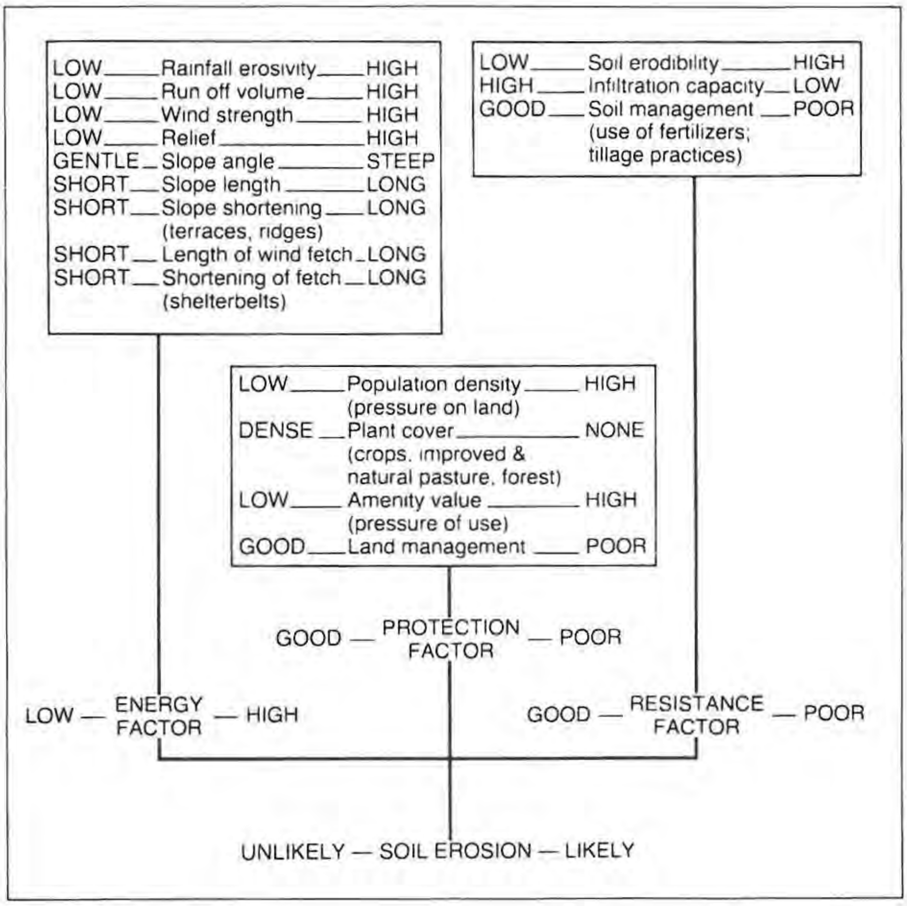



FIGURE 2:1: FACTORS AFFECTING SOIL EROSION (Morgan, 1986, p2).

### 2.1: Climate

"Climatic factors, particularly precipitation and temperature, directly and indirectly influence kinds of weathering, pedogenesis, and geomorphic processes and, in turn the kinds of soils and landforms that evolve from these processes" (Ruhe, 1975, p309). The strong interdependence between climate and other factors affecting soil erosion make it difficult to isolate the effect of climate on soil erosion. Vegetation and soils, for example, have been shown to vary with climate (Eyre, 1970); climate, in turn, is strongly influenced by relief in certain areas. The discussion on the relationship between soil erosion and climate will begin with a consideration of the interrelationship between two general climatic indicators (rainfall and altitude) and soil erosion, followed by a more detailed consideration of the climatic factor which receives most attention in the literature in relation to soil erosion, namely rainfall aggressiveness (erosivity).

**TABLE 2.1: FACTORS INFLUENCING SOIL LOSS AT DIFFERENT SCALES**
(Morgan, 1986, p7)

| SCALE OF ANALYSIS | | | EVIDENCE |
|---|---|---|---|
| Macro | Meso | Micro | |
| Climate | Lithology<br>Relief | | Sediment yield |
| Climate | Lithology<br>Relief | Microclimate<br>Lithology (soil) | Drainage density |
| Climate | Altitude | | Studies of erosion rates |
| Climate | | Plant cover<br>Micro-climate | Studies of soil loss from hillslopes |

Kirkby (1980) discusses the relationship between mean annual precipitation and soil erosion in very general terms. According to Kirkby (1980) a journey from desert to forest through areas of increasing amounts of mean annual precipitation in uncultivated conditions shows two effects on soil erosion. Increasing rainfall leads to increased overland or subsurface flow and to increased vegetation cover. In the initial stages, where vegetation cover is poor, increased runoff leads to increased soil erosion. Once mean annual precipitation is high enough to support semi-arid vegetation, the increasing plant cover does more to limit soil erosion than the increased runoff does to increase it; the nett result is a decrease in soil erosion with increasing runoff (Kirkby,1980). These ideas are supported by Langbein and Schumm (1958) and Douglas (1967). Figure 2.2 illustrates simplified relationships between mean annual precipitation and soil erosion. It should be pointed out that this simplistic relationship will inevitably be complicated by the effect of other climatic variables such as humidity and evapotranspiration which will cause considerable scatter around the idealised curves portrayed in Figure 2.2. This rational explanation has been termed the 'Langbein-Schumm' rule by a number of workers (Hadley, *et al.* 1985). The 'Langbein-Schumm' rule has recently been questioned following the availability of a growing body of global sediment yield data. Walling and Kleo (1979), for example, show that no clear relationship exists between sediment yield and mean annual precipitation, with a wide scatter in sediment yield values occurring across the range of MAP values used. Hadley *et al.* (1985) point out that although the 'Langbein-Schumm' rule might be applicable to the area in the United States of America where the data was obtained it is not globally applicable and other factors such as relief, geology and human impact may be of greater importance than mean annual precipitation. If the 'Langbein-Schumm' rule holds, it follows that in areas where orographic rainfall occurs and mean annual rainfall is influenced by altitude a strong relationship will exist between altitude, rainfall, vegetation and soil erosion.

Very little discussion on the relationship between soil erosion and altitude exists in the available literature. Zachar (1982) reports that in Chechoslovakia, although there is a high potential energy for erosion between 600 and 1400 m above mean sea level, erosion is slight because the soil is well protected by forests. When vegetation is removed, high intensity soil erosion occurs. Areas with unstable ecoclimatic conditions above the timberline often show higher soil erosion levels than those below this line (Zachar, 1982).

It is generally accepted that an index of 'climatic aggression' best describes the relationship between rainfall and soil erosion at the global scale. Fournier's (1960) index of climatic aggressivity (G) is an expression of the relationship between the maximum mean monthly rainfall (p) and the mean annual precipitation (MAP), where:

$$G = p^2/MAP \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 1$$

The bulk of research on climate as a primary factor in the soil erosion process has concentrated on rainfall erosivity. Laws (1941) studied natural rainfall and established that the concentration of soil in the runoff water increased directly with the energy of the raindrops. Ellison (1944) established that the mechanical action of raindrops formed the initial stage of the soil erosion process. Musgrave's (1947) equation recognised the importance of rainfall intensity in the soil erosion process with the inclusion of the $P_{30}$ (maximum 30 minute rainfall) index. Subsequent experimental studies have lent support to these early studies (for example Ekern, 1950; Hudson, 1957; Moldenhauer and Long, 1964; Fournier, 1972; Elwell and Stocking, 1975; Ulsaker and Onstad, 1984).

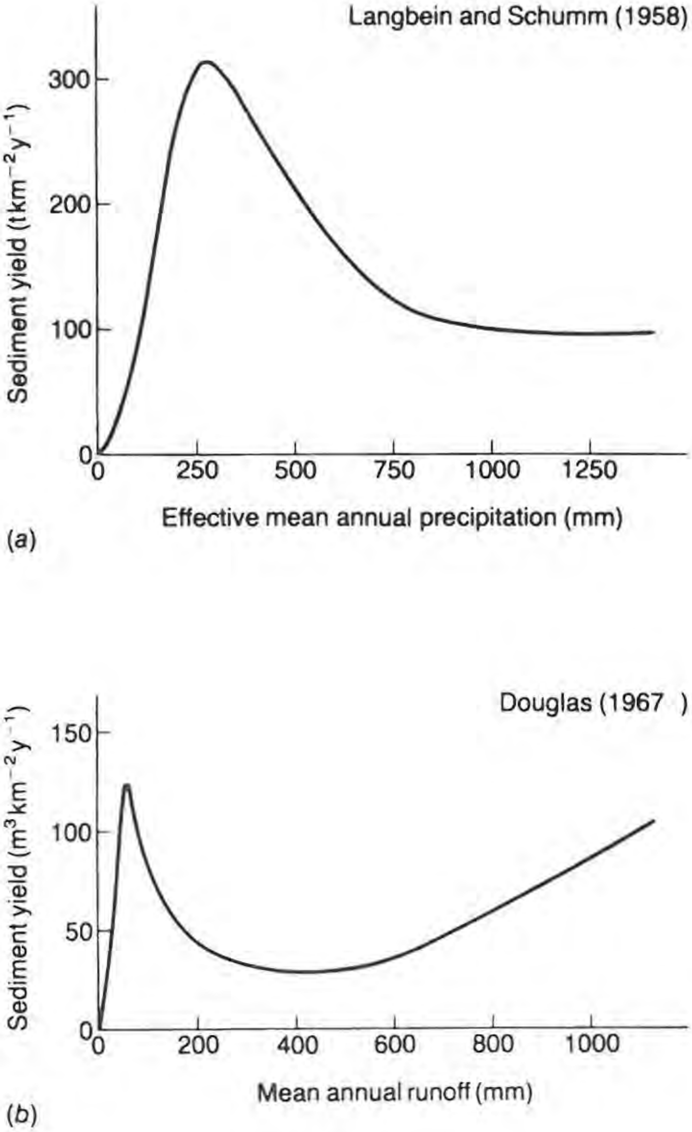



FIGURE 2.2: GENERALIZED RELATIONSHIPS BETWEEN SOIL EROSION AND RAINFALL (Morgan, 1986 p4).

The transference of momentum from raindrops to the soil particles has two effects; in the first instance it provides a consolidating force, compacting the soil and reducing infiltration rates and secondly it imparts a velocity to soil particles, dislodging them and launching them into the air (Morgan, 1980). Mannering and Wiersma (1969) showed rainfall kinetic energy to be a principal cause of surface sealing. This in turn results in a reduction of infiltration, an increase in surface runoff and increased soil loss. Young (1972) suggests that this surface sealing is due to the dispersal of fine soil particles from soil aggregates which are then translocated to infill macropores. Fullen and Reed (1986) noted that soils with a spongy, friable surface lose sediment mainly by splash with little runoff erosion; once surface capping and sealing had occured the tendency for runoff generation increased and the soils were eroded by even moderate falls of rain (5 - 10mm at 1,5 - 2,0 $mm.hr^{-1}$ ).

Direct detatchment of soil particles has been studied by a number of workers. High speed cinematographic studies have been used to quantify the relationship between the size of drops, the distribution of water droplets and their dispersion (Mutchler, 1970). Ghadiri and Payne (1978) found that splash angle was highly correlated with soil shear strength. Reeve (1982) and Wright (1986) both made contributions toward the modelling of the splash transport process. Although the high detail, low perspective research on splash erosion has led to a better understanding of the process of detatchment, such studies are of little direct use to erosion hazard assessments undertaken at the regional scale. What is required at this scale is an index or measure of erosivity by rain which can be determined from readily available data.

Several experiments have demonstrated the importance of rainfall kinetic energy in the splash erosion process (Mihara, 1951; Wischmeier and Smith, 1958; Free, 1960). The kinetic energy of rainfall is related to the mass of the rain drops and the velocity of fall (Hudson, 1981). Laws and Parsons (1943) and Hudson (1963) studied the relationship between the median drop diameter and rainfall intensity. The former author showed that drop diameter increases with rainfall intensity whilst Hudson (1963) showed that the direct relationship between rainfall intensity and drop diameter holds only up to an intensity of $100mm.hr^{-1}$. With greater intensities the physical upper limit of drop size is exceeded and the trend reverses (Hudson, 1981). Differences were seen to be due to different types of rainfall formation (i.e. convective or frontal rain). Based on the above, single rainfall erosivity parameters were derived by a number of workers (Table 2.2).

Wischmeier and Smith (1958 and 1978), Wischmeier (1959), Dragoun (1962), Stocking and Elwell (1973) and Ulsaker and Onstad (1984) have shown a strong correlation between $EI_{30}$ and soil loss. $EI_{30}$ is the sum of the products of the kinetic energies of individual storms, E (determined using equation 'a' of Table 2.2), and their maximum 30 minute intensities, $I_{30}$, taken over a selected time period, usually one year (Wischmeier and Smith, 1978). The determination of $EI_{30}$ requires rainfall data from continuously recording rain gauges over a sufficiently long period of time (Elwell and Stocking, 1973). In areas where these records are available it is feasible to determine $EI_{30}$ on a storm, daily, monthly, seasonal or annual basis depending on user needs. Where sufficient autographic stations exist, $EI_{30}$ can be mapped using iso-erodents (lines joining points of equal erosivity). Wischmeier and Smith (1978) have produced such a map for the United States. The Agricultural Research Service of the United States Department of Agriculture (U.S.D.A., 1975) produced a similar map for Hawaii. In most countries insufficient autographic rainfall records exist for the production of iso-erodent maps. Hudson (1981) warns against the use of other rainfall parameters as surrogates for $EI_{30}$ unless they are shown to have a direct relationship with soil loss. However, in the absence of sufficient rainfall intensity data or soil loss data, there would appear to be no alternative than to estimate $EI_{30}$ from the type of rainfall data that is available. Various authors in different parts of the world have used the relationship between $EI_{30}$ and other, more easily obtainable, rainfall indices to extend the $EI_{30}$ data base and to facilitate iso-erodent mapping. Examples of maps produced in this way are Stocking and Elwell's (1974) map for Zimbabwe, Roose's (1976) map for West Africa, Bolinne's *et al.* (1980) map for Belgium, Smithen and Schulze's (1982) iso-erodent map for Southern Africa and Hussein's (1986) map for Iraq.

**TABLE 2.2: EQUATIONS RELATING KINETIC ENERGY (E) AND INTENSITY (I) OF RAINFALL** (after Hudson, (1981)).

| | UNITS | |
|---|---|---|
| | Energy | Intensity |
| a. $E = 11{,}90 + 8{,}73 \log_{10} I$ | $J.m^{-2}.mm^{-1}$ | $mm.h^{-1}$ |
| b. $E = 29{,}8 - \frac{127{,}5}{I}$ | $J.m^{-2}.mm^{-1}$ | $mm.h^{-1}$ |
| c. $E = 9{,}81 + 11{,}25 \log_{10} I$ | $J.m^{-2}.mm^{-1}$ | $mm.h^{-1}$ |

Sources: a; Wischmeier and Smith, (1978), b; Hudson, (1965), c; Zanchi and Torri, (1980).

The use of $EI_{30}$ as an index of erosivity has not been without criticism. Mosley (1982) showed that in beech forests in New Zealand the coalescing of small droplets on leaves during low intensity events and the resulting high energy of the larger falling drops made the use of an index based on rainfall intensity suspect. Morgan (1983) used a laboratory simulator to show that rainfall erosivity and soil erodibility are not entirely independent of each other. Rose (1960) challenges the assumption that rainsplash erosion is dependent on kinetic energy of rain and suggests that an equally valid relationship exists between erosion and momentum.

While the results of these studies suggest more complex relationships between soil loss and rainfall properties, the $EI_{30}$ index remains the most widely used erosivity index in soil erosion studies (Smithen, 1981). The index is relatively easy to determine from readily available meteorological data and good correlations between $EI_{30}$ and daily rainfall parameters allow the extension of limited data bases where necessary.

### 2.2: Soil

Soil erodibility refers to the resistance of the soil to both detatchment and transport (Morgan, 1980). It is therefore an inherent soil property reflecting the fact that different soils erode at different rates when other factors that affect erosion are the same (Mitchell and Bubenzer, 1980). A number of soil characteristics have been identified as contributing to the overall erodibility of the soil. These include soil texture, structure, organic content, chemistry, shear strength and permeability.

According to Zachar (1982), Bennett (1926) was the first to point out the fact that those soils which are resistant to erosion have a good structure, are easily permeable, have a profile with few genetic horizons, and are mechanically homogeneous. The search began for the properties which could be related to field erosion. A number of early researchers stressed the importance of clay content as a factor affecting soil erodibility (for example Middleton, 1930; Lutz, 1934; Bouyoucos, 1935). Hjulstrom (1935) examined the relationship between soil particle size and critical water velocities required for particle entrainment. He noted that for grains coarser than 0,5mm (fine sand) the critical entrainment velocity was directly related to the size of the particles; larger, heavier particles requiring greater critical velocities for their entrainment. For particles finer than 0,5mm in diameter an inverse relationship between size and entrainment velocity exists due to increasing cohesiveness of the finer particles. The general conclusion to these studies is that the least erosion resistant soil particles are silts and fine sands whilst the most erosion resistant particles are clays and coarse sands.

Stability of individual peds on wetting was also shown to be a useful indicator of soil erodibility. A number of methods for the measurement of clod stability has been put forward (for example, Middleton, Slater and Beyers, 1934; Bryan, 1968; Hamilton, 1977).

The ability of the soil to absorb rainfall and consequently to limit the amount of water available for surface runoff and soil erosion will effect the erodibility of the soil. This ability is directly related to the infiltration capacity of the soil (Moldenhauer and Long, 1964). Namba (1952) recognised the importance of infiltration in its effect on erodibility. Young and Onstad (1982) and Morgan (1983) identify the importance of decreased infiltration rates and increased runoff and erosion following surface sealing due to raindrop compaction.

The organic matter of soils is another measurable soil attribute. Evans (1980) states that soils with an organic content of less than 2% can be considered erodible. Organic matter effects erodibility indirectly through its beneficial effect on the development of clods, increase of porosity and cohesiveness (Baver, 1948). Elwell (1986) clearly shows that the erodibility of subtropical clay soils in Zimbabwe is directly related to the size of water stable aggregates. The size of these aggregates is in turn positively correlated with the percentage organic carbon with a maximum clod size occurring at an organic carbon level of 2,5%.

The variability of natural rainfall events has limited the usefulness of plot data for the determination of soil erodibility indices. With the advent of the rainfall simulator it has become feasible to ascertain soil erodibility under constant simulated rainfall conditions (Hudson, 1981). Examples of studies where soil erodibility values were obtained under conditions of simulated rainfall include Barnett, *et al.* (1965), Wischmeier and Mannering (1969), McPhee, Hartman and Kieck (1983), Loch (1984) and Elwell (1986). A limiting factor with respect to simulator studies is the time and cost involved. Verhagen (1987) found small, low cost flumes to be a simple and reliable alternative to the rainfall simulator in soil erodibility studies.

Perhaps the most significant set of plot studies on soil erodibility were those undertaken by Wischmeier, Johnson and Cross (1971). Using rainfall simulators they studied soil loss on 55 different soil types in fallow condition. Percent silt plus very fine sand, percent sand greater than 0,10mm, organic matter content, structure and permeability were identified as the five most important soil erodibility parameters and were included in a soil erodibility nomograph. These parameters can be readily obtained for most soils with field observations and standard laboratory analyses. The K-factor derived from the nomograph is suitable for use in the Universal Soil Loss Equation (USLE). Mitchell and Bubenzer (1980) recommend values determined by the U.S.D.A. as being preferable to those determined by the nomograph. The nomograph remains useful in areas where measured soil erodibility values are not available.

The K-factor is defined as the rate of soil loss per unit of erosivity ($EI_{30}$) from a standard plot (Wischmeier and Smith, 1978). Ambar and Wiersum (1980) investigated various erodibility indices in West Java. They concluded that, with the present knowledge, the K-factor is the most reliable index where soil conditions are similar to those on which the index was derived. Vanelslande, *et al.* (1984) on the other hand found little agreement between plot-derived erodibility indices and K-nomograph values in Nigeria. According to Smithen, McPhee and Schmidt (1985), rainfall simulator work completed in South Africa has shown that with a few exceptions, the K-factor can be reasonably well estimated using the K-nomograph.

Schieber (1983) modified the K-nomograph for use in South Africa by including a sixth factor which takes the stability of aggregates into account. D'Huyvetter and Laker (1985) concur on the necessity of a soil descriptor reflecting aggregate stability in their study of Ciskei soils. They found that the exchangeable sodium percentage (E.S.P.) affected erodibility. High A horizon E.S.P. values induce colloidal dispersion which in turn promotes surface crusting, reduces infiltration, increases surface runoff and increases erosion.

Eloff (1973) reviewed the work done on erodibility of South African soils and added some of his own observations. He stressed at the time that more detailed and intensive research was required before a suitable index could be determined. According to Eloff (1973) the most important research on erodibility of South African soils completed at the time were:

i) van der Eyk, Macvicar and de Villiers (1969), who derived a simple scoring system for soils in the Tugela Basin,

ii) Scotney (1973), who derived a wind erosion index for Natal based on a number of criteria including grain size, and

iii) Macvicar (1973a) who derived a three tier scoring system for the Natal sugar farming region.

Eloff's (1973) own observations in the Orange Free State were that duplex soils with abrupt textural boundaries were the most susceptible to erosion. The Estcourt soils, for example, have a shallow sandy A and E horizon overlying a dense, prismacutanic B horizon. During high intensity storms, rapid saturation of the permeable A and E horizons and the low permeability of the B horizon result in rapid runoff and initiation of surface erosion. High dispersivities in the B horizon encourage serious gullying after the initial removal of the upper layers. Other soils in this region (e.g. Sterkspruit) are subject to erosion due to drying out and hardening of the A horizon which reduces permeability and increases runoff and erosion. Valsriviers also have a high potential for erosion due to their low permeability. In a recent study in Nigeria, Vanelslande, Lal and Gabriels (1987) found that erodibility values using the Wischmeier, *et al.* (1971) K index did not give a satisfactory measure of soil erodibility. They found that parameters related to structural stability and reduction in infiltration were important in determining soil erodibility. These observations seem to support those of Eloff (1973) for soils in the Orange Free State. Both of these studies reach similar conclusions to those made in Bennet's original work on soil erodibility in 1926.

The only existing index of erodibility which has been widely used on southern African soils is the F-index as recommended by SLEMSA (1976). The basic index is derived from the texture of the soil. Adjustments to the basic index are made according to various criteria, such as, layers with low permeability, surface crusting and tillage practice. The authors of SLEMSA provide tables of basic erodibility indices and erosion hazard rating for the various soil classes found in South Africa. Hartman, McPhee and Bode (1987) report a reasonable correlation between the F-index and the K-factor for 5 morphologically dissimilar soil forms in the East London district of South Africa.

Few examples of regional scale studies showing the spatial variation of soil erodibility exist. Pauwels, *et al.* (1980) used the nomograph developed by Wischmeier, Johnson and Cross (1971) to map the erodibility of soils in Belgium. On the other hand, lithology seems to be a fairly commonly used surrogate for soil erodibility in regional scale studies. The discussion thus far has considered erodibility in terms of the properties of the soil. Various authors have examined erodibility with reference to the parent material from which the soils are derived. In the long term, the mineral composition of the soil is controlled by weathering of parent material. Weathering, in turn is affected by addition or removal of minerals by organic processes, water movement within the soil and the relative stability of the various minerals within the parent rock (Thornes, 1980). Carol (1970) identified the weathering series outlined in Figure 2.3 and suggests weathering potential indices as outlined in Table 2.3.

Selby (1982) compares the weathering of igneous rocks and sedimentary rocks in a humid temperate climate as follows:

i) Igneous rocks undergo fracturing due to pressure release and the opening of fissures by physical processes initially. At the same time felspars, micas and ferromagnesium minerals are carbonated to produce clay minerals and insoluble quartz is released to form the inert soil mineral skeleton. Porosity is increased and eluvial processes result in the removal of calcium, magnesium, sodium and potassium compounds in solution. The secondary hydrated silicate minerals are further weathered and iron and aluminium oxides are produced and added to the residual soil mass.

ii) Sedimentary rocks break down initially into particles with a size determined by the original particle size and the nature of the cement which binds the grains. Sandstones always weather to produce sand but shales and mudstones may initially produce particles larger than the clay size if the cement binds the clay.

**TABLE 2.3: WEATHERING POTENTIAL INDEX (W.P.I.) FOR SOME COMMON ROCKS AND MINERALS**

| MATERIAL | W.P.I. |
|---|---|
| Olivine | 54 |
| Augite | 39 |
| Hornblende | 36 |
| Biotite | 22 |
| Muscovite | 10 |
| Labrodorite | 20 |
| Andesine | 14 |
| Oligoclase | 15 |
| Albite | 13 |
| Quartz | 1 |
| Granite | 7 |
| Orthoclase | 12 |
| Basalt | 20 |

In general, weathering always tends towards stability and insolubility (Selby, 1982). Mature soils will therefore be dominated by high stability minerals as depicted in Figure 2.3. The strong relationship between soil type and parent material has long been recognised and early attempts at soil classification (mid to late nineteenth century) were often based on parent material (Steila, 1976). More recently soil taxonomists have shown that a soil classification system based on parent material alone is only satisfactory for young soils. Mature soils are an expression of a number of interacting environmental factors including climate, parent material, biological factors, geomorphic factors and time (Steila, 1976).

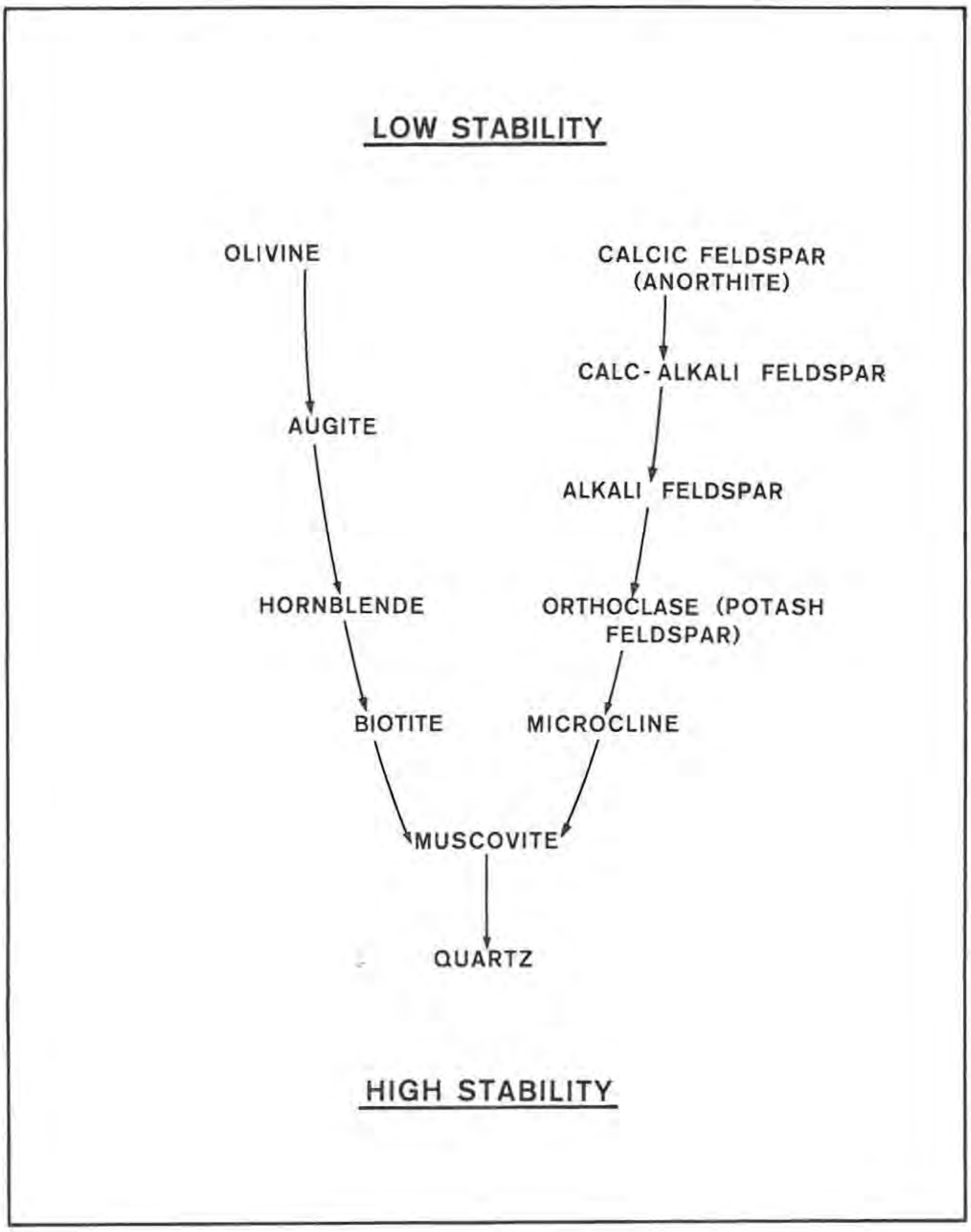



FIGURE 2.3: A WEATHERING STABILITY SERIES (Carol,1970).

Various workers have taken the relationship between parent material and soils one step further and have used parent material as an index of soil erodibility. Andre and Anderson (1961) found parent material to be highly significant in affecting the erodibility of Californian soils. Willen (1965) showed that soil texture and erodibility indices were significantly related to the variation in parent rock type in the Southern Sierra Nevada forest areas. In a study of soil erodibility in Hawaii, Yamamoto and Anderson (1967) found parent rock to be the most important variable explaining variation in erodibility. Berjak, *et al.* (1986) found gullying in the Umfolozi catchment (Natal, South Africa) to be least severe on dolerite and most severe on Dwyka tillite.

If a relationship exists between lithology and soil erodibility at a regional scale, the scope for producing maps of a soil erodibility index is greatly increased due to the availability of geological maps. Boundaries between different geological formations are also more easily defined than those between different soil types.

### 2.3: Relief

One of the fundamental environmental factors affecting the geographical distribution of soil erosion is relief. The effect of relief on soil erosion can be considered in simplified terms by considering various slope components (e.g. length, shape and steepness). In this section, the effect of the relief descriptors: slope angle, slope length, slope shape (profile and plan) and slope aspect on soil erosion will be considered in relation to the available literature. The discussion focusses on slope as a primary influence.

#### Slope Angle

Due to increased runoff coefficients, increased kinetic energy and carrying capacity of overland flow, decreasing soil and slope stability and the increased effectiveness of splash erosion, the likelihood of soil erosion is expected to increase in direct proportion with increasing steepness of slope (Zachar, 1982). Most of the literature on the effect of relief has been confined to runoff plot studies (Stocking, 1972a). The general conclusion of these studies is that soil erosion increases as a power function of slope angle:

$$E = f(S^m) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 2$$

Where: $E$ = soil loss
$S$ = slope angle
$m$ = an empirically derived exponent

The exact value which has been accorded to 'm' varies considerably with different workers. Table 2.4 summarizes some of these values.

**TABLE 2.4 : VALUES FOR THE EXPONENT 'm' IN EQUATION 2** (after Zachar, 1982).

| 'm' | AUTHOR | SLOPE RANGE |
|---|---|---|
| 0,4 | Gussak (1937) | 5 - 30° |
| 0,8 | Neal (1938) | 1,8 - 7,2° |
| 1,4 | Zingg (1940) | 4,8 - 12% |
| 1,35 | Musgrave (1947) | |

The above values (Table 2.4) are limited in use to local scale studies such as the design of conservation structures for agricultural lands. Stocking (1972a) made a study of eight different relief parameters in Zimbabwe to identify those which have the highest significant correlation with erosion. The physiographic parameters used were drainage density, proximity to natural drainage, highest stream order, three relative relief parameters, slope shape and average slope. A multi-variate analysis revealed that the single parameter, average slope, was dominantly significant in accounting for the distribution of erosion. Stocking (1972a) applied the derived relationship to Zimbabwe to map the potential erosion hazard due to relief.

An alternative method of expressing the importance of slope in its effect on soil erosion is the identification of critical slope angles at which erosion occurs. These critical slope angles can be defined for different rainfall intensities (e.g. Neal, 1938), for different crop types (e.g. Djorovic, 1980), for different soil types (e.g. Zachar, 1982; D'Huyvetter and Laker, 1985) or for different soil and crop combinations (e.g. Hartman, Erasmus and Brown, 1978). Smith and Wischmeier (1957) related soil loss to slope gradient using the quadratic equation:

$$A = 0{,}43 + 0{,}30s + 0{,}043s^2 \qquad \ldots\ldots 3$$

Where: $A$ = soil loss ($m^3.ha^{-1}$)
$s$ = slope angle (%)

Some recent studies show that the simple relationship between slope angle and soil loss becomes complicated by other environmental factors. The direct relationship between the two variables holds up until a threshold slope value, after which an inverse relationship develops. Heusch (1970), working in Morocco, attributed the reverse in trend to decreasing surface runoff and increasing subsurface flow on his particular research slopes. Odermeho (1986) obtained the following quadratic erosion-slope relationship for road-cut slopes in Nigeria:

$$\text{LogE} = 0{,}98 + 2{,}45\log S - 1{,}36\log S^2 \quad \ldots\ldots\ldots\ldots\ldots 4$$

Where: $E$ = soil loss ($t.ha^{-1}$)
$S$ = slope per cent

**Slope Length**

The observed increase in soil loss with increased slope length is generally attributed to an increase in total surface runoff with slope length (Morgan, 1980). Various workers have determined the relationship between slope length and soil loss as:

$$E = f(L^e) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 5$$

Where: $E$ = soil loss ($t.ha^{-1}$)
$L$ = slope length (m)
$e$ = an exponent

Table 2.5 summarizes the values obtained by different authors for the exponent 'e' (Equation 5).

**TABLE 2.5 : VALUES OBTAINED FOR THE EXPONENT 'e' IN EQUATION 5.**

| e | SOURCE |
|---|---|
| 0,5 | Kornev (1937) |
| 0,6 | Zingg (1940) |
| 0,5 | Musgrave (1947) |
| 0,2 - 0,5 | Wischmeier and Smith (1978) |

Lal (1982), working on 10 - 15% slopes in Western Nigeria, showed that runoff decreased with increasing slope length at a rate of $6mm.m^{-1}.yr^{-1}$. This is contrary to the generally accepted trend. Lal's studies (1982) showed, however, that irrespective of the decrease in runoff with increased slope length, there was a marked increase in annual soil loss of 2,4 $t.ha^{-1}.m^{-1}$ for slope lengths between 5 and 20m.

**Combined Slope Angle and Length**

Various attempts have been made to produce a single topographic factor which combines slope length and angle. Zingg (1940) used data from a number of experimental stations of the U.S. Soil Conservation Service to derive the equation:

$$Qs \propto \tan^{1,4} O . L^{0,6} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 6$$

Where: Qs = soil loss per unit area
O = gradient angle
L = slope length

According to Morgan (1980), the values for the exponents in Equation 6 have been confirmed by Musgrave (1947) and Kirkby (1969). Meyer and Monke (1965) also showed that runoff erosion increases with slope length and steepness. Other authors have shown that values for the exponents differ according to climate (Hudson and Jackson, 1959), soil characteristics (Gabriels, Pauwels and De Boodt, 1977) and the relationship between subsurface flow and surface runoff (Heusch, 1970). Perhaps the most widely used combined slope angle and length parameter is that derived by Wischmeier and Smith (1978) for use in the USLE (Equation 7).

$$LS = \left(\frac{X}{22,13}\right)^m (0,065 + 0,045s + 0,0065s^2) \ldots\ldots\ldots\ldots 7$$

Where: LS = combined slope angle and length factor
X = slope length (m)
s = slope gradient (%)
m = 0,5 if slope GE 5%
0,4 if slope LT 5% and GT 3%
0,3 if slope LE 3% and GE 1%
0,2 if slope LT 1%

Slope Shape

All of the relationships discussed thus far assume that the slopes have a uniform, straight shape. Straight slopes are indicative of an equilibrium between weathering and erosion (Besler, 1987). This is rarely the case in real world situations. Thornes (1980, p159) explains slope shape as being "...the interaction of angle and distance (with) important effects on the total magnitude of erosion. Where slope length increases but steepness decreases (concave slopes) the effects should offset each other. On convex slopes with increasing length and slope the rates should be at a maximum". Zachar (1982) makes a similar observation for undulating terrain where soil losses are at their smallest due to the balancing effect of erosion and deposition operating simultaneously.

There is general agreement in the literature that convex slopes are most susceptible to erosion and concave slopes are least susceptible to soil erosion. Various authors have quantified the relationship between profile slope shape and soil loss (Foster and Wischmeier, 1974; D'Souza and Morgan, 1976; Zachar, 1982). Castro and Zobeck (1986) produced a table of corrected LS values for concave slopes. According to Morgan (1986, p57), "...no studies have been made of the influence of slope shape in plan (on erosion), but Jackson (1984) found from erosion surveys and laboratory experiments that discharge varies with an index of contour curvature to the power of 5,5. If soil loss is assumed to vary with the square of the discharge, the value of 'm' (Equation 7) becomes 3,5". Although this relationship is likely to hold for unvegetated slopes, the findings of both Henninger *et al.* (1976) and Anderson and Kneale (1980) that soil moisture increases with increasing proximity to streams is likely to complicate matters on vegetated slopes. The higher soil moisture levels in laterally concave portions of the landscape would be more favourable for vegetation development than on laterally convex slopes where lower density vegetation would develop. Under these circumstances, the trend observed by Jackson (1984) would be inverted. In a study of surface soil moisture in small watersheds, Hawley *et al.* (1983) showed that cultivated slopes such as wheat seemed to mitigate differences in soil moisture caused by topographic variations. These areas are more likely to behave according to Jackson's (1984) model.

Moore and Burch (1986) derived an alternative to the LS factor based on unit stream power theory. The major advantage of the latter mentioned factor is that it takes into account the effect of lateral slope concavity on the concentration of flow (lateral slope convexity dissipates flow). This approach is in keeping with the trend amongst hillslope hydrologists to move away from Horton's (1933) model of overland flow and to develop the variable source area concept of runoff generation (Chorley, 1979; Ward, 1984). Although Campbell (1985) makes a plea for the application of variable source area theory to sediment production modelling, very little evidence of attempts to adopt this approach could be found in the literature available. Kirkby (1978) provides a theoretical consideration of the application of variable source area theory to sediment transport modelling. Jones (1987) studied the effect of soil piping on contributing areas and erosion patterns in mid-Wales.

**Landform Units**

There is evidence in the literature that the spatial distribution of soil erosion is closely linked to the occurrence of different landform units. Morgan (1980) lends support for erosion surveys linked with landform classification in his plea for a more dynamic approach to erosion survey by way of some form of geomorphological mapping. King and Fair (1944) observed that gullies in Natal occurred more frequently on what King (1962) termed the waning slope of hillslopes. This observation is contradictory to some of the theory mentioned earlier in that these slopes are usually of a relatively gentle angle and concave in profile shape.

Daniels, Gwilliam, Cassel and Nelson (1985) produced evidence that erosion severity is closely linked to different landform units in North Carolina. They found that shoulders and linear valley slopes tend to be moderately to severely eroded, the footslopes (King's waning slopes) were slightly to moderately eroded whilst the interfluves varied equally between being slightly and severely eroded.

**Slope Aspect**

Slope aspect affects soil erosion indirectly due to the different degrees of insolation occurring on sunny versus shaded slopes. Sunny slopes (north-facing in the southern hemisphere) have increased rates of organic matter decomposition, higher rates of evapotranspiration, and a higher degree of soil salt accumulation. All of the above affect the soil loss positively (Zachar, 1982). Although little work seems to have been carried out on the effect of slope aspect on soil loss, Zachar (1982) refers to various studies undertaken in eastern European countries which show that erosion on slopes with sunny aspects is higher than that occurring on their shaded counterparts. Both Kennedy (1976) and Churchill (1981) conclude that differences in slope morphology between between north- and south-facing slopes is most likely to be due to differences in the rate and type of weathering and erosion that result from aspect-induced topo-climatic differentials.

Slope aspect can also affect the efficiency of rainsplash erosion. Slopes facing rainbearing winds are more susceptible to rainsplash than leeward slopes (Besler, 1987). Likewise Cuff (1985) found that slopes facing storm-bearing winds showed a higher degree of slip and gully erosion than leeward slopes in a New Zealand watershed. Reid (1973) showed that north-facing slopes had a higher soil moisture content than their south-facing counterparts in a small catchment study in North Yorkshire. Aspect-related differences in insolation and soil moisture have an important effect on vegetation type. Edwards (1981) recognises the importance of slope aspect to pasture in South Africa. The growth conditions for plants are affected due to the fact that southern hemisphere northern aspects are hotter and drier than southern aspects. In the southern hemisphere, sweetveld (natural vegetation comprising mainly palatable species) is found on north-facing slopes with sourveld (natural vegetation comprising mainly unpalatable species) on south-facing slopes. In uncontrolled grazing situations animals tend to overgraze the more palatable sweetveld and underutilize the less palatable sourveld. Danckwerts (1987) observes that there are surprisingly few quantitative data showing the ill effects of not separating vegetation types when fencing farmland. This lack of data is ascribed by Danckwerts to the fact that the resulting area-selective grazing is obviously visible, avoiding the necessity for quantification. Slope aspect also has an effect on fires. In the southern hemisphere, vegetation on north-facing slopes is dryer and hotter fires are found than on the south-facing slopes which have moister vegetation. The vegetation on south-facing slopes contains less turpentines and is therefore less susceptible to fire (Trollope, 1987, pers. comm.). A further factor which will affect the relationship between slope aspect and the incidence of fires is the direction of high velocity, hot, dry winds (Granger, 1984). Slopes facing these winds will be more prone to fires than those on the leeward side. The hot, dry winds of the Ciskei region (berg winds) blow from the north (Heydorn and Tinley, 1980) and would therefore have a greater effect on north-facing slopes than on south-facing slopes.

In summary, the relief factors which have been identified as having a primary effect on soil loss are slope angle, slope length, slope shape, landform unit and slope aspect. The exact nature of the relationship between these relief parameters and soil erosion seems to vary from one study to another. There seems to be a strong interdependence between relief factors and other soil erosion promoting factors. Vegetation varies according to slope aspect as well as other slope characteristics. Soil catenas are closely linked to slope configuration and soil erodibility will therefore vary alongside the slope parameters. Both rainsplash erosion and erosion by overland flow are strongly dependent on slope. Relief characteristics must therefore be studied in conjunction with other soil erosion promoting variables.

## 2.4: Vegetation

The effect of varying levels of kinetic energy on soil loss has been discussed. Vegetation plays an important role in dissipating the kinetic energy of both rainsplash and sheetwash. The vegetation characteristics which are most important in reducing erosion are the canopy height and continuity, density of ground cover and root density (Morgan, 1980).

Thornes (1985) points out that even though the importance of good vegetation cover in reducing soil loss has long been realized, our understanding of the role of vegetation has long been neglected. Reasons given by Thornes (1985) for this lack of understanding include the complex nature of both the vegetation growth process and the erosion process, the slow rate at which the processes occur, the complex nature of human interference and the inherent vulnerability of natural environments. Notwithstanding Thornes' comments, a number of researchers have produced evidence of variable rates of soil erosion under different types of vegetation and different vegetation management practices.

The effect of raindrop interception on soil loss is clearly shown by the plot experiments of Hudson (1957). Soil loss recorded over a 10 year period from a bare fallow plot was 135 times greater than that recorded for a plot protected by a fine wire mesh gauze. The importance of vegetation goes beyond just interception. Vegetation also increases the water infiltration capacity of the soil through roots opening up the soil and increasing the proportion of macropores (Morgan, 1980). An indirect effect of vegetation is the increase in organic content via litter which increases soil stability and further enhances macropore development (Arnett, 1976) hence increasing infiltration and reducing the potential for soil loss through overland flow.

Intensive studies at the plot scale using rainfall simulators and under natural rainfall conditions have been undertaken to ascertain the effect of different crop types and different cropping management practices on soil loss. Zachar (1970), for example, found that soil loss from plots planted to potatoes was 22 times higher than an adjacent plot planted to rye during the same rainfall event. The effect of the extent of vegetation cover on soil loss was investigated by Holy (1965) who found that bare plots produced 6 times more soil loss than partially vegetated plots, which in turn produced 105 times more soil loss than fully vegetated plots. The extent of vegetation cover is used by Elwell and Stocking (1976) as a basis for the crop cover index used in SLEMSA. The index expresses soil loss as a function of mean seasonal vegetal cover.

Wischmeier (1960) and Wischmeier and Smith (1965, 1978) used the extensive data base from USDA plot experiments to derive a cropping management factor (C) for use in the USLE. This factor (C) represents the ratio of soil loss from a specific cropping or cover condition to the soil loss from tilled, continuous fallow condition for the same soil and slope for the same rainfall (Mitchell and Bubenzer, 1980). Maximum soil loss occurs under fallow conditions with rates reducing as the vegetation crop cover increases. The dynamic nature of vegetation growth makes C one of the most difficult factors to quantify in the USLE. Tables of average annual C values have been produced for the United States (Wischmeier and Smith, 1978).

Much effort has gone into determining the effect of crop canopy and surface mulches in the South African rainfall simulation program (McPhee, Smithen, Venter, Hartman and Crosby, 1983). The emphasis here has been on wheat, maize and pineapple lands. Platford (1979) has determined the effect of different methods of sugar cane cultivation on soil loss. The general conclusion of these and other studies is that soil loss is inversely related to the amount of mulch cover and the extent of canopy cover.

The relatively few investigations on soil loss under conditions of natural vegetation reveal that erosion rates are low under undisturbed conditions. Man can, however, increase the soil loss either directly through road clearing and cultivation or indirectly through overgrazing and fires. Gifford (1972) observed that cultivation of natural sagebrush in Utah resulted in lower infiltration and higher sediment production. Hart (1984), using rainfall simulators on sagebrush sites in Utah, found that previously negligible rates of soil loss increased significantly once the plots were cleared.

Various authors (Brown, 1972; Good, 1973; Wells, 1981; Blong, Riley and Crozier, 1982; Bosch, Schulze and Kruger,1984; van Wyk, 1986) have shown that soil loss under natural vegetation increases considerably following bushfires. Increased soil loss following fires is not only a result of decreased vegetation cover. Durgin (1985) showed that ash, leaching into the soil after fires can increase soil erodibility considerably by increasing the dispersivity of the soil. Megahan and Molitor (1975) came up with similar findings and suggested that slash beneath forest should be disposed of to avoid increased ash build up. Mooney and Parsons (1973) identified a distinct, non-wettable layer in chaparral soils. This layer is comprised of soil particles coated with carbonic substances leached from shrubs or their litter. According to Goudie (1981), the high temperatures accompanying chaparral fires cause these hydrophobic substances to be distilled and to condense on lower soil layers. The process results in a shallow layer of wettable soil overlying a non-wettable layer. This results in severe erosion more than 1000 times greater than that occurring in areas unaffected by fire (Goudie, 1981).

Alderfer and Robinson (1947) reported high runoff from heavily grazed pastures, with little or no runoff from ungrazed areas. High runoff is ascribed to the lack of soil cover and compaction of the surface layer by animal hooves. Menzel, Rhoades, Olness and Smith (1978) observed twenty-fold differences in soil loss between range land with limited grazing and that which has been heavily grazed. Snyman and van Rensburg (1987) showed that soil loss in the *Themeda cymbopogon* veld* of central Orange Free State (South Africa) varies from 3,9 $t.ha^{-1}$ for a simulated rainfall event in pioneer grass to zero for climax grass cover. Although Barnett, Beaty and Dooley (1972) showed no increase in soil loss under controlled grazing of fertilized fescue, the general trend in natural grazing areas seems to indicate that increased stocking rates of grazing animals leads to increased soil loss.

Various authors report minimal soil losses under natural forest conditions with marked increases following deforestation (Beschta, 1978; Riega, Olive and Burgess, 1979; Chang, Roth and Hunt, 1982; van Lear, Douglass, Cox and Augspurger, 1985). Davis (1976) showed that a change in land use from natural forest to cropland resulted in a forty -fold increase in the rate of sediment deposition in Frain Lake, South Michigan. There is, however, also evidence that well managed cultivation of previously afforested slopes can result in soil losses well within acceptable limits (Lundgren, 1980).

Gerlach (1976) investigated the relative rates of erosion from forest, pasture and cultivated lands in the Tatra mountains. He found that soil loss was greatest from cultivated lands and least from forested lands. He found soil loss to be 15 to 1 200 times greater on cultivated lands than on pasture lands and 15 to 30 000 times greater on cultivated lands than on forested lands (Zachar, 1982). Zachar's (1982) table of the relative soil conservation effects of different crops (Table 2.6) shows a range in soil conservation effect with forest providing the most effective cover, followed by grass stands, cultivated crops and a maximum loss occurring from bare fallow plots.

*"Veld" is a term used in South Africa to describe natural vegetation used for grazing and/browzing. Veld need not necessarily be climax vegetation as species composition may be influenced by management practices (Trollope, 1987).

TABLE 2.6: RELATIVE SOIL CONSERVATION EFFECTS OF DIFFERENT CROPS
(Zachar,1982)

| | |
|---|---|
| Fallow or barren land | 100% |
| Orchards with managed soil | 80 - 90% |
| Sugar beet, grain maize | 85% |
| Root and tuber crops | 50 - 80% |
| Spring cereals | 30 - 50% |
| Winter cereals | 5 - 35% |
| One year old grass stands | 1 - 5% |
| Older grass stands | 0,5% |
| Forests | 0,01% |

Thornes (1985) points out that empirically based studies on vegetation-soil erosion relationships such as those mentioned thus far have done little to help understand the complex interaction between these two variables. Thornes (1985) makes a plea for an ecologically-based approach based on the concept of competition between soil erosion and vegetational growth through time and space. A theoretical model is suggested where erosion and vegetation compete logistically while each is inhibited by the other. Sometimes erosion wins the struggle, sometimes vegetation. In this model grazing reduces the fitness of vegetation to compete with erosion in three ways: a) Grazing animals reduce the standing crop of vegetation (reducing litter production and fall), b) by preferring herbaceous species they tend to increase the relative percentage of woody species, favouring erosion, c) they compact the soil reducing infiltration (Thornes, 1985). Godron *et al.* (1981) use similar arguments in describing the deterioration of natural pasture in the Mediterranean where continuous grazing tends to shift the system from good herbaceous cover to a dominance of woody species and a higher erosion potential. Aucamp (1980) has found that similar trends occur in the False Thornveld of the eastern Cape where high densities of *Acacia karroo* following heavy grazing result in lowered grazing capacities.

Most of the studies mentioned above are based on site specific experiments. Very little information exists in the literature on the quantification of vegetation as an erosion promoting factor at the regional level. The importance of vegetation is however indirectly implied in some of the models of global sediment yield which use climate as an independent variable (Langbein and Schumm, 1958; Fournier, 1960; Dendy and Bolton, 1976). This gap in the literature is somewhat surprising when one considers the detail at which vegetation has been mapped in various parts of the world. The botanical accounts accompanying these maps often include observations regarding the stability of the vegetation type and the occurrence of erosion within that particular vegetation zone. Acocks (1953) and Roux and Vorster (1983) for example mention the effect of selective grazing and overgrazing of certain veld types* on soil erosion in various regions of South Africa.

Pentz (1959) and Moore *et al.* (1979) emphasize the importance of maintaining good natural grass cover in reducing soil loss. The importance of vegetation conservation in reducing soil loss in Ciskei was realized by Story (1952) and Robb (1952) and is still being emphasized in more recent publications (e.g. Trollope, 1976; Hill, Kaplan and Scott, 1977; Trollope and Coetzee, 1978). Although these workers continue to refer to "widespread erosion" within certain overexploited veld types, there seems to be no attempt at quantitatively defining this problem. One of the difficulties lies in the fact that vegetation-type alone does not truly reflect the ability of that vegetation unit to withstand erosion.

Crosby *et al.*(1981) produce figures that suggest that various natural veld types in South Africa have different soil loss potentials (C factors). For example it is suggested that Karoo vegetation is 6 times more susceptible to soil loss than Stormberg sweetveld. These values cannot be applied at any level of specificity due to the dynamic nature of veld types. Man, via deforestation, fires and overgrazing, affects the ability of vegetation to protect the soil in both time and space. Various environmental controls within one vegetation type such as soil moisture, slope aspect, slope steepness, soil type and insect activity also affect the spatial and temporal variation in the ability of the veld to withstand erosion.

The condition of natural veld is not only of interest to soil erosion studies. Pasture scientists have observed the dynamic nature of natural veld in both time and space and have identified the need for a more flexible method of veld classification than those traditionally applied. The assessment of veld condition, i.e. the state of health of the veld in terms of its potential for producing forage for sustained optimum livestock production (Willis and Trollope, 1987), has become one of the major foci of pasture science research in South Africa. The Veld Condition Score (V.C.S.) is an index of the potential of the veld for providing forage for sustained optimum livestock production (Trollope, 1987). According to Trollope (1987, pers.

* "Veld type" is a unit of vegetation whose range of variation is small enough to permit the whole of it to have the same farming potentialities (Acocks, 1975).

comm.) methods of determining V.C.S. are very much at the developmental stage especially with reference to the veld types found in the Ciskei region. Key publications in this field include Foran, Tainton and Booysen (1978), Aucamp (1979), Aucamp and Barnard (1980), Danckwerts and Trollope (1980), Danckwerts (1981), Danckwerts and Daines (1981), Teague, Trollope and Aucamp (1981), Danckwerts (1982 a & b), Aucamp, Danckwerts, Teague and Venter (1983), Teague and Danckwerts (1984) and Trollope (1986). According to Trollope (1987) the veld condition refers to the state of health of the veld in terms of its ecological stability and its potential for producing forage for livestock production.

Veld condition is assessed on both the grass and the bush component. The condition of the veld is compared with a benchmark site in terms of its botanical composition (Danckwerts, 1981). Benchmark sites comprise the subjectively chosen site which is the most productive and stable example of veld within a veld type. Herbaceous plants are classified into decreaser species, increaser species I and II and invader species. Decreaser species are those which dominate in good veld but decrease with mismanagement. Increaser I species are those species which dominate in poor veld and increase with understocking or selective grazing. Increaser II species are those which dominate in poor veld and increase with overstocking. Invader species are those not indigenous to the area (Trollope, 1987). The botanical composition of sample sites is then compared to the benchmark to determine the V.C.S. The percentage frequency of each species category is multiplied by a forage factor and then summed and the total score is expressed as a percentage of the total score for the benchmark (Trollope, 1986). For example, a V.C.S. of 60% means that the veld in the sample site is only 60% of its potential condition. V.C.S. data is used for formulating recommendations on stocking rates, rotational grazing and veld burning.

Mapping of vegetation in terms of V.C.S. has commenced in Ciskei and this could prove useful in establishing the vegetation characteristics which determine the spatial distribution of erosion. These data will more adequately fulfil Thornes' (1985) plea for an ecologically based approach than the commonly available information on vegetation types.

### 2.5: Man

The most important anthropogenic factors affecting soil erosion have been discussed in section 2.4, namely overgrazing, cultivation, deforestation and fires. High soil erosion rates are also associated with construction and urbanisation. Wolman and Schick (1967) and Wolman (1967) showed that sediment yields during construction reached 55 000 $t.km^{-2}$ in

Maryland. Yields for forest in the same year were 80 - 200 $t.km^{-2}$ and those under farming 400 $t.km^{-2}$. Walling and Gregory (1970) found suspended sediment concentrations in streams affected by upstream urbanisation to be as much as 100 times greater than those from undisturbed areas. Leigh (1982) notes that excessive soil losses occurred on sites cleared of vegetation but awaiting development in Kuala Lampur, Malaysia. Gullies of up to 10m deep are found in some ill-planned urban areas around the city.

Odermeho and Sada (1984) investigated the soil erosion problems of Auchi, Nigeria. They found that badly planned stormwater drains had resulted in channeling of runoff and the development of severe gullying. In a more recent study of erosion in Auchi, Omuta (1986) shows a definite link between increased population pressures and soil erosion in the area. Besides poorly planned stormwater drains, vegetation destruction for urban development and bad planning and control of land uses correlate well with badly eroded areas (Omuta, 1986).

Trampling in the areas surrounding settlements result in vegetation destruction and soil compaction both of which result in increased flow and increased potential for erosion. Quinn, Morgan and Smith (1980) carried out laboratory studies of soil erosion induced by human trampling which suggest that the breakdown of soil by trampling occurs whilst vegetation wear is still in progress and not, as is usually assumed, after the vegetation cover has disappeared. Bryan (1977) showed that the footpaths used by hikers in Sweden tend to encourage soil erosion. The severity of erosion on these hiking trails was shown to be dependent on soil properties. Both Bainbridge (1979) and Garland (1979) have noted that footpath and wheel tracks lead to serious erosion in the Drakensberg mountains. Garland (1983) developed conceptual models showing the sequence of events following footpath and vehicle track development. In both models, erosion is related to reduction in vegetation cover and organic content. On footpaths, surface smearing results in reduced infiltration capacity and increased runoff. On vehicle tracks, increased compaction results in reduced infiltration capacity, channelling of runoff and increased runoff and erosion.

The high concentration of foot traffic along paths leading to wood and water sources in rural areas makes these zones particularly vulnerable to this type of erosion. The problem can be exacerbated where herding of livestock occurs along similar paths. Roux and Opperman (1986) point out the important role of grazing animals concentrating around watering points in causing accelerated erosion in the Karoo. Valentin (1985) found similar problems around waterholes in the Sahel belt.

The method of cultivation as a factor affecting soil loss has been assessed at various levels. It is commonly believed that traditional forms of cultivation are more susceptible to high soil loss than those practiced in commercial farms. Stocking (1983) showed the reverse in Zambia. Traditional farming practices in the Mkushi district showed fewer signs of erosion than adjacent commercial farms. Weaver (1987) came to a similar conclusion and found that white owned commercial farmland in the Yellowwoods drainage basin (King Williams Town district) showed a greater reduction in the area of uneroded land than adjacent black owned, traditional farming land over a 9 year period.

Dregne (1982) in a review on accelerated erosion, states that accelerated erosion is associated with developing countries in which population numbers and land pressures are increasing rapidly. This trend is ascribed to the improper management of productive soil and the exploitation of marginal lands. The general conclusion to studies relating soil erosion to human occupation is that areas of high population are associated with high erosion levels. Stocking (1972b) found population density in Zimbabwe to be directly related to soil erosion and population density was used as one of the indices in an erosion risk map produced for that country (Stocking and Elwell, 1973).

The preceding discussion has illustrated the multi-dimensional nature of possible soil erosion promoting factors. A variety of methods exist for the quantification of the individual soil erosion promoting factors. The final selection of erosion hazard indices to be used in any study is not only a function of the state of art, but also the scale of operation and the availability of data.

# CHAPTER THREE

# MAPPING SOIL EROSION AND SOIL EROSION HAZARD

Various techniques are available for the quantification of soil loss and the assessment of soil erosion hazard. The final choice of a technique depends in the first instance on the purpose and the scale of the exercise and secondly on the reliability, accuracy and availability of the data (Hudson, 1980). This chapter considers the various possible scales of soil erosion study and the various possible approaches to soil erosion and soil erosion hazard mapping in general.

## 3.1: The Scale of Soil Erosion Study

The scale at which soil erosion studies have taken place varies considerably. At the microscale detailed process studies such as those on soil detachment by splash ( e.g. Ghadiri and Payne, 1980; Wright, 1986) have been undertaken. At the macroscale workers such as Fournier (1960), Corbel (1964) and Strakhov (1967) have produced maps showing the global distribution of soil erosion. In between these two extremes are investigations at the plot ( e.g. Lal, 1982), field ( e.g. Wischmeier and Smith, 1965), drainage basin ( e.g. Stromquist, Lunden and Chakela, 1985; Weaver, 1987), and regional ( e.g. Rooseboom, 1975; Stocking and Elwell, 1976) scale. There is generally an inverse relationship between the amount of detail and the perspective of the study, with low perspective, high detail study occurring at the microscale and high perspective, low detail type studies occurring at the macroscale. Most studies involved specifically with soil erosion hazard assessments take place at the drainage basin to regional scale with mapping varying from 1:10 000 ( e.g. Morgan,1974) to 1:1 500 000 (e.g. Makkaveyev *et al.*, 1984). The choice of scale depends on the purpose of the investigation as well as the scale at which the original data are available.

## 3.2: Soil Erosion Mapping

Soil erosion mapping is undertaken for a number of reasons. Morgan (1980) identifies the main reasons for mapping soil erosion as:

i) the depiction of the nature and location of erosion to distinguish between natural and accelerated erosion,

ii) to relate spatial variations in erosion intensity to other environmental factors,

iii) to understand interrelationships between erosion and deposition,

iv) to help in the design of conservation structures,

v) to enable delineation of areas of similar land use suitability,

vi) to provide the foundation for estimating erosion risk.

Techniques of soil erosion survey differ according to the eventual aims of the survey. In mapping changes in gully morphology over a short space of time, Welch, Jordan and Thomas (1984) found repetitive low level stereo photographic techniques to be useful. Keech (1968) used 1:25 000 aerial photographs to measure the density of rills and gullies in Zimbabwe. Another approach by Keech (1969) was to use aerial photographs to outline gullies on transparencies. Outlines from sets of sequential photographs then provided the basis for the determination of soil erosion trends in the Mondoro tribal trust land in Zimbabwe. Makhanya (1978) used sequential aerial photographs to map changes in erosion and to identify areas of high erosion risk in Lesotho. The maps produced by Makhanya's study were used to locate areas requiring immediate attention by soil conservation agencies. Whitlow (1986) used a series of 1 ha grids on acetate overlays to assess different types of erosion using aerial photos under 3 X magnification. Thwaites (1986) discusses a method used to depict soil erosion by symbols using 1:10 000 orthophotomaps. The method is similar to that described by Williams and Morgan (1976). Infra-red colour oblique photographs have proved to be useful data sources for the detection of different forms of soil erosion in cases where crops obscure direct observation from standard black and white photographs (Pihan, 1980).

Advances in remote sensing technology have opened up new prospects for soil erosion mapping. Satellite imagery clearly shows severe and very severe classes of erosion where highly reflective subsoil or windblown sand are easily recorded. For large scale mapping, it is however very costly and time consuming in view of the number of images to interpret (Riquier, 1980). Aerial photographs provide a far higher resolution but inevitably of a smaller area than satellite imagery (Keech, 1980). Millington and Townshend (1984) review the usefulness of different forms of remote sensing for erosion mapping and conclude that the ability to identify erosion features is a function of the scale of the erosion process and the pixel size. The level of resolution of most aerial photographs makes it possible to map all erosion processes whereas satellite imagery is limited to processes occurring over extensive areas only. With respect to erosion type , the aerial photograph is most valuable. Sheet, rill and gully erosion can be identified, mapped and quantitatively recorded (Bode, 1986). A scale of approximately 1:25 000 is the most effective scale to use, smaller scales lose detail and larger scales involve sacrifice in terms of the synoptic view (Keech, 1980).

One of the problems of soil erosion mapping from aerial photographs is the subjectivity of the viewer. To reduce this problem a systematic approach to soil erosion classification should be adopted. The mapping of soil erosion in South Africa is based on the classification system of the Southern African Regional Commission for the Conservation and Utilization of the Soil (SARCCUS) (1981). The main objective of this system is to provide a common approach to the identification and assessment of existing erosion in the SARCCUS region. The classification system was designed to meet several requirements. These are that it should:

i) be simple and descriptive in nature,
ii) meet planning needs at both farm and regional levels,
iii) indicate the types, classes (degree of intensity) and activity of erosion, and
iv) be applicable to air - photo interpretation supported by field surveys and other assessments (SARCCUS, 1981).

The types of erosion commonly found in the SARCCUS region (Botswana, Lesotho, South Africa (including homelands) and Zimbabwe) are sheet erosion (S), rill erosion (R), gully erosion (G), landslide erosion (L), terracette erosion (T), creep erosion (C), streambank erosion (B) and wind erosion (W). The soil erosion classification system identifies the degree and intensity of erosion within a given area of land or agro-ecological zone. The identification of the different classes is generally carried out through air-photo interpretation supported by field checks. The soil erosion classes in this system include:

Class 1 : No Apparent Erosion
Class 2 : Slight Erosion
Class 3 : Moderate Erosion
Class 4 : Severe Erosion
Class 5 : Very Severe Erosion

Each erosion map unit is identified by a code showing the symbols for the type or types of erosion, the class of erosion and the activity. The dominant type of erosion is indicated by placing the symbol first in the code order. A summary of the types and classes of soil erosion by water as given by SARCCUS (1981) appears in Table 3.1. The authors of the system stress the importance of carrying out field checks to support aerial photograph interpretations. Weaver (1987) produced a simplified version of the SARCCUS (1981) system for use in the Yellowwoods drainage basin. The basic problem with the SARCCUS system as it was originally presented is that the degree of detail suggested is too great for a system which is based on a fairly subjective assessment. The large number of classes suggested by the original SARCCUS system make it difficult to accurately assign an area to a particular erosion class. The result being that there is a high probability of overlap between adjacent erosion classes.

Field checking of the aerial photograph assessments involves the measurement of the depth and intensity of rills and gullies in the field and assessing the extent to which the mapped boundaries agree with the observable differences in field conditions. More detailed field assessment methods include detailed surveys of soil volume loss from gullies, sediment accumulation in reservoirs and measuring the exposure of datable tree roots (Rooseboom, 1981). Morgan (1980) produced a coding system for soil erosion appraisal in the field (Table 3.2).

### 3.3: Soil Erosion Hazard Mapping

Young (1973) defines land resource evaluation as "...the process of estimating the potential of land for one use or several uses" (p5). The land use potential can be defined either quantitatively or qualitatively. Erosion hazard assessment is a specialized form of land resource evaluation, the objective of which is to identify areas of land where a maximum sustained productivity from a given land use is threatened by excessive soil loss. The method aims at dividing the land area into regions, similar in their degree and kind of erosion hazard, as a basis for planning soil conservation work (Morgan, 1980). There is no agreed definition of the term 'region' when unqualified by an adjective; but it seems to be generally used with reference to a part of the earth's surface which is distinguished in some defined way from the surrounding areas (Grigg, 1970). In soil erosion hazard mapping, this distinction is based upon the identification of soil erosion promoting factors. The mapping of regional variation in erosion hazard can be based on a single criterion such as rainfall erosivity, or on a number of criteria such as erosivity, erodibility and slope angle.

TABLE 3.1: SUMMARY OF THE TYPES AND CLASSES OF SOIL EROSION CAUSED BY WATER (After SARCCUS, 1981)

| TYPE OF EROSION | CLASS OF EROSION | SYMBOL | DESCRIPTION AND REMARKS |
|---|---|---|---|
| SHEET (SURFACE) | None apparent | S1 | No visible signs of erosion on air-photo. Level of management appears to be high. |
| Uniform removal of surface soil | 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 air-photos. Plant cover very poor and sediment deposits extensive. Associated with small rills. |
| | Severe | S4 ) | Sheet erosion of such severity always associated with rill and gullies. |
| | Very Severe | S5 ) | Much or all of the A-horizon has been removed. |
| RILL Removal of soil in small channels or rivulets, mainly on arable land | None apparent | R1 | As for sheet erosion. |
| | Slight | R2 | Small, shallow (mainly 0,1m) rills present but not readily observed on air-photos. |
| | Moderate | R3 | Rills or considerable depth (mainly 0,1 to 0,3m) and intensity usually observed on air-photos. |
| | Severe | R4 | An abundance of deep rills (less than 0,5m) easily observed on air-photos. Subsoil may be exposed. |
| | Very 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 sheet erosion. |
| | Slight | G2 | Clearly observed on air-photos and usually up to 1m deep. Cannot be crossed by farm machinery. |
| | Moderate | G3 | Intricate pattern of deep gullies (mainly 1m to 3m) exposing entire soil profile in places. Many 'Islands' of topsoil remain. |
| | Severe | G4 | Landscape dissected and truncated by large (3m to 5m deep) gullies. 25% - 50% of area unproductive. |
| | Very severe | G5 | Large and deep (often 5m) gullies have totally denuded over 50% of the area. |

TABLE 3.2: CODING SYSTEM FOR SOIL EROSION APPRAISAL IN THE FIELD
(Morgan, 1980, p39)

| CODE | INDICATORS |
|---|---|
| 0 | No exposure of tree roots; no surface crusting; no splash pedestals; over 70% plant cover (ground and canopy). |
| 1/2 | Slight exposure of tree roots; slight crusting of surface; no splash pedestals; soil level lightly higher on upslope or windward sides of plants and boulders; 30-70% plant cover. |
| 1 | Exposure of tree roots, formation of splash pedestals, soil mounds protected by vegetation, all to depths of 1- 10mm; slight surface crusting; 30-70% plant cover. |
| 2 | Tree root exposure, splash pedestals and soil mounds to depths of 1-5cm; crusting of surface; 30-70% plant cover. |
| 3 | Tree root exposure, splash pedestals and soil mounds to depths of 5-10cm; 2-5mm thickness of surface crust; grass muddied by wash or wind; less than 30% plant cover. |
| 4 | Tree root exposure, splash pedestals and soil mounds to depths of 5-10cm; splays of coarse material; rills up to 8cm deep; bare soil. |
| 5 | Gullies; rills over 8cm deep; blow-outs and dunes; bare soil. |

The objective of soil erosion hazard mapping is to identify those areas of land where a maximum sustained productivity from a given land use is threatened by excessive soil loss. The aim is to divide the land-area into regions, similar in their degree and type of erosion hazard, as a basis for soil conservation work (Morgan, 1980).

Single factor assessments of soil erosion hazard have been used by various workers. Stocking and Elwell (1976), Smithen and Schulze (1982), Bergsma (1980) and Zanchi and Torri (1980) developed maps showing the spatial variability of rainfall erosivity. These maps can be used to assess spatial differences in the potential for soil erosion due to rainsplash. Soil erodibility maps, indicating spatial variabilities in the ability of the soil to resist erosion have, for example, been produced for Belgium (Pauwels, *et al.*, 1980), Bavaria (Becker, *et al.*, 1980) and Venezuela (Sentis, 1981). Elwell and Stocking (1976) used vegetation cover as a single index to assess soil erosion hazard in Zimbabwe.

The complex nature of the soil erosion process limits the applicability of single index methods of soil erosion hazard assessment. A more complex assessment of soil erosion hazard should involve the integration of the various soil erosion promoting factors discussed in Chapter 2. Examples of multiple index methods of soil erosion hazard assessment include Fournier's (1960) combined climate and topography index which was applied to South Africa by Doornkamp and Tyson (1973). Models such as the USLE (Wischmeier and Smith, 1962) and SLEMSA (Elwell, 1977) can also be used to estimate spatial variabilities in soil erosion hazard. Briggs and France (1982) quantified the input variables to the USLE on a 1km grid square scale to produce a choropleth map showing the distribution of soil erosion in South Yorkshire. They conclude that their method is capable of providing a broad picture of erosion for their study area. Vold, Sondheim and Nagpal (1985) applied similar techniques in the Lower Fraser River valley to provide an erosion potential map for the area. Stephens, MacMillan, Daigle and Cihlar (1985) used a slightly different approach and applied the USLE directly using input data obtained from colour-infrared photographs. They found the procedure to be efficient where appropriate soil and topographic data is available to supplement that obtained from infrared photographs. The F.A.O. (1979) system for assessing soil erosion at the 1:5 000 000 scale for North Africa and the Middle East comprises a simplified version of the USLE which uses approximate values representing means over large areas. A similar approach was adopted in Italy by Giordano (1984). Morgan *et al.* (1982) produced a simplified version of Meyer and Wischmeier's (1969) model for application in Malaysia. The model of Morgan *et al.* (1984) was applied to rain forest conditions in Indonesian Borneo by Besler (1987). Higginson (1973) used a cluster analysis to compare soil erosion classes with land systems to determine the erosion hazard of these systems in the Hunter Valley.

Stocking and Elwell (1973) mapped soil erosion hazard for Zimbabwe. The method used adopts a simple factorial scoring technique whereby five erosion factors are allocated values between 1 and 5. The erosion factors used are erosivity, erodibility, cover, slope and human occupation. Factorial values are summed for each area and an erosion risk value between 0 and 25 is obtained for each region. Similar multi-factorial approaches were adopted by Rowan and Downes (1963), Keech (1969), Higginson (1973), Williams and Morgan (1976), Barsch and Mausbacher (1979), Schwing and Vogt (1980) and Dickert and Olshansky (1986).

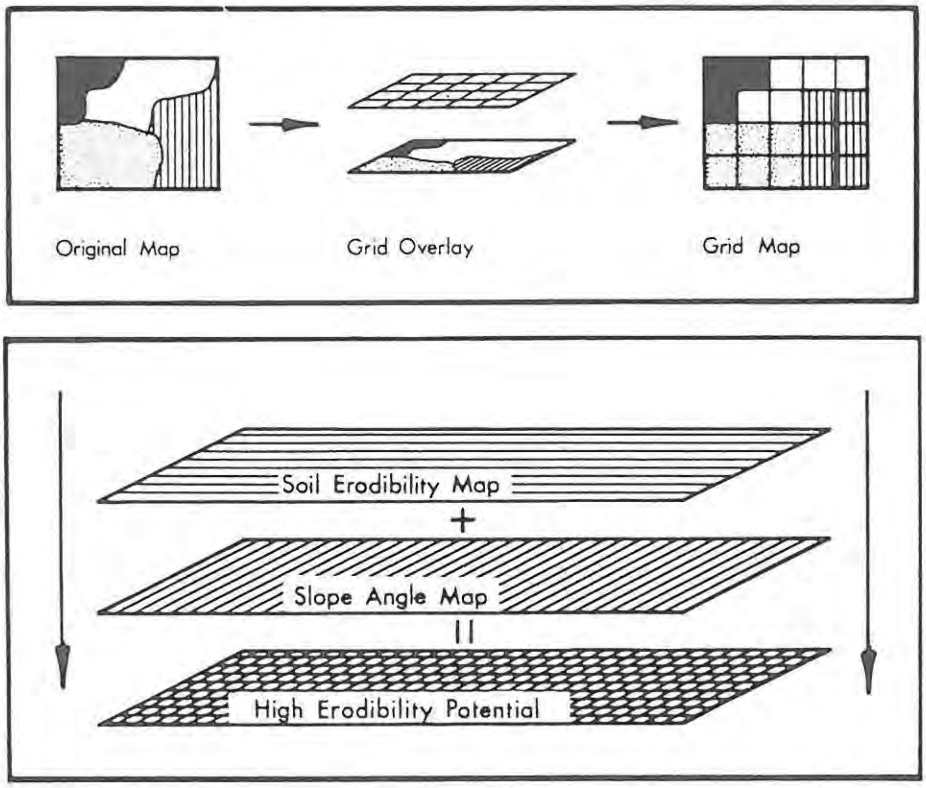
There is very little evidence in the literature of attempts to correlate maps of erosion hazard to actual erosion. In the past, erosion hazard maps have been derived on the basis of the generally accepted literature on the soil erosion promoting parameters. These parameters are quantified in terms of differing levels of erosion hazard and are combined in either a map or a mathematical model. The basic assumption being that the parameters adequately identify spatial variations in susceptibility to soil erosion. Whitlow (1988) showed that there is a poor correspondence between erosion (as mapped by Stocking and Elwell (1973)) and the extent of actual erosion. Whitlow's (1988) study illustrates the need to relate erosion risk maps to maps of actual erosion to ensure that the correct combination of erosion hazard indices is selected.

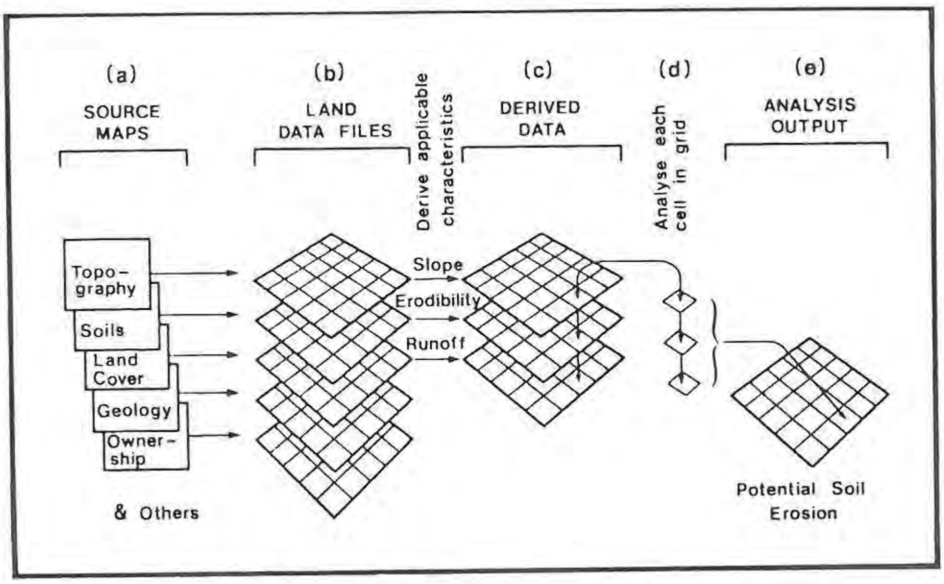
Methods for the quantitative comparison of data in mapped form are widely discussed in the literature and could be adapted for use in comparing the spatial distribution of soil erosion promoting factors to the distribution of actual soil erosion. Hammond and Walker (1984) discuss a computerised overlay technique which can be used for land capability assessments. This approach is similar to the geographic information systems (G.I.S.) approach to natural resource management. Walsh (1985) discusses the usefulness of G.I.S. for correlating essential planning information ( e.g. land cover) with a variety of environmental factors relating to such indicators as surface runoff, drainage basin area and terrain configuration. Walsh (1985) also identifies the possible use of G.I.S. in refining models like the USLE. Millington and Townshend (1984) advocate the use of G.I.S. in soil erosion studies. A G.I.S. is defined as a system that integrates layers of spatially oriented information either manually or automatically (Horvath, 1981). The G.I.S. could be described as an "automated filing cabinet" which facilitates rapid data retrieval and can be used to produce an integrated description of nominated attributes over all of a set of nominated locations (Cocks and Walker, 1987).

Figure 3.1 summarizes the procedures used in compiling a raster based G.I.S. Spatial information is transferred from a map into an array of X, Y and Z coordinates. X and Y relate the geographic position of the grid point or cell while the Z value indicates the attribute for the cell. The G.I.S. allows the user to discover and display information gained through the testing of interactions between phenomena and to organise and appraise variable coefficients for predictive models (Walsh, 1985).

Browne and Millington (1983) discuss the use of grid squares in computerised choropleth maps. They refer to a soil erosion study undertaken in Sierra Leone (Millington, Robinson and Browne, 1982) where the technique was used to represent various soil erosion phenomena spatially. Data were collected from a matrix of grid squares superimposed on the study area.

Data transformation from original map
to grid base (top). Data overlaying for
composite mapping (bottom).




Analysis procedure using geocoded data.

FIGURE 3.1: AN HYPOTHETICAL EROSION HAZARD GEOGRAPHICAL INFORMATION SYSTEM (Walsh, 1985 p204)

Information collected included slope, soils, vegetation and relief data. Comparisons of the different types of data allowed the authors to draw certain conclusions regarding the spatial variability of soil erosion in Sierra Leone (Browne and Millington, 1983).

It appears from the literature that the geographical information system concept presents an ideal facility for the integration of spatially variable soil erosion promoting parameters for the purpose of developing a soil erosion hazard model. The system can also be used to compare the spatial variation in actual soil erosion to the spatial variability in soil erosion promoting parameters.

# CHAPTER FOUR

## RESEARCH FRAMEWORK

In this chapter the research framework is presented by way of a problem definition, a statement of the research aims and the formulation of a research hypothesis. Since any problem is by its nature an unanswered question, posing a question is an accepted scientific method of stating a problem (Haring and Lounsbury, 1983). The key question to this thesis is:

"What factor or combination of factors can be used to explain the spatial variation in soil erosion in Ciskei ?"

The factors which are to be examined in the thesis are selected on the basis of the literature review (Chapter 2 and 3) and the availability of data in Ciskei (Chapter 5). The factors include soil erodibility, slope morphology, erosivity, geology, stock density, population density and vegetation.

The aim of the study is to develop an erosion hazard assessment technique for Ciskei which makes use of readily available data as its inputs. The realisation of this aim will only become possible once the research problem is satisfactorily resolved. The primary objective of the project is to identify the factor or combination of factors which most efficiently account for the spatial variation in soil erosion in Ciskei.

A single general research hypothesis has been formulated so that the study can be undertaken within a scientific and structured framework, i.e.:

"Soil erosion severity in Ciskei can be accounted for by a combination of factors which can be measured or evaluated using readily available data and techniques applicable at the regional scale of study."

Those factors which are likely to be influential in determining soil erosion severity have been previously identified in the literature as: mean annual precipitation, altitude, rainfall erosivity, soil erodibility, soil type, geology, slope steepness, slope length, the L.S. factor, profile slope shape, lateral slope shape, three-dimensional slope shape, slope aspect, land use, veld type, veld carrying capacity, veld condition score, population density, proximity to nearest settlement, footpath density and livestock density.

The testing of the study hypothesis entails the assessment of a number of different combinations of the erosion factors in relation to actual erosion. To enable this type of assessment to be made, data on soil erosion (the dependent variable, Y) and on the soil erosion promoting factors (the independent variables, $X_1, X_2, X_3 \ldots X_{21}$) need to be collected for the study area. Data collection is discussed in Chapter 6. If relationships between Y and the various X variables can be determined, then it will become possible to formulate an erosion hazard assessment technique. This technique could then be used for the estimation of erosion hazard in areas not already quantified and for the prediction of erosion effects given future changes to the relevant independent variables. Figure 4.1 outlines the sequence of questions that need to be addressed in the research programme. Figure 4.2 outlines the conceptual framework for the research procedure which, in turn, provides the basis for the methods of analysis (Chapter 7).

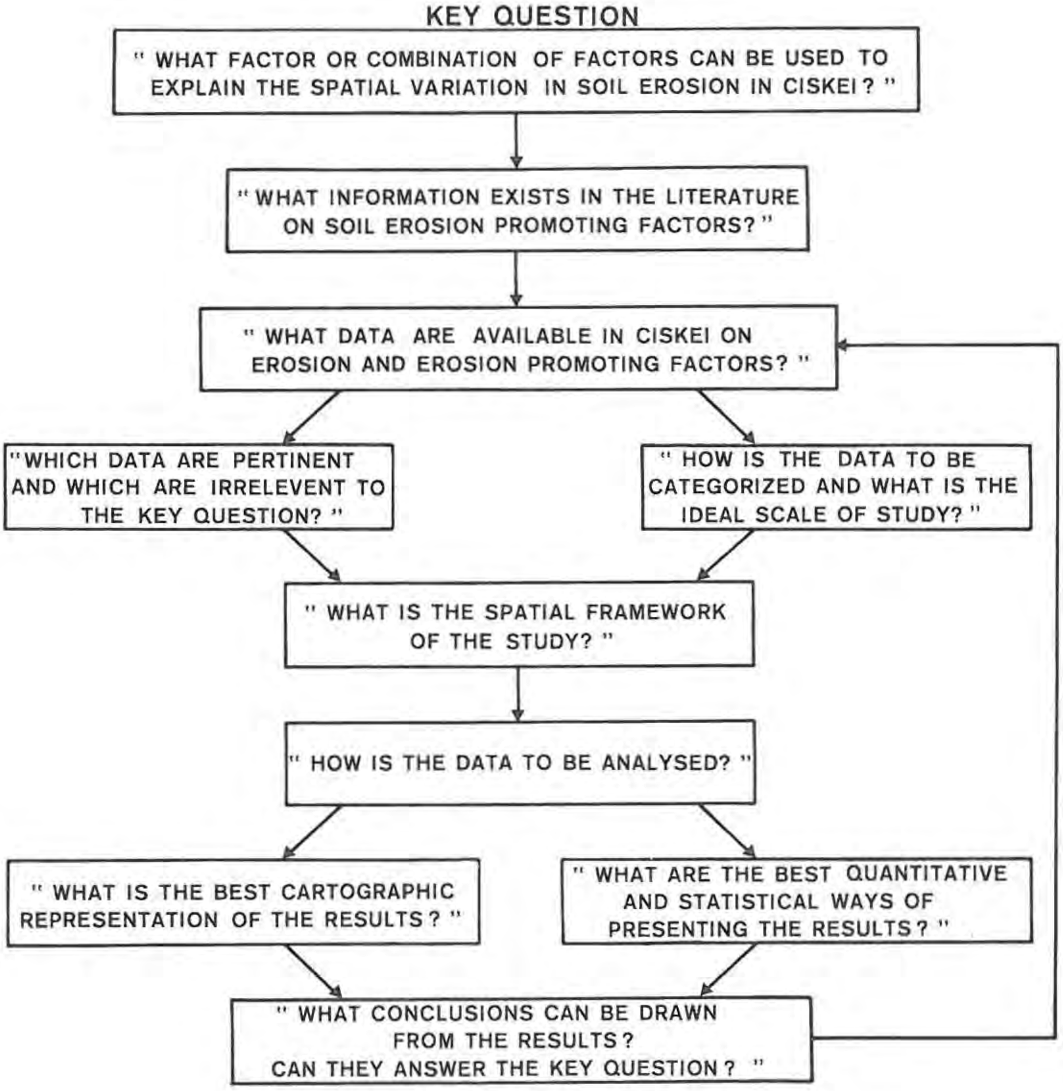



FIGURE 4.1 : KEY QUESTION AND SUBSEQUENT QUESTIONS TO BE ANSWERED THROUGHOUT THE RESEARCH PROCEDURE.

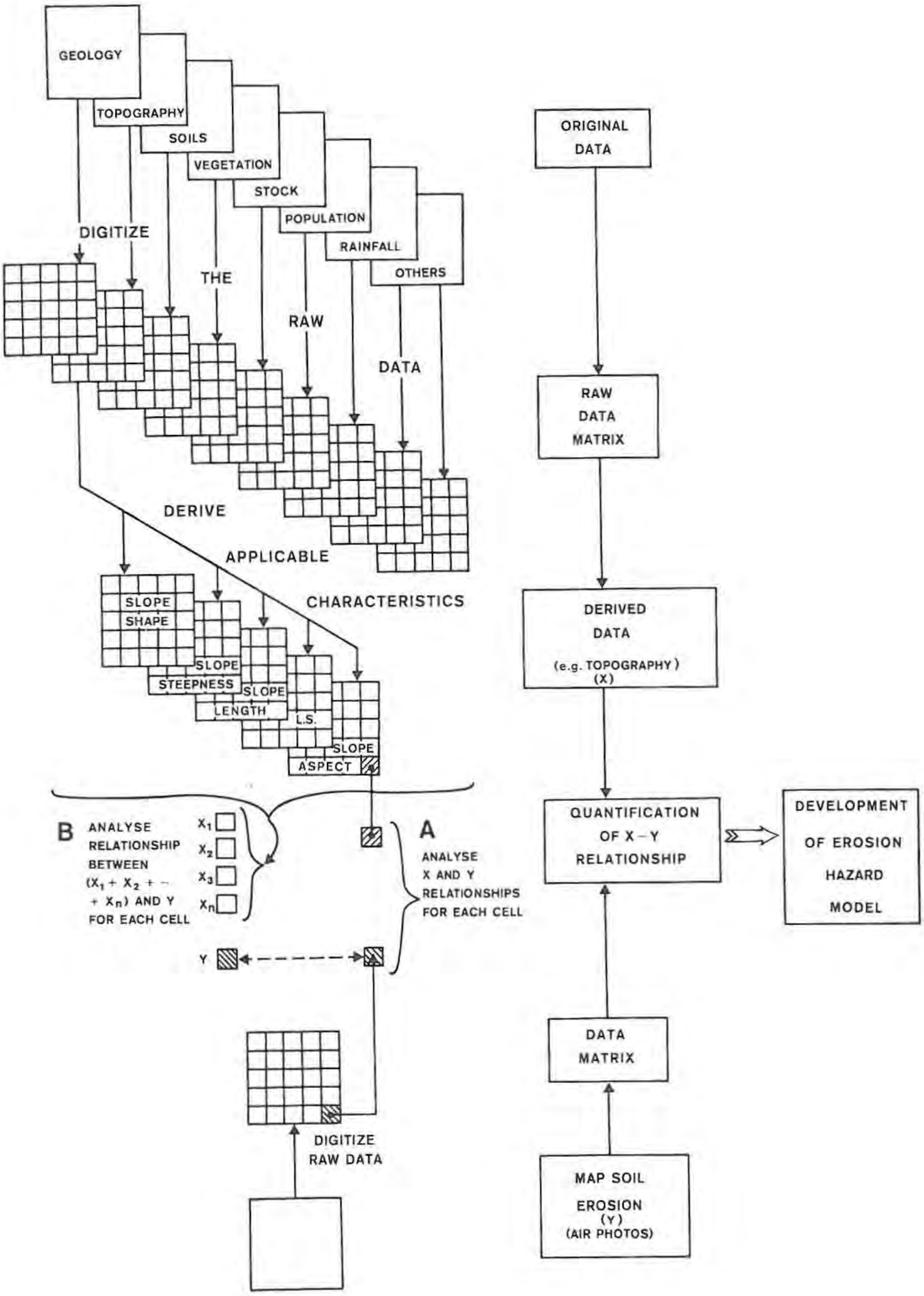



FIGURE 4.2: CONCEPTUAL FRAMEWORK FOR THE RESEARCH PROCEDURE.

# CHAPTER FIVE

# THE STUDY AREA

In this chapter, the general characteristics of Ciskei which are relevant to the study will be considered and will form the basis for the selection of study areas. The important question of data availability for the selected study areas will be discussed in relation to the hypothesis set in the previous chapter. Figure 5.1 shows the location of Ciskei and the major towns and transport routes in the area. The environmental characteristics which deserve general discussion are climate, geology, soils, topography, vegetation and population density.

## 5.1: Climate of Ciskei

Various climatic parameters such as evaporation, humidity, and temperature have an indirect effect on soil erosion because of their influence on, for example, vegetation and soil. Very little evidence could be found in the literature regarding the use of these indices in soil erosion hazard assessment. The direct effect of rainfall on soil loss is discussed in Chapter 2. This section will concentrate on the characteristics of the rainfall regime of Ciskei. Figure 5.2 shows the distribution of mean annual precipitation for Ciskei and Table 5.1 summarizes the relative amounts of mean annual rainfall occurring in Ciskei.

**TABLE 5.1 : PERCENTAGE AREA COVERED BY EACH MEAN ANNUAL RAINFALL CLASS IN CISKEI**

| MAP | PERCENTAGE OF TOTAL CISKEI AREA |
|---|---|
| 400 - 600 mm | 37,8 |
| 600 - 800 mm | 41,6 |
| 800 - 1000 mm | 15,9 |
| 1000 - 1200 mm | 3,0 |
| 1200 - 1400 mm | 1,0 |
| > 1400 mm | 0,7 |

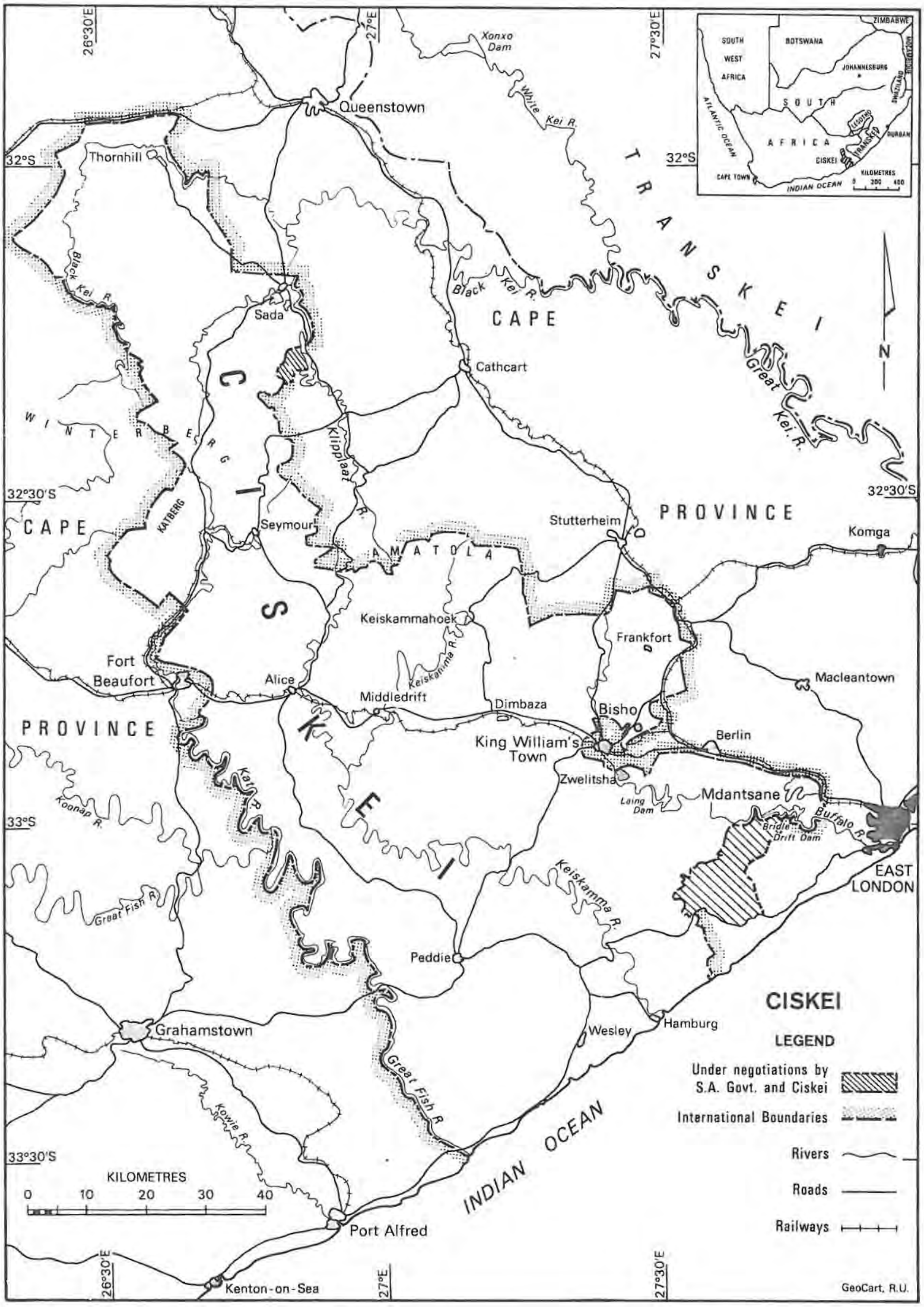



FIGURE 5.1: LOCATION OF CISKEI

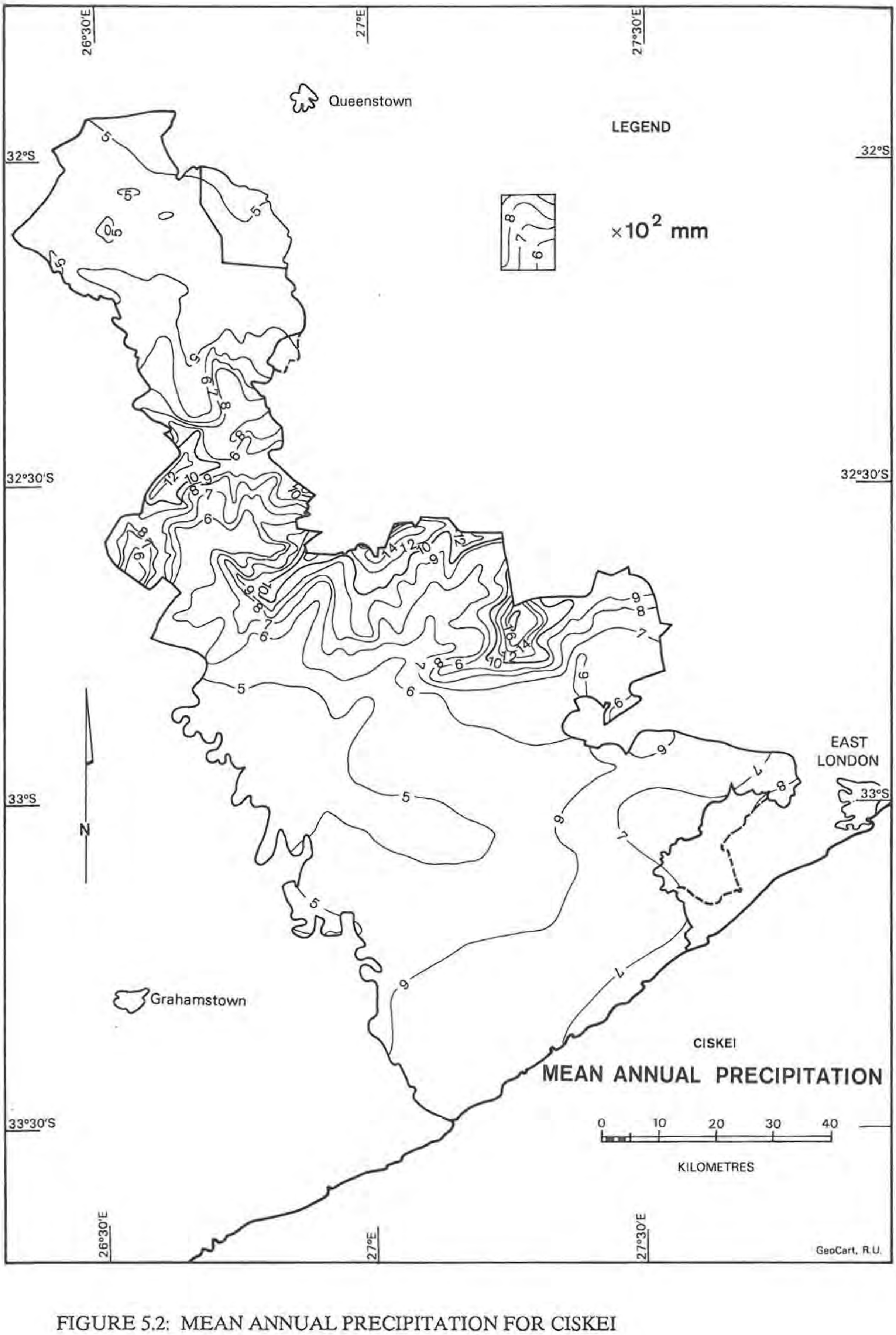



FIGURE 5.2: MEAN ANNUAL PRECIPITATION FOR CISKEI

Marais (1978) identifies four major climatic zones within Ciskei (Table 5.2):

i) A subtropical coastal belt up to 300m above msl having an MAP which decreases from 800mm in the east to 624 mm in the west. The rainfall is evenly distributed over spring, summer and autumn with a well-defined minimum (100 - 150mm) during the 3 winter months (Els, 1971).

ii) The coastal plateau region between the escarpment and the coastal plain and referred to as the East Cape Midlands by Whitmore (1957). This is gently undulating land rising to 600m above msl with deeply dissected ridges. MAP varies from 500mm in the west to 650mm in the east while values of less than 500mm are found in the Keiskamma River Valley. There is a well defined rainfall peak for March and a less distinct one in October. Winters are generally dry receiving only 50 - 100mm.

iii) The humid Amatole mountain region where orographic effects result in annual rainfalls in excess of 1000mm. Considerable variation occurs with some areas receiving more than 1500mm and others less than 700mm on average. Much of this variation may be attributed to localised rain shadow effects.

iv) The area to the north of the Winterberg is distinct from the rest of Ciskei. It represents a

**TABLE 5.2 : SUMMARY OF CLIMATIC CONDITIONS IN CISKEI**
(After Marais, 1978)

| | Type of Climate | MAP | Frost |
|---|---|---|---|
| i) Coastal Belt | Subtropical | 600 - 800mm | None |
| ii) Coastal Plateau | Semi-arid<br>Sub humid | 400 - 650mm | 30 days per year |
| iii) Amatole Mountain Region | Humid | 700 - 1700mm | 90 days per year |
| iv) North of Winterberg | Sub humid | 500 - 1000mm | 110 days per year |

sub-humid transitional zone between the eastern highveld areas and the semi-arid Karoo. It lies in the rain shadow of the Amatole Mountains and experiences MAP's of less than 500mm. Only a small area to the south and south west of the region receives more than 600mm. The winters are dry with most of the rain falling in late summer during convective storms.

Figure 5.3 shows the relationships between 100 year return period precipitation events of varying duration and mean annual precipitation for a number of Ciskei rainfall recording stations (data obtained from Adamson, 1983). The figure illustrates the relative importance of extreme events in the drier regions of Ciskei. These extreme events are likely to be important in terms of soil loss in the region. Rainfall in the wetter regions of Ciskei on the other hand is less aggressive and is likely to be more effective in terms of plant utilisation. Hill, Kaplan and Scott (1977) note a direct relationship between MAP and vegetation cover in Ciskei. Kirkby (1980) notes that erosion is often at its greatest where intense rain and vegetation are out of phase, as is normally the case in semi-arid and Mediterranean climates.

Currently available rainfall erosivity data for the area is that published by Smithen and Schulze (1982) who show mean annual $EI_{30}$ values to vary between 100 and 250 for Ciskei. This data is considered to be at too coarse a scale to be of use to the present study. Ciskei has no autographic rainfall stations with sufficiently long data records for the calculation of rainfall erosivity. Figure 5.4 shows the distribution of daily rainfall and autographic rainfall recording stations in and around Ciskei. The rainfall records from these stations represent the most comprehensive form of rainfall data available for Ciskei. Possible methods of computing erosivity from monthly data are mentioned in Chapter 2. The methods used to determine $EI_{30}$ in this study are described in Chapter 6.

It was decided to select study areas with a range in rainfall similar to the range found in Ciskei. The steep gradient in rainfall which occurs between the coastal plateau region and the escarpment reflects this range adequately and experiences a combination of rainfall types (cyclonic, advective and orographic).

### 5.2: Geology of Ciskei

Figure 5.5 shows the surface geology of Ciskei and Table 5.3 summarizes the relative area covered by each geological type. The 'typical' geology of Ciskei comprises sediments of the Beaufort Group intruded by dolerite. Outcrops of Ecca, Dwyka and Witteberg Group rocks

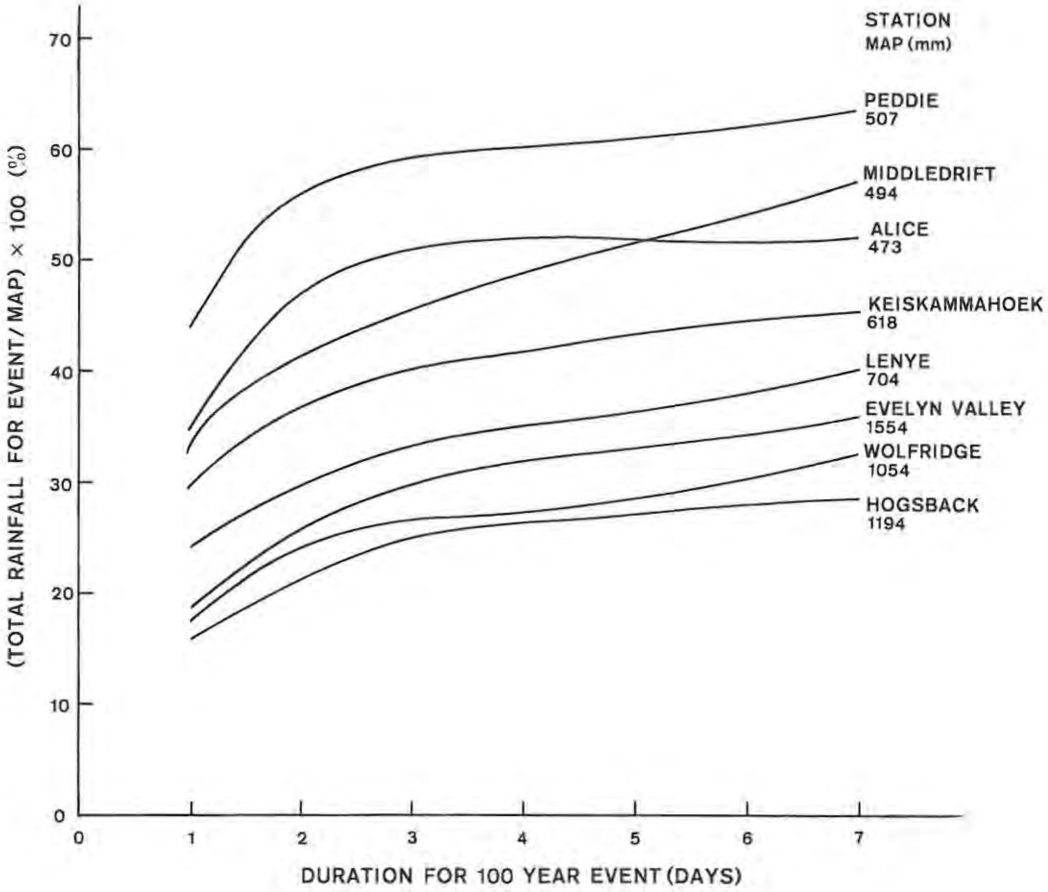



FIGURE 5.3: THE RELATIONSHIP BETWEEN EXTREME RAINFALL AND MEAN ANNUAL PRECIPITATION FOR EVENTS OF VARYING DURATION

do occur in the south western portion of the country with some more recent deposits occurring along the coast. The geological description that follows is drawn mainly from the legend to the 1:250 000 King Williamstown sheet (Johnson and Keyser, 1976).

Rocks of the Beaufort group are of Permian age. The group is subdivided into the Adelaide and Tarkastad subgroups. The Middleton and Balfour formations of the Adelaide subgroup

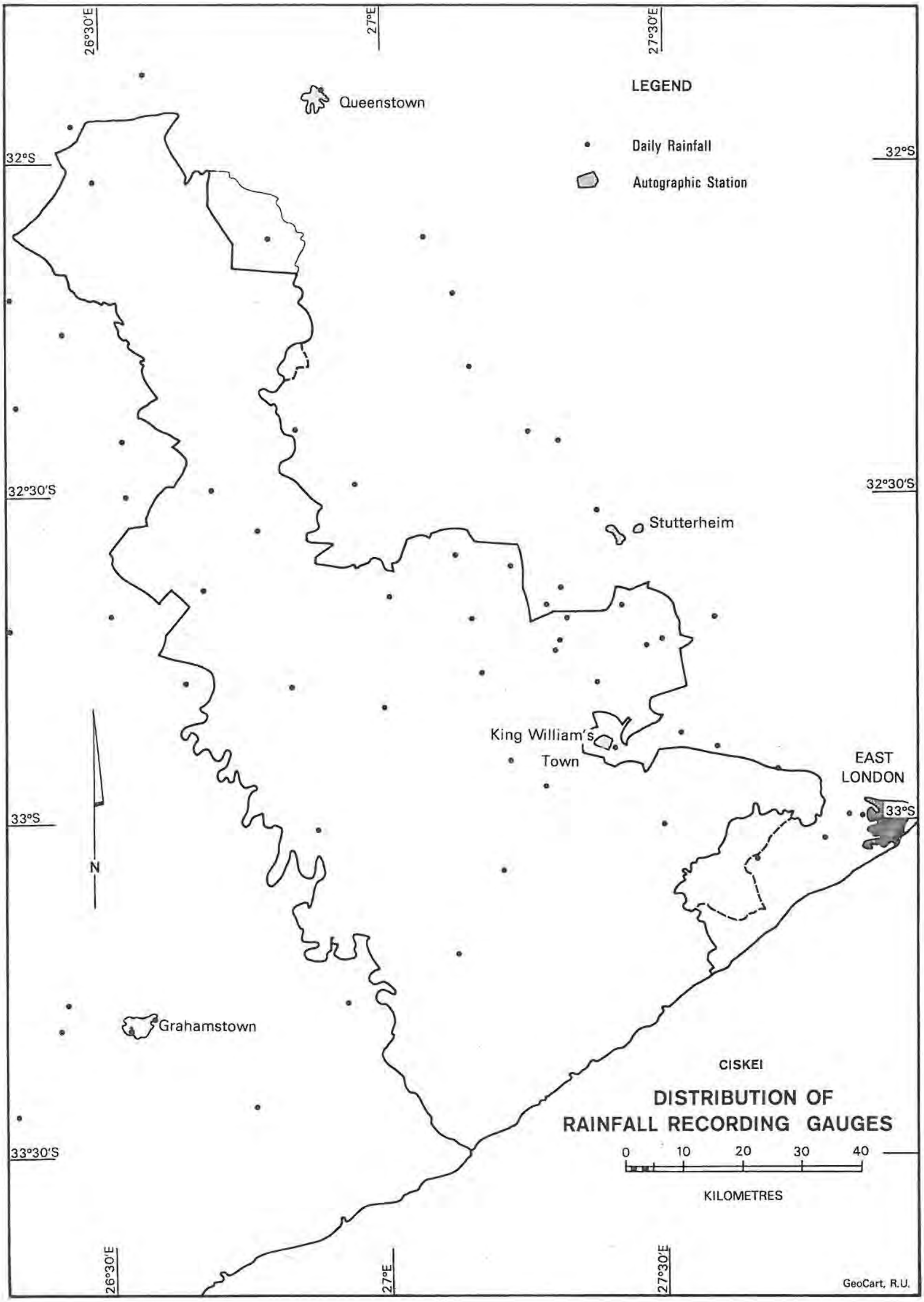



FIGURE 5.4: DISTRIBUTION OF RAINFALL RECORDING GAUGES IN AND AROUND CISKEI

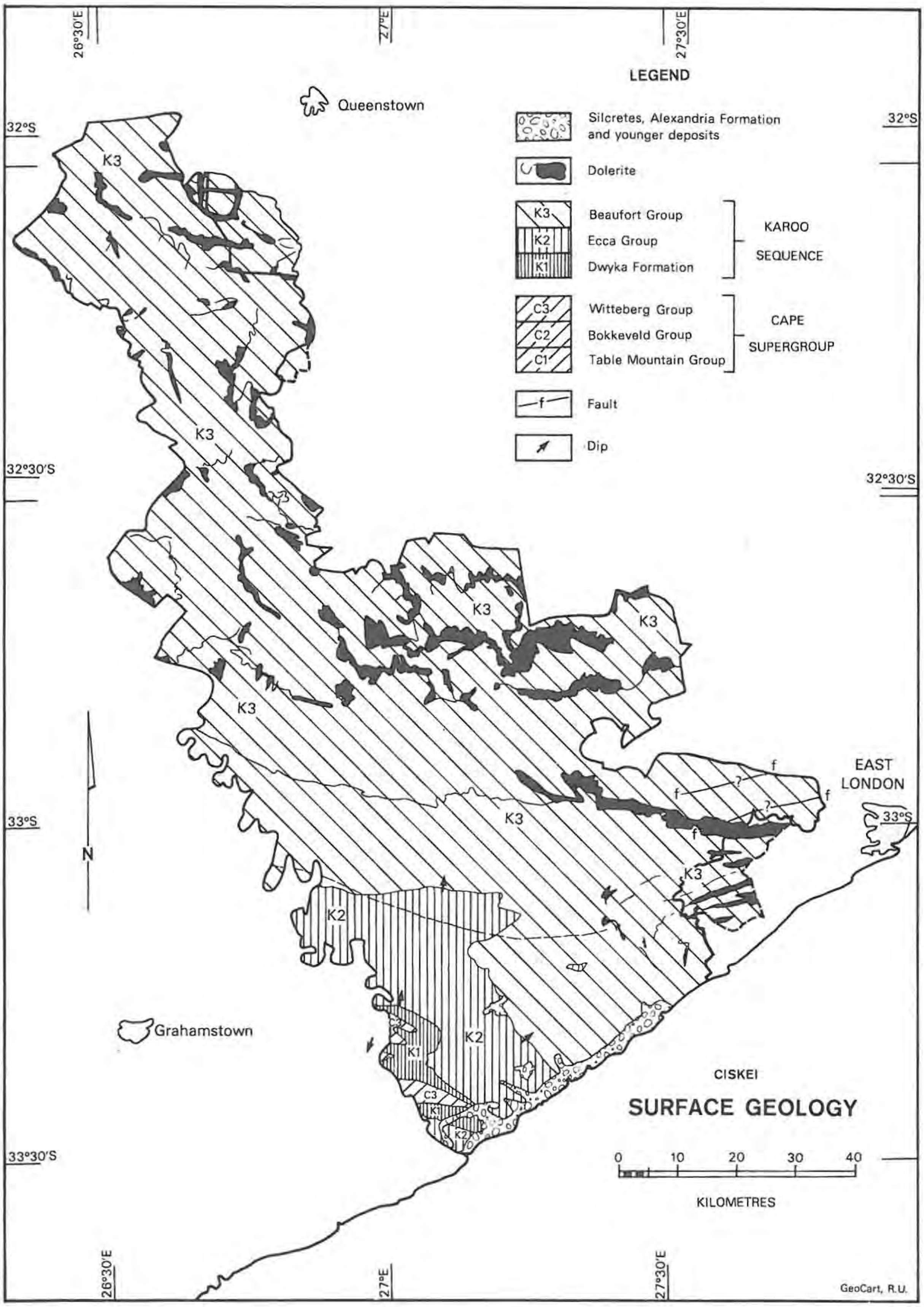



FIGURE 5.5: SURFACE GEOLOGY OF CISKEI

contain alternating layers of fine grained, grey sandstone (about 25%) and grey mudstone (about 75%). The only difference between the two subgroups is that there is some red mudstone in the Middleton group. The top of the Adelaide subgroup is defined as the horizon above which sandstone predominates over mudstone.

Mountain (1952) observed that the finer mudstone in the Beaufort group is easily weathered and under ordinary circumstances is highly erodible. On weathering this material breaks into smaller and irregular blocks which crumble easily when wet. The coarser sediment, on the other hand tends to be more resistant to erosion (Mountain, 1952).

**TABLE 5.3: PERCENTAGE AREA COVERED BY VARIOUS ROCK-TYPES OF CISKEI.**

| ROCK-TYPE | PERCENTAGE OF CISKEI AREA |
|---|---|
| Silcretes, Alexandria Formation and younger deposits. | 5,6 |
| Dolerite | 7,5 |
| Beaufort Group | 75,6 |
| Ecca Group | 9,4 |
| Dwyka Formation | 1,4 |
| Witteberg Group | 0,5 |

These coarser sedimentary rocks comprise the Tarkastad subgroup. The Katberg formation is dominated by sandstone (90% - 95% of the total thickness) with mudstone constituting the remainder. The Adelaide and Tarkastad subgroups show evidence of a fluviatile origin whilst the Balfour formation indicates deposition in a large inland body of water (Johnson and Keyser, 1976).

These sedimentary rocks have been intruded by numerous dykes, sills and inclined sheets of Jurassic age dolerite (Johnson and Keyser, 1976). Where distinctive outcrops do not occur, the dolerite outcrops can be identified by reddish brown, grading to black, soil (Mountain, 1952). The soils are very clayey with a well-defined crumb structure (Mountain, 1952). Both Mountain (1952) and Bader (1962) suggest that the dolerite soils of the Ciskei region are less prone to erosion than the soils associated with the sedimentary rocks of the Beaufort group.

Due to the predominance of Beaufort rocks and the possibility of significant differences between erosion on soil derived from Beaufort sediments and those derived from dolerite, the research areas will be restricted to these rock types. Although areas underlain by Dwyka and Ecca sediments have been excluded from the study, it should be pointed out that soils derived from these rock-types have been shown to be highly dispersive and susceptible to both compaction and erosion (Johnstone, 1981). Geological maps at a 1:50 000 scale are available for most areas in Ciskei from the South African Geological Survey Department.

### 5.3: Soils of Ciskei

One of the problems of describing the spatial variability of any environmental attribute is that different scales of description involve large differences in the level of detail and often different systems of classification. This is particularly true for soils. Figure 5.6 represents a very generalised description of the soils found in Ciskei with a summary of the relative occurrence of each soil in Table 5.4. Solonetzic soils represent the bulk of soils present in Ciskei, covering 68,8% of the total area.

**TABLE 5.4: PERCENTAGE AREA COVERED BY DIFFERENT SOILS IN CISKEI**

| SOIL | PERCENTAGE OF TOTAL CISKEI AREA |
|---|---|
| Latosols | 2,3 |
| Solonetzic Soils | 68,8 |
| Red Clays and Solonetzic Soils | 13,4 |
| Weakly developed soils on rock with much rocky land; lime rare | 8,2 |
| Weakly developed soils on rock with lime; with much rocky land | 6,9 |
| Weakly developed soils on rock with lime in bottomland sites | 0,4 |

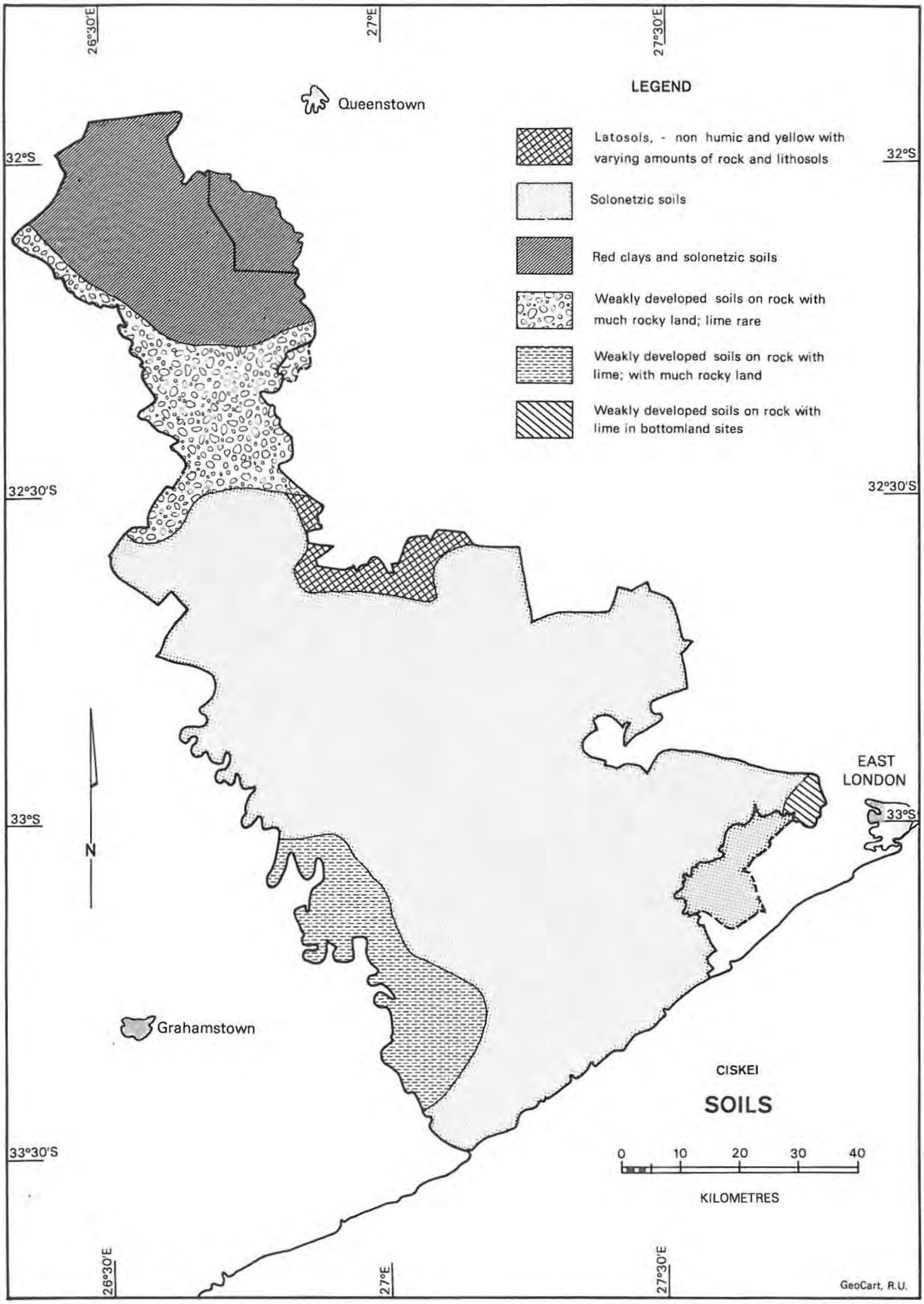
The slightly more detailed account of soils given by Hensley and Laker (1978) reveals that there is in fact a far more complex variation in soil types within the generalised boundaries designated by MacVicar (1973b). More detailed maps of soils exist for certain areas of Ciskei at scales varying from 1:10 000 to 1:50 000. The availability of detailed soils maps will be an important criterion in study area selection.

**5.4: Relief of Ciskei**

The Winterberg range forms an important physiographical barrier in Ciskei, dividing northerly and southerly flowing rivers. The effect of this range on the rainfall patterns in Ciskei has already been discussed. Figure 5.7 depicts the relief of Ciskei. Slope steepness is an important variable for consideration in this study. Figure 5.8 represents the slope steepness map produced by Page (1976) and Table 5.5 summarizes the areal extent of different slope classes. Other than the obvious tendency for steeper slopes around rivers incised into the coastal plain and the escarpment, there is a fairly widespread variation in slope steepness in Ciskei (Figure 5.8). The selection of an area which adequately represents the variation in slope should not, therefore, pose a problem.

**TABLE 5.5: PERCENTAGE AREA COVERED BY DIFFERENT SLOPES IN CISKEI**

| SLOPE % | PERCENTAGE OF TOTAL CISKEI AREA |
|---|---|
| > 20 | 34,4 |
| 10 - 20 | 32,6 |
| 5 - 10 | 21,4 |
| 0 - 5 | 11,6 |



(MacVicar, 1973)

FIGURE 5.6: MAJOR SOIL TYPES OF CISKEI

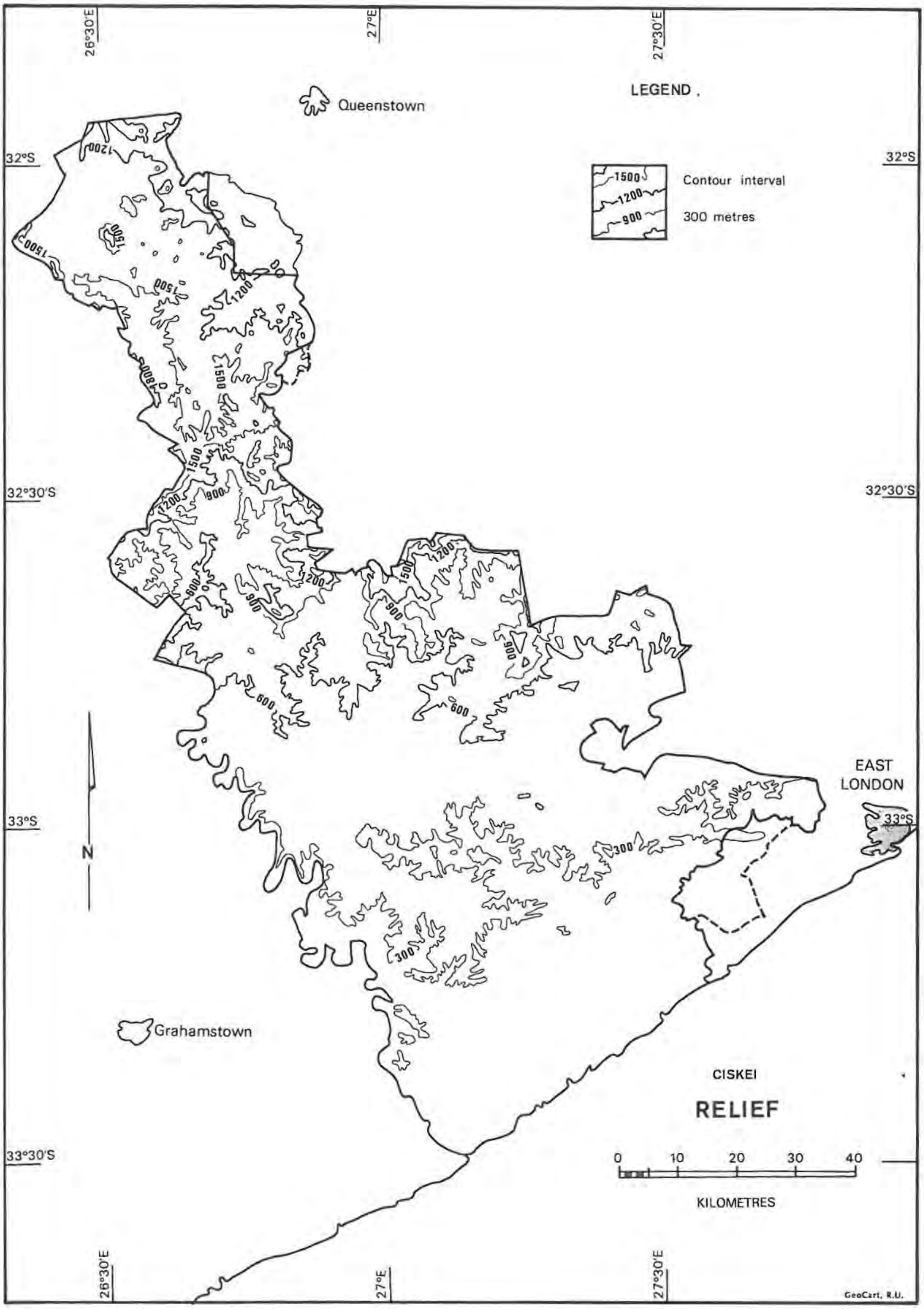



FIGURE 5.7: RELIEF OF CISKEI

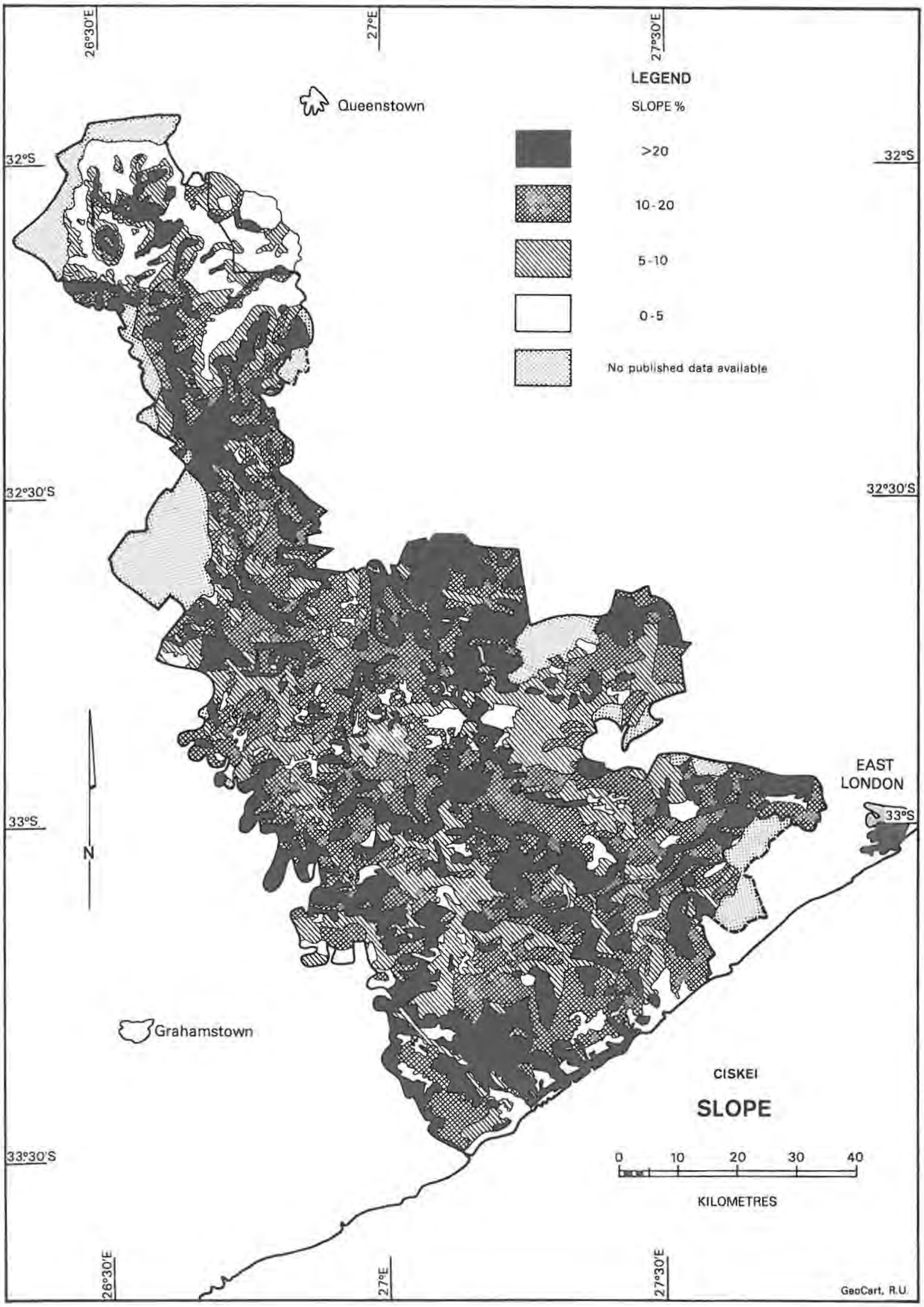



FIGURE 5.8: SLOPE STEEPNESS IN CISKEI

### 5.5: Vegetation of Ciskei

Figure 5.9 depicts the areal distribution of the veld types of Ciskei as defined by Acocks (1975). Table 5.6 shows the relative proportion of each of the veld types depicted in Figure 5.9. The description of the veld types that follows is based on Acocks (1975) and Trollope and Coetzee (1978). The veld types are grouped according the four biomes identified by Lubke, Tinley and Cowley (1988) for the purposes of this discussion.

**TABLE 5.6: PERCENTAGE AREA COVERED BY EACH OF THE VELD TYPES OF CISKEI** (Trollope and Coetzee, 1978).

| VELD TYPE | PERCENTAGE OF TOTAL CISKEI AREA |
|---|---|
| Valley Bushveld | 27,7 |
| Eastern Province Thornveld | 16,2 |
| False Thornveld of Eastern Province | 13,7 |
| Highland Sourveld and Dohne Sourveld | 12,3 |
| Coastal Forest and Thornveld | 8,4 |
| Dry Cymbopogon - Themeda | 7,3 |
| Alexandria Forest | 6,2 |
| Karroid Merxmuellera Mountain Veld | 5,8 |
| Invasion of Grassland by *Acacia karroo* | 2,4 |

#### Forest

This biome comprises the Coastal Forest and Thornveld and the Alexandria Forest.

i) Coastal Forest and Thornveld is transitional between the typical coastal forests in the north and the drier Alexandria Forest in the south and is also referred to as Acacia Savanna (Lubke, Everard and Jackson, 1986). Open thornveld with numerous and extensive patches of relic forest typify the area. The grassveld is scrubby with tall herbs and tall coarse grasses. Evergreen vegetation predominates. Rainfall is insufficient in amount and distribution to support a true forest. Forest in the region needs to be able to endure the dry winters.

ii) The Alexandria Forest veld type occupies the narrow coastal strip between the Keiskamma and Great Fish Rivers. Much of this area has been cleared for pineapple farming. Due to the dryness of the area, it is characterized by a wide variety of short trees with many scramblers and a grassy undergrowth. *Acacia karroo* replaces the forest in the drier area near the mouth of the Great Fish River.

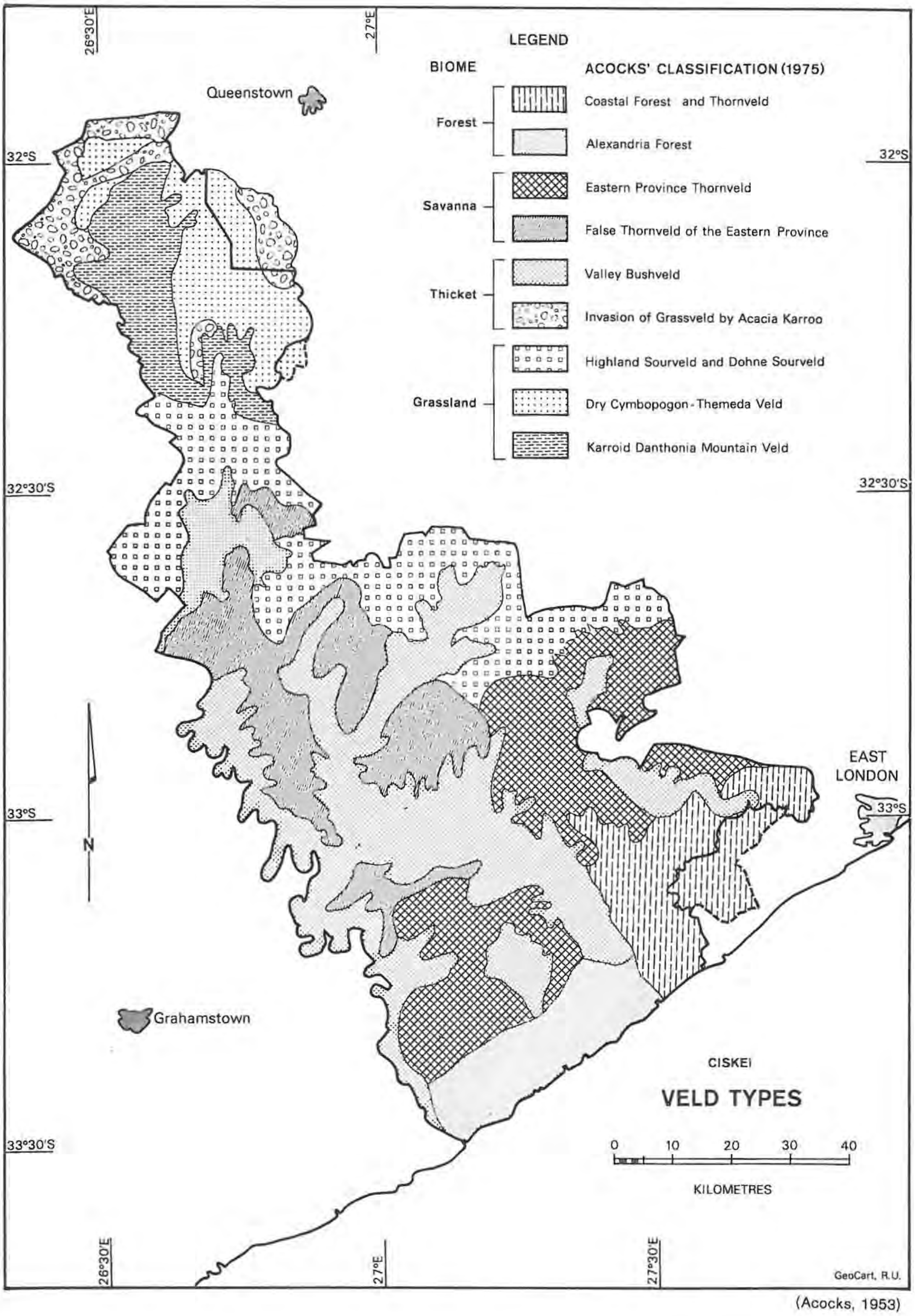



FIGURE 5.9: VELD TYPES OF CISKEI

**Savanna**

The Savanna biome of the area comprises Eastern Province Thornveld and False Thornveld of the Eastern Province.

i) Eastern Province Thornveld occupies the major part of the coastal plateau making it the second largest veld type (in extent) of Ciskei. Although the climax vegetation would have been short forest and scrub forest, this veld type is today essentially thornveld dominated by *Acacia karroo*. In many areas there are no trees and it is in essence grassveld. Dense, sourish mixed grasses typify the region with patches of sweetveld on dolerite soils.

ii) The False Thornveld of the Eastern Province is found mainly on the undulating foothills of the escarpment. Although this veld type was probably either Eastern Province Grassveld or marginal scrub forest, it currently ranges from grassveld, densely interspersed with *Acacia karroo*, to dense, clumpy shrub bushveld similar to Valley Bushveld and even to a False Karroid Broken veld. According to Acocks (1975, p 50) "...it is this thorn-bushclump veld which is invading the grassveld and by reducing the grass cover and assisting erosion, is opening the way for the spread both of the less mesophytic Valley Bushveld and of the Central Lower Karroo, an alien to these parts. The result is False Karroid Broken Veld, an extremely poor substitute for the short, dense grassveld which belongs here." The invasion of the grassveld by *Acacia karroo* has been linked with overgrazing (Acocks, 1975). According to Trollope and Coetzee (1978) these areas are covered mainly by inferior vegetation and are amongst the most badly eroded areas in Ciskei. They occur in areas of unreliable rainfall with poor quality soils.

**Thicket**

This biome contains a single Acocks (1975) veld type, Valley Bushveld. Valley Bushveld comprises the largest single area of Ciskei (27,7%) and, as the name implies is confined to the dry valleys dissecting the coastal plateau. Two sub-types have been identified in Ciskei. The Valley Bushveld proper, southern variation which includes all Valley Bushveld areas of Ciskei other than those in the Fish River Valley. This is a scrub forest dominated by tree - *Euphorbia*. According to Acocks (1975, p54) "...the bush tends to be scrubbier and reaches a higher altitude on the hotter and drier northern and western aspects, than it does on southern and eastern aspects. On the latter it is regularly tall *Euphorbia* forest, often with *Aloe bainesii*, merging on the upper slopes directly into forest, or where the forest has been destroyed, into grassveld or thornveld." *Acacia karroo* with mixed grass is generally found on the northern and western aspects. The second sub-type of the Valley Bushveld, Fish River Scrub, is found between the mouth of the Great Fish River and Committees Drift. This represents an adaptation of Valley Bushveld to lower rainfall and hotter temperatures. It comprises dense semi-succulent thorny scrub (2 - 2,5m high) invaded in places by prickly pear and *Euphorbia bothae*.

**Grassland**

The Grassland biome comprises four of Acock's (1975) veld types.

i) Invasion of Grassveld by *Acacia karroo* covers only 2,4% of Ciskei. This veld type represents an invasion of the dry Cymbopogon-Themeda Veld by *Acacia karroo* changing what was previously grassveld to a false bushveld. According to Acocks (1975) the taller *Acacia karroo* species shade out the grass and cause soil erosion, by bringing about concentration of grazing pressure on the sweeter and more palatable vegetation that develops under them.

ii) Highland Dohne Sourveld and Dohne Sourveld occur in the higher rainfall belts in the upper catchment area for the major Ciskeian rivers. The vegetation comprises forest, grassland, Macchia and scrub. Overexploitation has reduced much of the dense natural forest to scrub forest. Wattle has invaded indigenous forests in places. Encroachment of grassland by fynbos (macchia) has reduced the agricultural productivity of these areas in places. The forest portion of this veld type can be included in the forest biome (Lubke, pers comm., 1988).

iii) Dry Cymbopogon-Themeda Veld comprises 7,3% of Ciskei and is found in the northern portion of the country. Encroachment by *Acacia karroo* is a problem. Overgrazing of the grass component has led to a reduction in grass productivity.

iv) Karroid Merxmuellera Mountain Veld comprises 5,8% of Ciskei and is restricted to the northwestern portion of the region.

The preceding discussion of vegetation has been highly generalised and, as with soils, a far more complex variation occurs at the local level. The availability of detailed vegetation maps for Ciskei varies. Detailed maps exist for the Buffalo River Basin (Gibbs-Russel and Robinson, 1982), The Fish River Basin (Hill,Kaplan and Scott, 1979) and for the Keiskamma River Basin (Hill, Kaplan and Scott, 1977) at the 1:50 000 scale. The study areas selected should include representative veld types from each of the four major biomes and, if possible, the major veld types of Ciskei. The area should also include those veld-types which have suffered from overexploitation.

### 5.6: The Population Distribution of Ciskei

The final spatial variable considered important to the selection of study areas is the population density. Figure 5.10 depicts the population density for Ciskei whilst Table 5.7

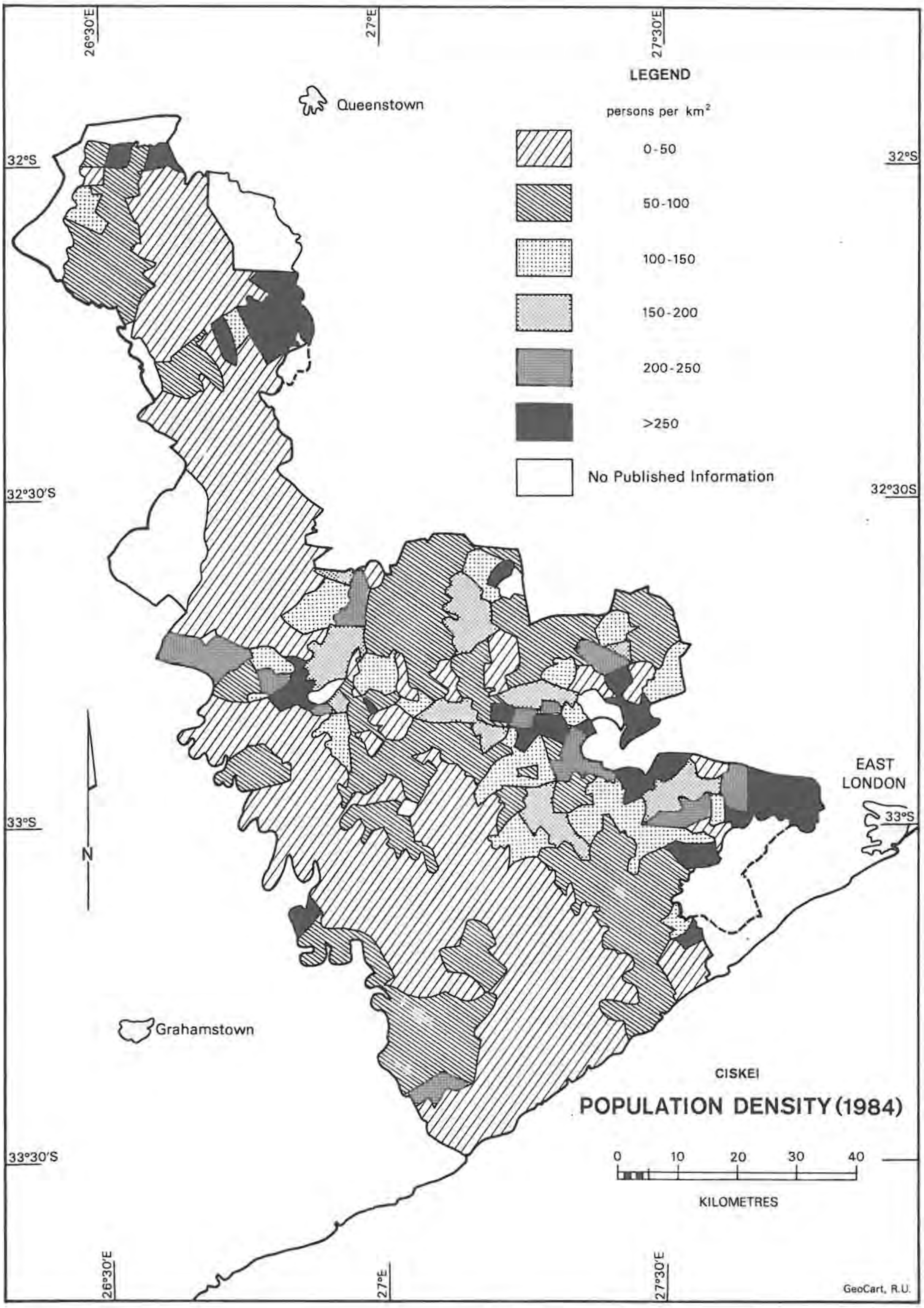



FIGURE 5.10: POPULATION DENSITY OF CISKEI

summarizes the areal extent of different population densities.

The highest concentration in population occurs in the vicinity of the road linking East London and Fort Beaufort. This includes the villages of Middledrift, Alice and Dimbaza as well as Bisho (the position of these villages is indicated in Figure 5.1). According to the Ciskei Commission of Enquiry (Swart, 1983) the average rural population density of Ciskei is approximately 50 persons.km$^{-2}$. As can be seen from Figure 5.10, population densities decrease to the north and south of the axis described. A localised high population density occurs in the Sada area. In selecting a suitable area for study, it will be necessary to reflect as a wide range in population densities as shown in Figure 5.10 as possible. Detailed population data are available on a village basis from the Ciskei Directorate of Planning's 1984 census.

**TABLE 5.7: PERCENTAGE AREA WITHIN EACH POPULATION DENSITY CLASS IN CISKEI**

| PERSONS km$^{-2}$ | PERCENTAGE OF TOTAL CISKEI AREA |
|---|---|
| 0 - 50 | 46,8 |
| 50 - 100 | 28,5 |
| 100 - 150 | 8,1 |
| 150 - 200 | 5,3 |
| 200 - 250 | 4,2 |
| > 250 | 7,1 |

**5.7: Selection of Study Areas**

A study representative of the entire Ciskei region would be beyond the scope of this thesis. It was therefore decided to concentrate on central Ciskei, i.e. the area between the Winterberg escarpment and the coastal belt. This region comprises 54% of Ciskei and includes the area where most development is occurring and where population growth is at its highest (Black, McCartan and Clayton, 1986). The lack of available data for some areas of Ciskei precludes the possibility of adopting a random sampling procedure, based on grid squares for example, covering the whole of the region. Sample areas had to be selected on the basis of the availability of data and the need to reflect the range in conditions typical for central Ciskei. Additional advice on study area selection was sought from researchers familiar with the area

(Laker, D'Huyvetter, Trollope and Lundstrom (1985, pers. comm.)).

Figure 5.11 shows the areas selected for study. All of the areas selected have previously been mapped for soils and vegetation. The Yellowwoods basin and the Amatole-Middledrift area include both coastal plateau and escarpment regions with their differing relief, climate, vegetation and soils. The Roxeni Basin is the only basin for which fairly accurate sediment-yield data are available. The basins selected have a variety of population and stock density values. The areas chosen are underlain by Beaufort Group sediments and dolerites, the most common geological groups of Ciskei. The four major veld-types of Ciskei are found in the basins selected (Eastern Province Thornveld, False Thornveld, Valley Bushveld and Dohne Sourveld). If one includes the forested portion of the Dohne Sourveld in the forest biome, then all of the four biomes of Ciskei are included in the areas selected for study. The results of the study will therefore not be applicable to the area north of the Winterberg-Amatole escarpment nor the coastal belt. Figure 5.11 also depicts the area of Ciskei for which the study is expected to be applicable.

The question of sample bias still remains and it is necessary to test the results obtained for these areas in other regions before an erosion hazard assessment technique truly representative of the region delimited in Figure 5.11 can be recommended. The location of additional catchments for this purpose is given in Figure 5.11. The main consideration governing the selection of catchment areas as study units is that data on vegetation and soils are available on a catchment-area basis. The catchment also forms a well-defined landscape unit for geomorphological study.

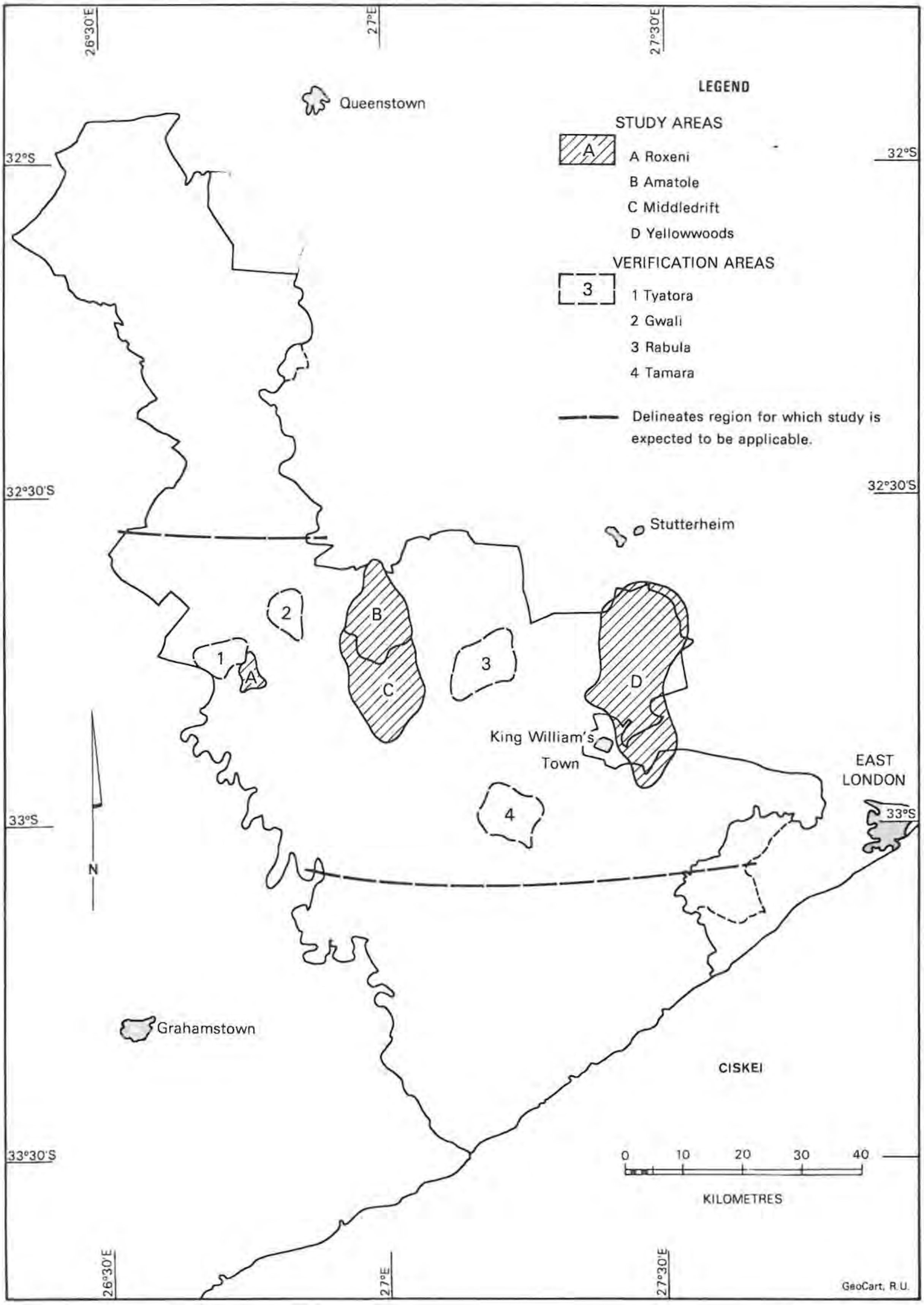



FIGURE 5.11: LOCATION OF STUDY AND VERIFICATION AREAS

# CHAPTER SIX

## METHODS OF DATA COLLECTION

Data for the study areas were collected in map form with the scale of mapping varying from 1:10 000 to 1:50 000 depending on the nature of the original data. To avoid loss of resolution due to reducing maps to a single scale, the grid overlays used were scaled according to the original data set. Due to the number of maps produced (96), only working maps were compiled. The only catchment maps included in the thesis are those depicting spatial variations in the dependent variable, soil erosion. This chapter describes the nature of the original data sources and the methods used for the quantification of the variables.

### 6.1: Soil Erosion Survey

Methods of assessing soil erosion are outlined in Chapter 3. The technique selected for this study is a modification of the SARCCUS (1981) system of soil erosion classification. The system is chosen because of its applicability to southern African conditions. The use of a locally developed system will also make comparison with similar studies in the sub-continent a viable possibility.

The original SARCCUS system is simplified by excluding wind erosion, streambank erosion, terracette erosion and landslides as these forms of erosion are localised in occurrence and are not significant at the regional scale of mapping. The three major types of erosion mapped are sheet, rill and gully erosion. The SARCCUS (1981 p2) definitions of sheet, rill and gully erosion are applied, i.e.:

"Sheet or surface erosion is the more or less uniform removal of all soil from an area caused by the detachment of soil particles through raindrops and subsequent transport by runoff water. Water channels, if present are very small and ill defined and are not identifiable by airphoto interpretation.

Rill erosion is the removal of soil through the concentration of overland flow into numerous small but conspicuous channels or rivulets. For the purpose of this erosion classification, rill erosion can be crossed with normal tillage implements.

Gully erosion is the removal of soil resulting from the excessive concentration of runoff water which causes the formation of relatively large channels or gullies. The gullies cannot be crossed with normal farm machinery. They occur in drainage ways or lower slope positions where they spread in a fan-like pattern, leaving small islands of land, too small for efficient farming."

Field observations revealed that it is seldom possible to classify an area into a single erosion class. Keech (1968) and Stocking (1972a) found a strong correlation between gully, sheet and rill erosion in Zimbabwe. Glymph's (1957) findings in the United States support this observation. In the present study in Ciskei it was found that areas of severe gully erosion are usually found in association with severe rill and sheet erosion. The resultant classification for such an area would be S4,R4,G4 (Table 3.1). Similarly, areas with no signs of sheet erosion are unlikely to have rill or gully erosion. It was therefore decided to devise a ranking system based on the SARCCUS system with 16 possible classes. In the system derived, gullying assumes precedence over rilling, which, in turn, assumes assumes precedence over sheet erosion in terms of severity. The system includes only those SARCCUS classes found and is summarized in Table 6.1.

Initial field studies revealed that some of the erosion classes identified are extremely rare resulting in an uneven distribution of classes (Figure 6.1). Further modifications were made to the system with the final simplified version illustrated in Table 6.2 and the distribution of erosion classes shown in Figure 6.2. Although the final erosion classification system used is a modification of the original SARCCUS (1981) system, the ranking system described in Table 6.1 was strictly adhered to in the initial mapping. Reclassification using the system outlined in Table 6.2 was undertaken at a later stage.

The 1:30 000 aerial photographs as flown in 1984 by Aircraft Operating Company were used for the stereoscopic analysis of the study areas. Initial mapping of soil erosion into the various categories defined in Table 6.1 was done using a Chinagraph pencil under a mirror stereoscope. This information was then transferred to a 1:30 000 enlargement of the 1:50 000 topocadastral sheets. The problems of distortion were overcome by selecting a series of control points (e.g. roads, railway lines, trigonomic beacons, huts and rivers) on each photograph. Where necessary, 1:10 000 orthophotos were consulted to ensure that the final positioning of erosion units on the 1:30 000 map is accurate.

Groundtruthing was undertaken for all of the units mapped. Groundtruthing entailed visiting the units mapped and visually assessing the degree of erosion in each of the SARCCUS classes. Where necessary, the depth of rills and gullies was measured to ensure that the correct classes were chosen. Field checks resulted in very few alterations to the stereoscopic analysis. Final soil erosion maps were produced at a scale of 1:50 000. Reduced versions of these maps appear in Figures 6.3 to 6.6. The key to these maps is presented in Figure 6.7.

**TABLE 6.1 : EROSION CLASSIFICATION SYSTEM FOR CISKEI**

| EROSION SCORE | SARCCUS EQUIVALENT | DESCRIPTION |
|---|---|---|
| 1 | S1,R1,G1 | No visible signs of erosion. |
| 2 | S2,R2,G1 | Slight rill and sheet erosion. Deduced from poor plant cover. |
| 3 | S3,R2,G1 | Obvious sheet erosion with some small, shallow rills. |
| 4 | S2,R3,G1 | Obvious rill erosion with slight sheet erosion. |
| 5 | S3,R3,G1 | Obvious rill and sheet erosion, no gullying. |
| 6 | S2,R2,G2 | Evidence of rill and sheet erosion and about 1 metre deep gullies. |
| 7 | S3,R2,G2 | Obvious sheet erosion, small rills and gullies evident. |
| 8 | S2,R3,G2 | Obvious rills with evidence of gully and sheet erosion. |
| 9 | S3,R3,G2 | Obvious sheet and rill erosion with evidence of gullies. |
| 10 | S4,R4,G2 | Severe sheet and rill erosion with evidence of gullies. |
| 11 | S2,R2,G3 | Intricate gully systems with evidence of rill and sheet erosion. |
| 12 | S2,R3,G3 | Intricate gully and rill systems with evidence of sheet erosion. |
| 13 | S3,R3,G3 | Extensive sheet and rill erosion with intricate pattern of deep gullies (1 - 3m deep). |
| 14 | S3,R4,G3 | Extensive sheet erosion with abundant rills and intricate gullying. |
| 15 | S4,R4,G3 | Severe sheet and rill erosion with intricate gullying. |
| 16 | S4,R4,G4 | Severe sheet, rill and gully erosion. 20 - 50% of the area unproductive. (3 - 5m gullies). |

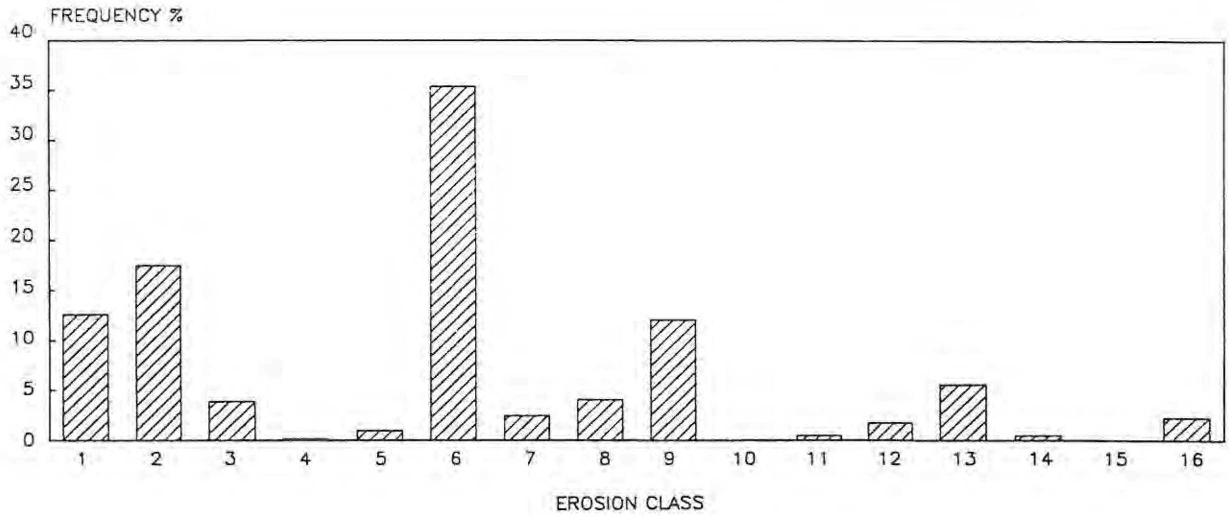



FIGURE 6.1: FREQUENCY DISTRIBUTION OF ORIGINAL SOIL EROSION DATA FOR ALL STUDY AREAS

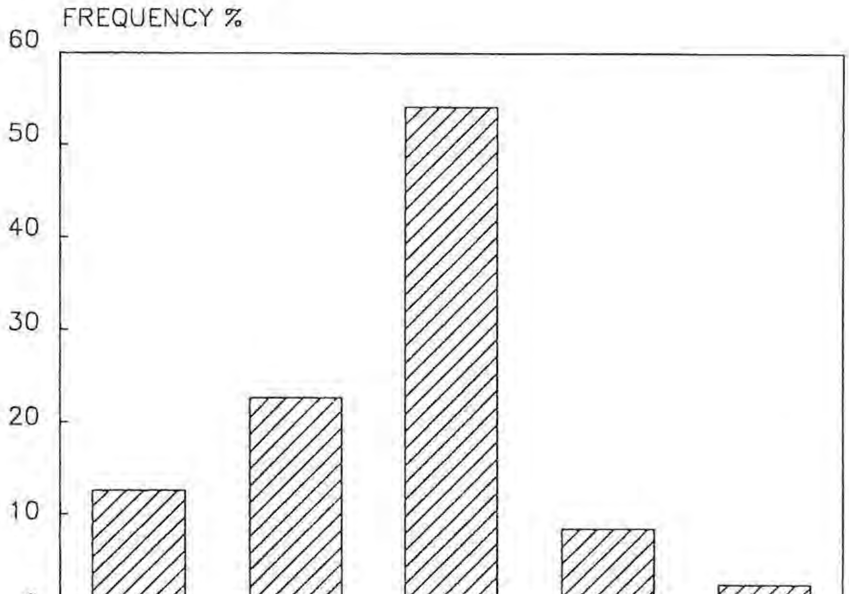



FIGURE 6.2: FREQUENCY DISTRIBUTION OF REGROUPED SOIL EROSION DATA FOR ALL STUDY STUDY AREAS.

TABLE 6.2 : FINAL EROSION SCORING SYSTEM USED.

| EROSION CLASS | TABLE 6.1 EQIVALENT | DESCRIPTION |
|---|---|---|
| 1 | 1 | NO EROSION |
| 2 | 2,3,4 & 5 | SHEET AND RILL EROSION ONLY - NO GULLYNG |
| 3 | 6,7,8,9 & 10 | OBVIOUS SHEET AND RILL EROSION - EVIDENCE OF GULLIES |
| 4 | 11,12,13,14 & 15 | INTRICATE GULLIES |
| 5 | 16 | SEVERE GULLIES |

### 6.2: Rainfall, Altitude and Rainfall Erosivity

Mean annual rainfall data were obtained for the various stations in and around the study area from the South African Weather Bureau. These data were used to construct isohyets on the 1:50 000 topocadastral sheets. Altitude was obtained directly from the 1:50 000 topocadastral sheets.

Methods available for the determination of rainfall erosivity are outlined in Chapter 2. The calculation of rainfall kinetic energy requires the use of autographic rainfall recorders with suitable periods of record. The generally accepted index of erosivity ($EI_{30}$) as derived by Wischmeier and Smith (1978) (Table 2.2, Equation a) was selected for this study. Ciskei has no autographic raingauges with sufficiently long records for the determination of mean annual $EI_{30}$. Consequently, an alternative approach which makes use of Wischmeier and Smith's (1978) equation as well as other forms of rainfall data is required. The South African Weather Bureau operates autographic stations at East London, King Williams Town, Stutterheim and Queenstown. In addition, daily rainfall totals are recorded at more than 50 stations in and around Ciskei. The autographic records vary from 5 to 12 years in length while many of the daily records extend from the present day back to the end of the 19th Century. Figure 5.4 shows the distribution of the rainfall monitoring stations available for this study.

The techniques used for the mapping of mean annual $EI_{30}$ in Ciskei are largely determined by the constraints of a limited data base as discussed. In summary the technique involves firstly the establishment of the relationship between erosivity values (calculated on a daily basis using

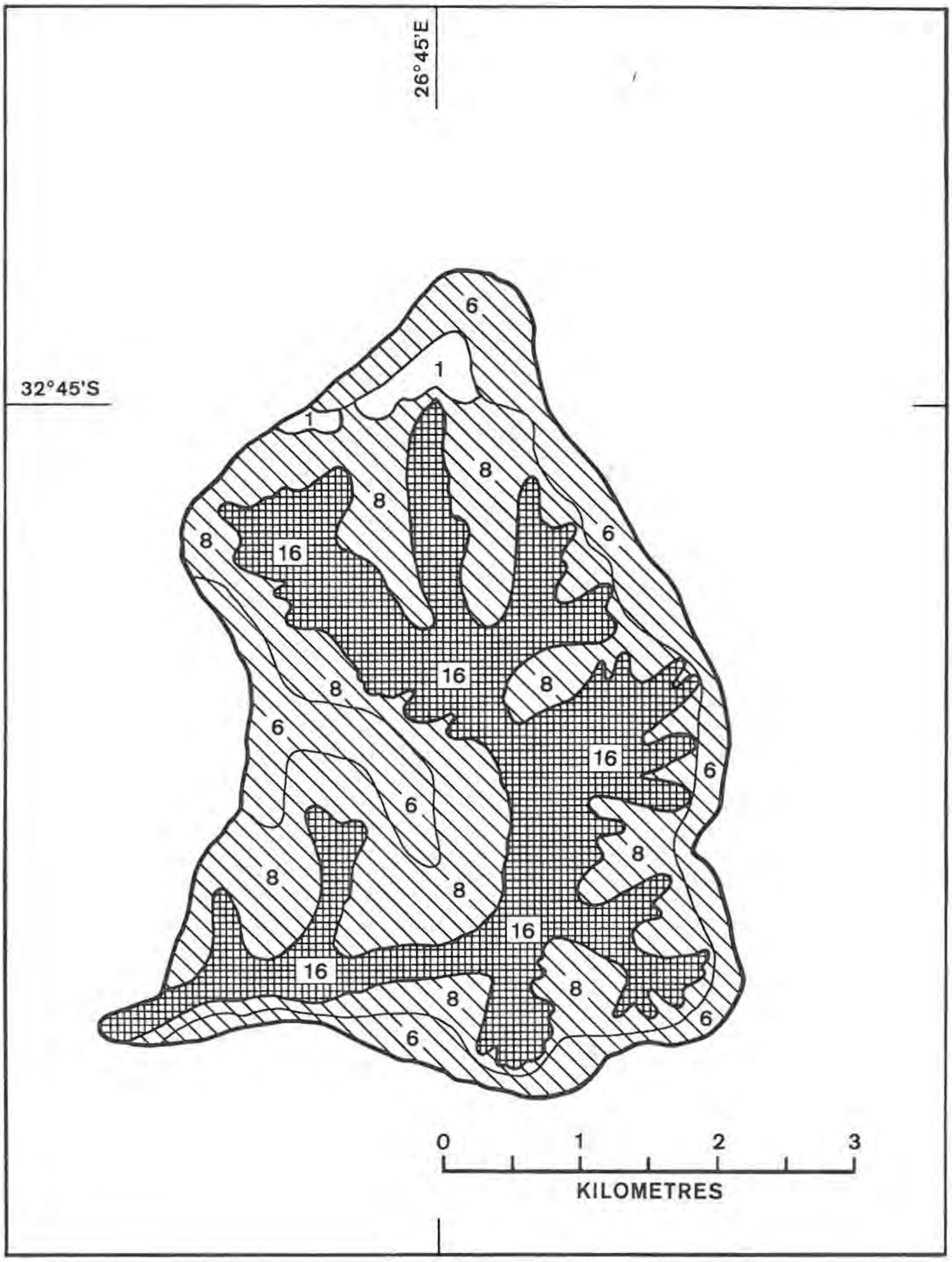



FIGURE 6.3: SOIL EROSION IN THE ROXENI BASIN (See Figure 6.7 for key)

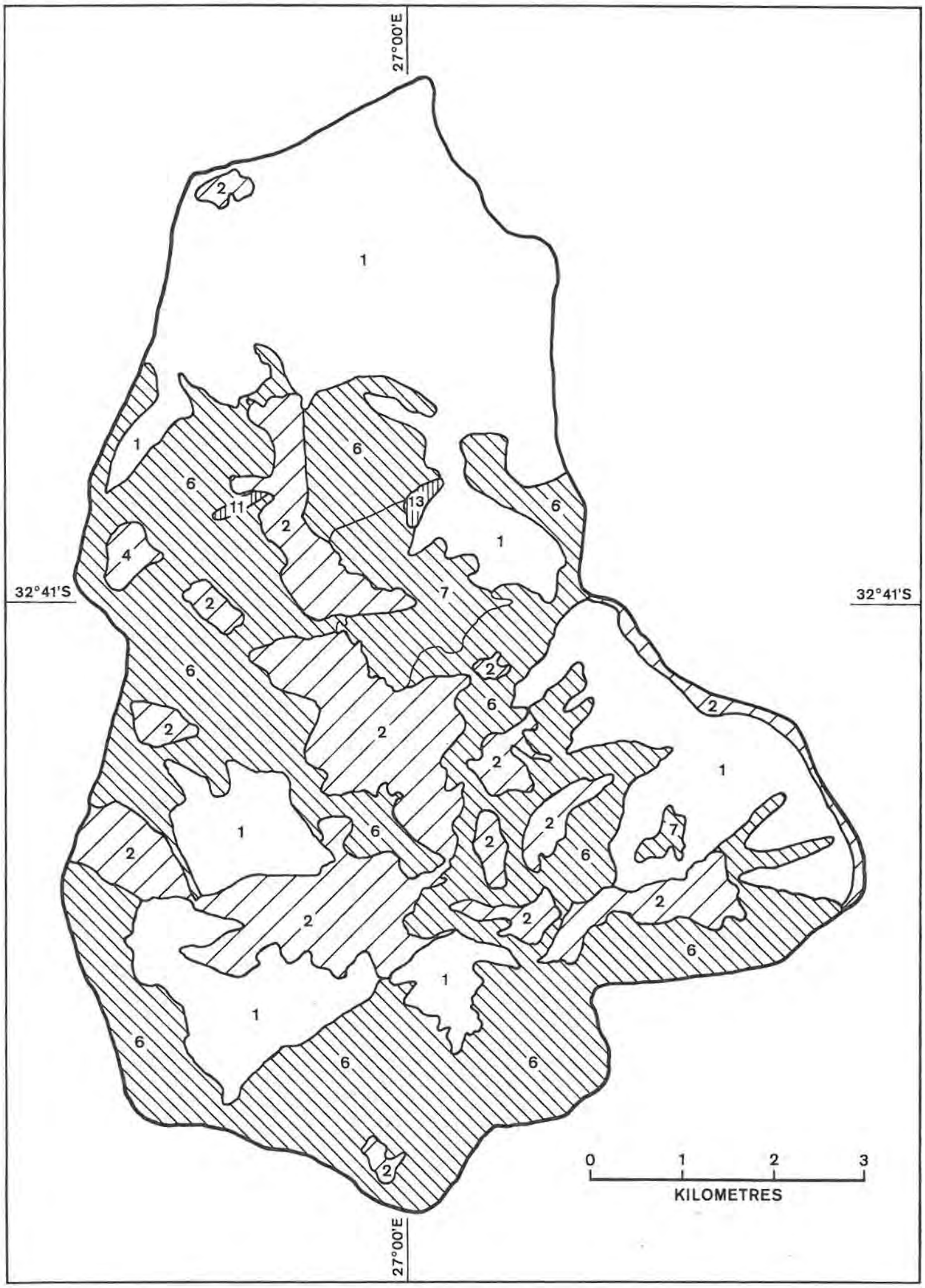



FIGURE 6.4: SOIL EROSION IN THE AMATOLE BASIN (See Figure 6.7 for key)


FIGURE 6.5: SOIL EROSION IN THE MIDDLEDRIFT AREA (See Figure 6.7 for key)

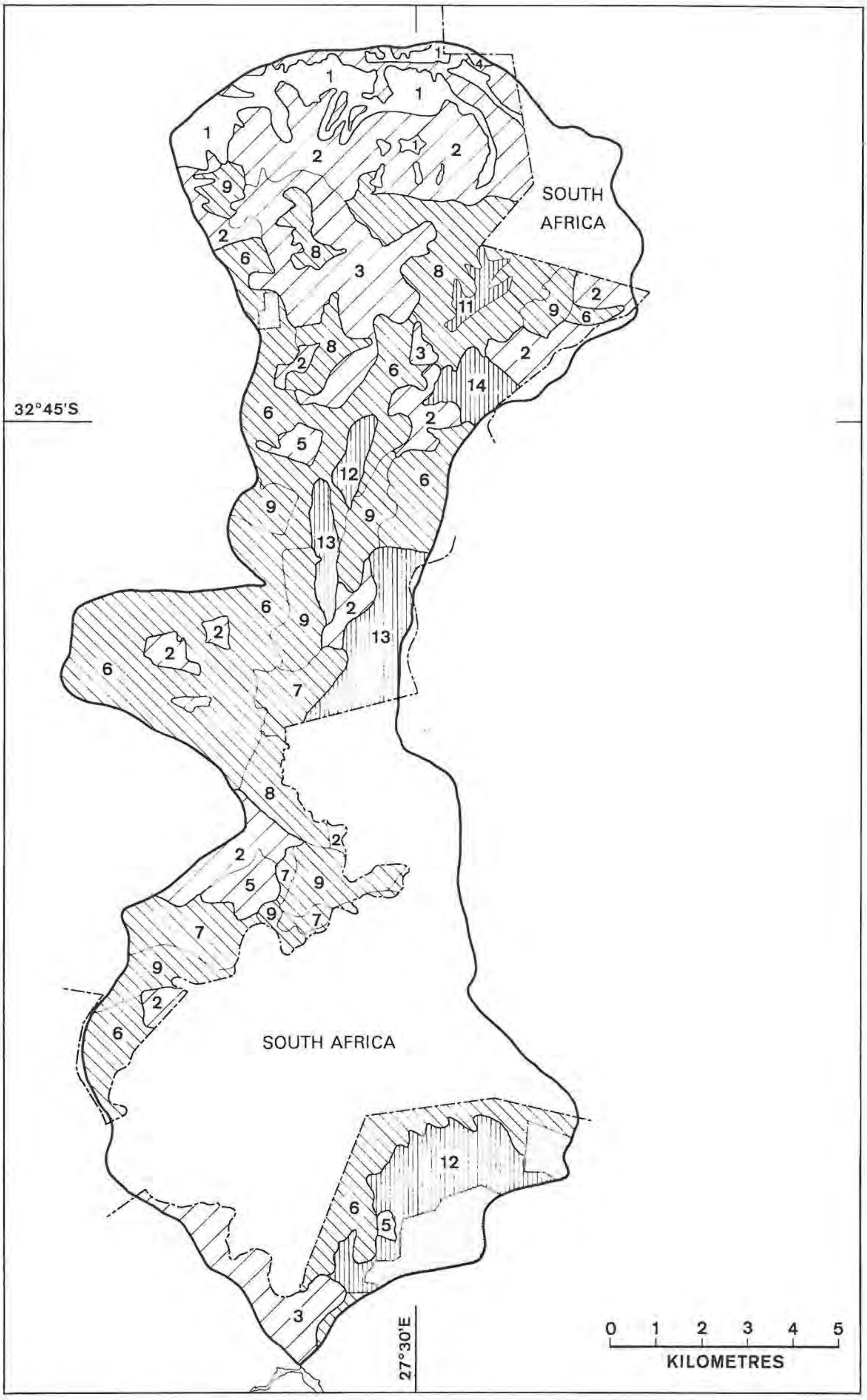



FIGURE 6.6: SOIL EROSION IN THE YELLOWWOODS BASIN (See Figure 6.7 for key)

| MAP CODE | EROSION CLASS | SARCCUS CODE | DESCRIPTION |
|---|---|---|---|
| 1 | 1 | $S_1R_1G_1$ | NO EROSION |
| 2 | 2 | $S_2R_2G_1$ | SHEET AND RILL EROSION ONLY - NO GULLYING |
| 3 | | $S_3R_2G_1$ | |
| 4 | | $S_2R_3G_1$ | |
| 5 | | $S_3R_3G_1$ | |
| 6 | 3 | $S_2R_2G_2$ | OBVIOUS SHEET AND RILL EROSION - EVIDENCE OF GULLIES |
| 7 | | $S_3R_2G_2$ | |
| 8 | | $S_2R_3G_2$ | |
| 9 | | $S_3R_3G_2$ | |
| 10 | | $S_4R_4G_2$ | |
| 11 | 4 | $S_2R_2G_3$ | INTRICATE GULLIES |
| 12 | | $S_2R_3G_3$ | |
| 13 | | $S_3R_3G_3$ | |
| 14 | | $S_3R_4G_3$ | |
| 15 | | $S_4R_4G_3$ | |
| 16 | 5 | $S_4R_4G_4$ | SEVERE GULLIES |

RESIDENTIAL AREA

CATCHMENT BOUNDARY

SOUTH AFRICA - CISKEI BOUNDARY

FIGURE 6.7: KEY TO THE SOIL EROSION MAPS (FIGURES 6.3, 6.4, 6.5 and 6.6).

the Wischmeier and Smith (1978) equation) and daily rainfall totals for the available continuous rainfall data. The second step is to apply the relationships to the much greater number of daily rainfall stations in order to obtain estimates of erosivity over a larger area.

Both daily rainfall and $EI_{30}$ show a positively skewed distribution. To satisfy the assumption of normality, logarithmic transformations were undertaken prior to regression analyses. Figure 6.8 illustrates the effect of transformation on the rainfall and $EI_{30}$ values for King Williamstown. Linear regression relationships between $Ln(EI_{30})$ and Ln(daily rainfall) were calculated (Table 6.3 and Figure 6.9).

**TABLE 6.3 : RESULTS OF REGRESSION ANALYSIS OF $Ln(EI_{30})$ ON Ln (RAINFALL) FOR FOUR AUTOGRAPHIC STATIONS.**

| STATION | NUMBER OF POINTS | $R^2$ | INTERCEPT | SLOPE |
|---|---|---|---|---|
| King Williamstown | 127 | 0,59 | -3,51 | 1,65 |
| Stutterheim | 199 | 0,47 | -2,82 | 1,42 |
| East London | 231 | 0,68 | -3,26 | 1,56 |
| Queenstown | 56 | 0,35 | -2,32 | 1,25 |

All $R^2$ values significant at the 1% level.

The regression equations relating erosivity to daily rainfall were used to estimate erosivity values over the whole of Ciskei and, more specifically, the study areas. Before this could be done it was necessary to establish which equations were to be applied to which area.

Initially, the interstation correlations between daily rainfall for the autographic stations and the daily rainfall stations were investigated. Very low correlations resulted due to the time lag in daily values between stations. Monthly values were therefore chosen for the regional interstation correlations. A suitable index of association is the coefficient of efficiency (Aitken, 1973) and these values based upon monthly data were used to map regions of similarity around the autographic stations. Coefficient of efficiency values of 0,5 were used to define boundaries. A more detailed discussion of the methods used appears in Weaver and Hughes (1986).

The regression equations obtained (Table 6.3) were then applied to the daily rainfall data and

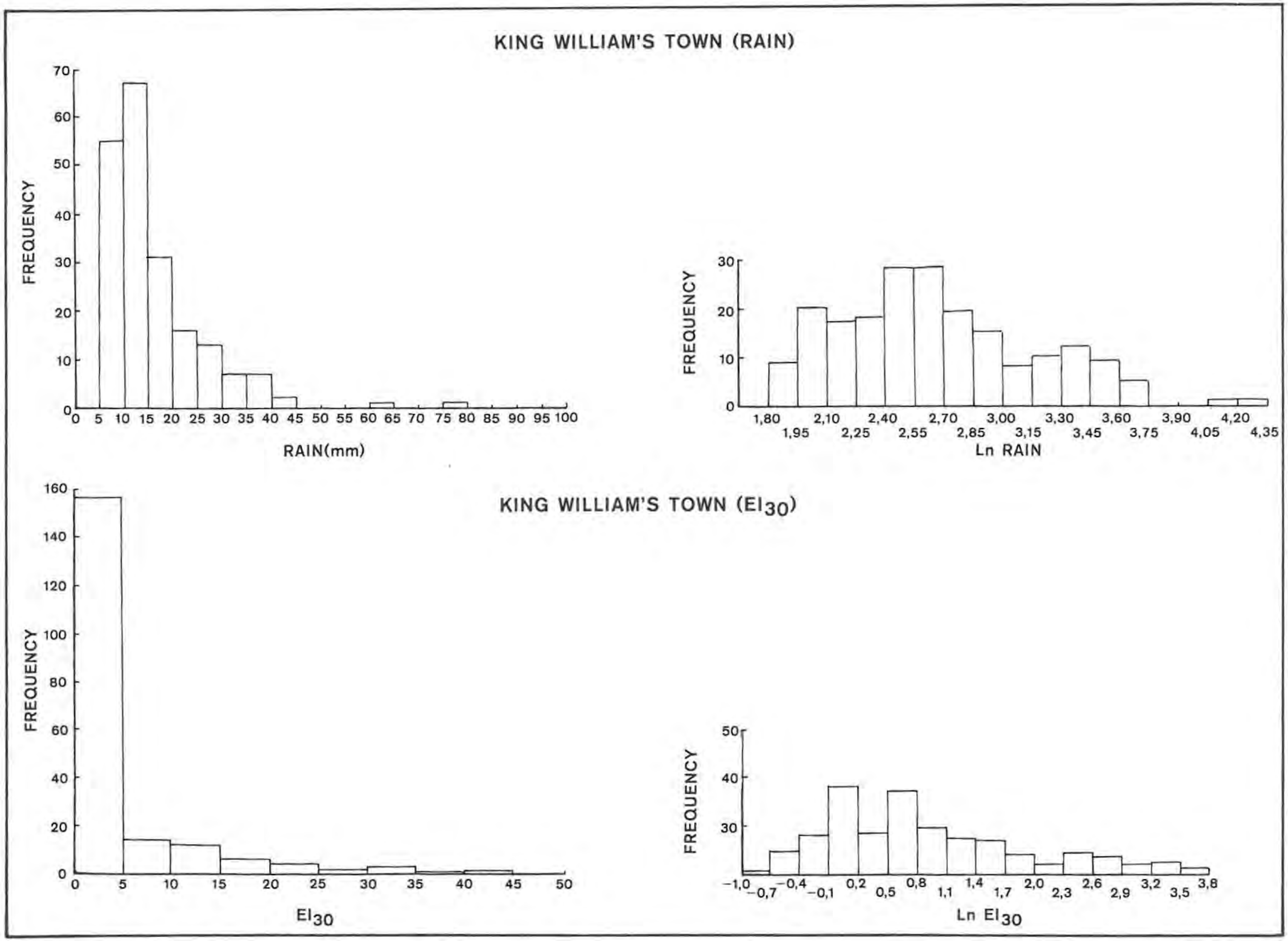



FIGURE 6.8: THE EFFECT OF TRANSFORMATION ON RAINFALL AND $EI_{30}$ FOR KING WILLIAMSTOWN

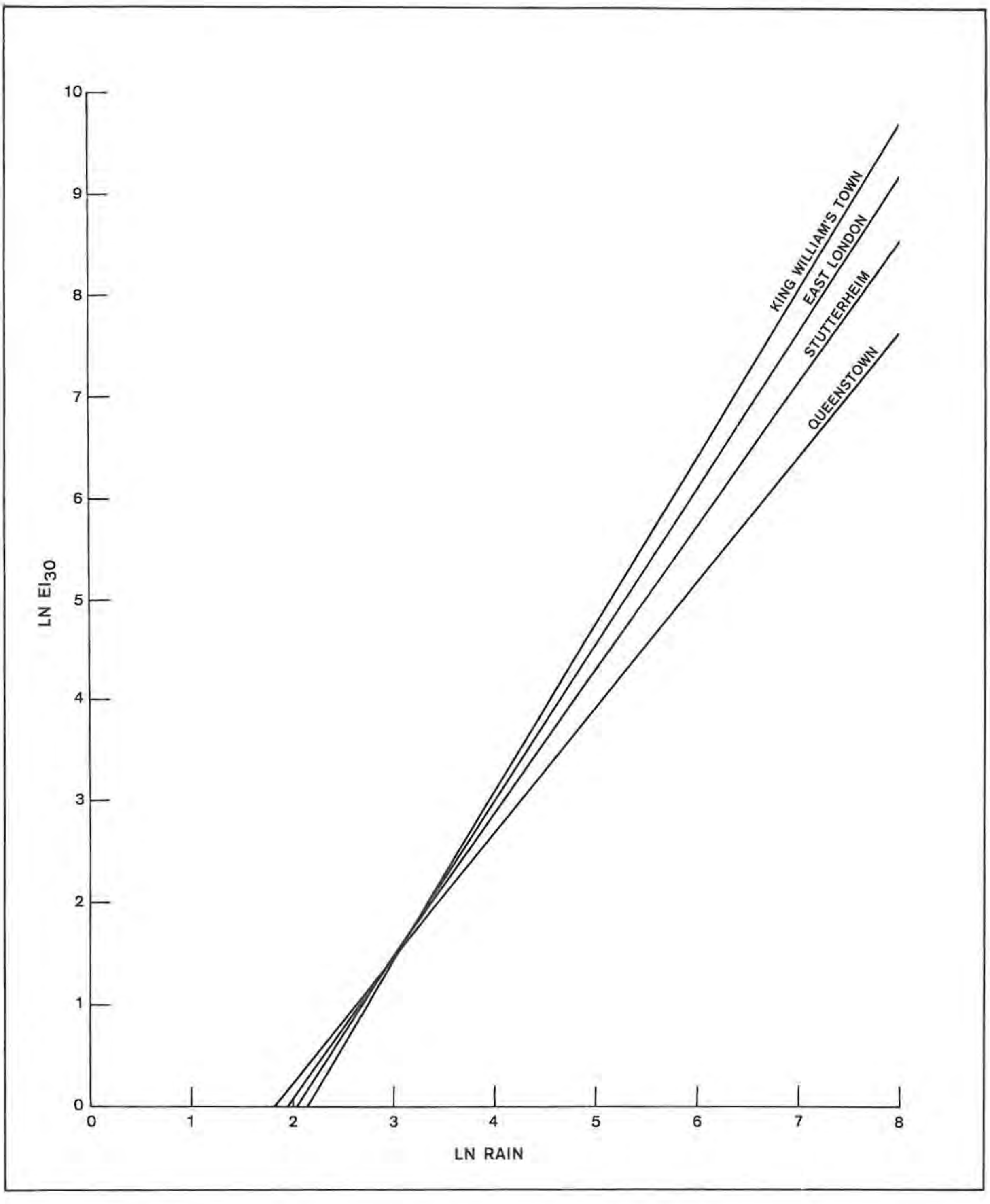



FIGURE 6.9: LEAST SQUARES REGRESSION LINES OF Ln ($EI_{30}$) ON Ln (DAILY RAINFALL) FOR ALL YEAR DATA FOR THE FOUR AUTOGRAPHIC STATIONS

surrogate $EI_{30}$ values were obtained and plotted on a 1:250 000 scale map. It became clear that considerable variations occur over short distances in the mountainous regions of central Ciskei and that insufficient data were available for accurate $EI_{30}$ mapping at the 1:250 000 scale.

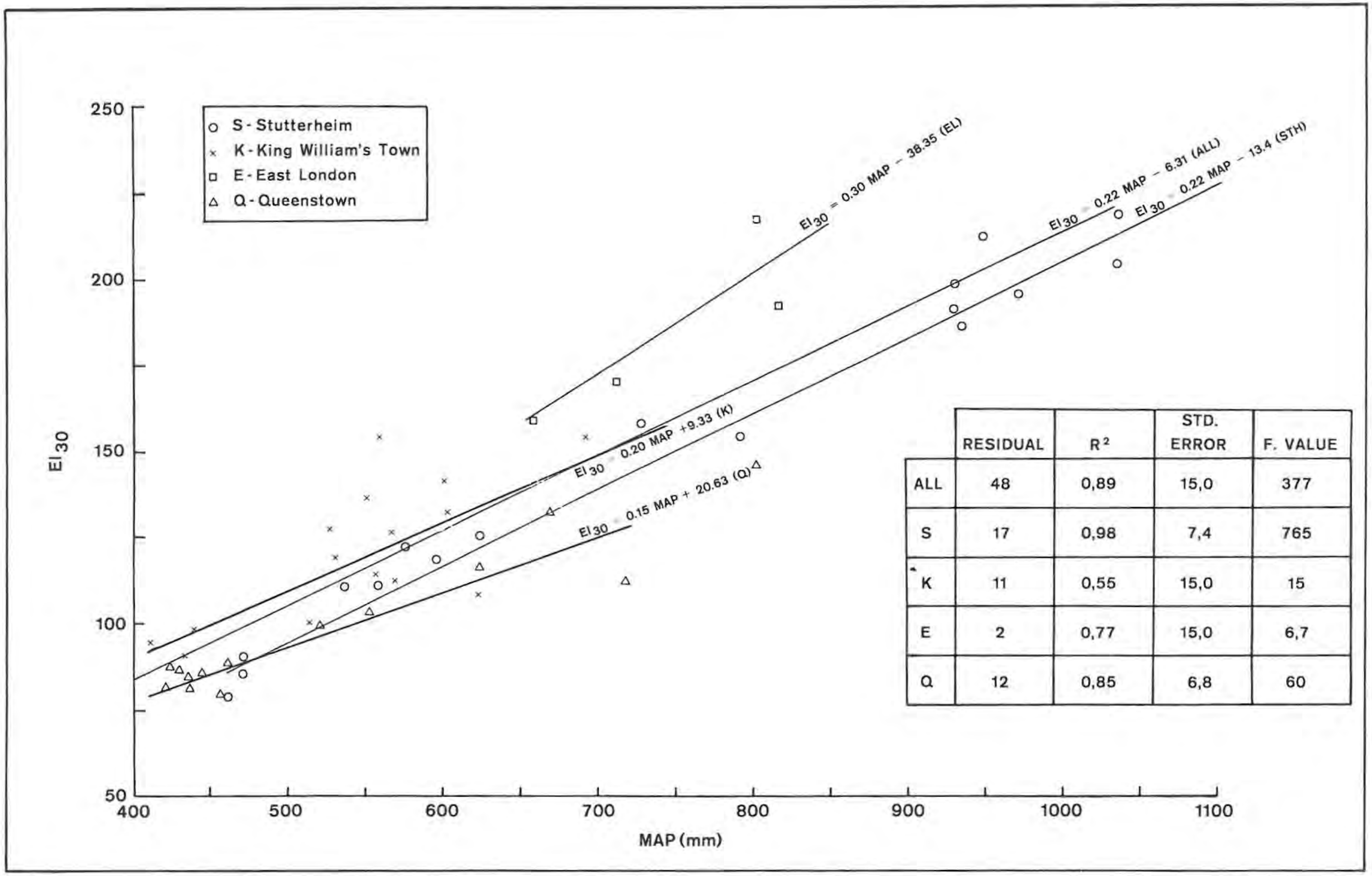
The relationship between mean annual $EI_{30}$ and mean annual precipitation was therefore determined using a linear regression analysis. The results of this analysis is shown in Figure 6.10. This analysis enables conjunctive use of available detailed 1:250 000 isohyet maps (Hydrological Research Division, 1966a and 1966b) for the final mapping of $EI_{30}$. The interval chosen for isoerodent lines is 25 units of $EI_{30}$ at the 1:250 000 scale and 5 units of $EI_{30}$ at the 1:50 000 scale (for individual study areas). The resultant $EI_{30}$ map for Ciskei is shown in Figure 6.11. $EI_{30}$ values for individual catchment areas were interpolated from the 1:50 000 maps. Considerable variation in $EI_{30}$ occurs in the Middledrift-Amatole catchment as well as the Yellowwoods catchment due to the influence of the mountainous regions to the north of these catchments on rainfall patterns.

### 6.3: Soil Erodibility, Soil Type and Geology

Soil erodibility is discussed in Chapter 2. Methods of soil erodibility determination include *in situ* field experimentation, laboratory simulation, point sampling and the determination of soil erodibility indices using the K-nomograph (U.S.D.A., 1975). For studies equivalent in scale to the present one it is normal practice to make use of soil maps in conjunction with a table of soil erodibility indices.

The most comprehensive table of soil erodibility indices available for southern African soils is that published in SLEMSA (1976). These erodibility indices (Fb) are used in conjunction with soils maps of the Yellowwoods Basin (Hill, Kaplan and Scott, no date a), the Roxeni Basin (Hill, Kaplan and Scott, no date b), the Keiskamma Drainage Basin (Hill, Kaplan and Scott, 1977), the Amatole Basin (ARDRI, 1981) and field surveys. The Fb ratings for the soils found in the area are summarized in Table 6.4.

A full set of 1:50 000 geological sheets was obtained from the Geological Survey of South Africa. The geology of the areas under investigation comprise predominantly shales, mudstones and sandstones of the Adelaide subgroup (Beaufort group) intruded by dykes and sheets of dolerite of Jurassic age. The Adelaide subgroup is further divided into the Balfour




| | RESIDUAL | $R^2$ | STD. ERROR | F. VALUE |
|---|---|---|---|---|
| ALL | 48 | 0,89 | 15,0 | 377 |
| S | 17 | 0,98 | 7,4 | 765 |
| K | 11 | 0,55 | 15,0 | 15 |
| E | 2 | 0,77 | 15,0 | 6,7 |
| Q | 12 | 0,85 | 6,8 | 60 |

FIGURE 6.10: MAP : $EI_{30}$ RELATIONSHIPS FOR CISKEI

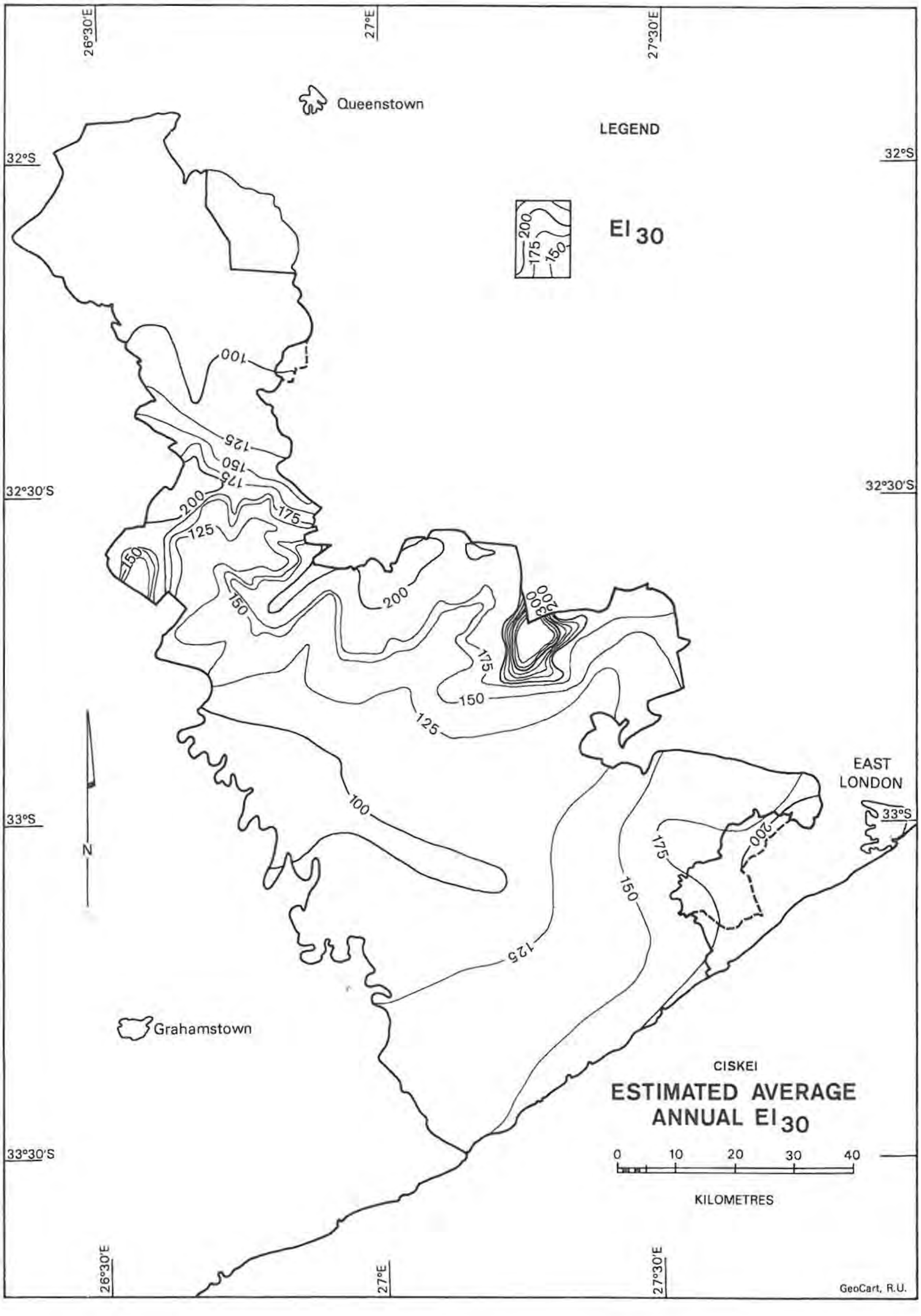



FIGURE 6.11: ESTIMATED AVERAGE ANNUAL $EI_{30}$ FOR CISKEI

**TABLE 6.4: SOIL SERIES AND SOIL ERODIBILITY RATINGS** (SLEMSA, 1976)

| *CODE | SOIL SERIES | Fb | ERODIBILITY RATING |
|---|---|---|---|
| Cv17 | Clovelly | 6.5 | Very Low |
| Hu17 | Farningham | 6.5 | Very Low |
| Hu27 | Doveton | 6.0 | Very Low |
| My11 | Msinsini | 6.0 | Very Low |
| Oa37 | Koedoesvlei | 6.0 | Very Low |
| My21 | Pafuri | 5.5 | Low |
| Hu37 | Makatini | 5.5 | Low |
| Mw11 | Milkwood | 5.5 | Low |
| Sd21 | Glendale | 5.5 | Low |
| Sw11 | Skilderkrans | 5.5 | Low |
| Oa36 | Jozini | 5.0 | Low |
| Oa16 | Leeufontein | 5.0 | Low |
| My10 | Mayo | 5.0 | Low |
| Ar40 | Arcadia | 4.5 | Moderate |
| Gs16 | Williamson | 4.5 | Moderate |
| Hu36 | Shorrocks | 4.5 | Moderate |
| Va11 | Waterval | 4.5 | Moderate |
| We12 | Rietvlei | 4.0 | Moderate |
| Ms10 | Mispah | 4.0 | Moderate |
| Va41 | Lindley | 4.0 | Moderate |
| Oa33 | Vaalriver | 3.5 | High |
| Ka20 | Killarney | 3.5 | High |
| Sw30 | Rosehill | 3.5 | High |
| Sw31 | Swartland | 3.5 | High |
| Kd16 | Bluebank | 2.5 | High |
| Ss26 | Sterkspruit | 2.5 | High |

* As used by Macvicar, *et al.* (1981).

formation and the Middleton formation, both of which are found in the study areas. Johnson and Keyser (1976) point out that the only significant difference between these two formations is the presence of red mudstone in the Middleton formation. For this reason, the two formations were grouped together. Based on field observation and the work done by Mountain (1952) the dolerite is expected to exhibit a lower degree of erosion than the sedimentary rocks of the Adelaide subgroup.

## 6.4: Relief

Various relief parameters are discussed in the literature as having an influence on soil erosion (Chapter 2). Seven relief parameters are examined in this study, namely, slope length, slope angle, LS, lateral slope shape, profile slope shape, a combined slope shape parameter and slope aspect. All of the slope data can be obtained from 1:50 000 topographical sheets.

Slope length is measured as the length of a line drawn orthogonal to the contours from the relevant data point to the interfluve. Slope angle is determined using the equation:

$$s = \frac{(H2 - H1) \text{ X } 100}{SL} \quad \ldots\ldots\ldots\ldots\ldots\ldots 8$$

where: s = slope angle (%)

H2 = contour height at watershed (m)

H1 = contour height at relevant data point (m)

SL = slope length (m)

The combined slope length and slope angle factor (LS) as recommended by Wischmeier and Smith (1978) is used (Equation 7). A simple FORTRAN program requiring H2,H1 and SL as inputs was used for the determination of s and LS.

Slope profile shape and lateral shape were mapped for entire catchments using the 1:50 000 topocadastral sheets. Three categories of slope shape are used in each dimension: concave (C), convex (V), and straight (S). The system put forward by Ruhe (1975) was modified and combined shape descriptors were obtained by superimposing the lateral and profile slope shape maps. Tables 6.5 and 6.6 summarize the slope descriptors used in the study.

The significance of slope aspect to soil erosion is discussed in Chapter 2. According to the theory, north-facing slopes are more susceptible to erosion than south-facing slopes for a number of reasons. Slope aspect is interpolated from the 1:50 000 topocadastral series maps. Only two classes of slope aspect are identified, north and south.

**TABLE 6.5 : SINGLE DIMENSION SLOPE SHAPE DESCRIPTORS**

| | |
|---|---|
| Profile : | Convex (C) |
| | Straight (S) |
| | Concave (V) |
| Lateral : | Convex (C) |
| | Straight (S) |
| | Concave (V) |

**TABLE 6.6: TWO DIMENSION SLOPE SHAPE DESCRIPTORS**

| PROFILE SHAPE | LATERAL SHAPE | | |
|---|---|---|---|
| | Concave (C) | Straight (S) | Convex (V) |
| Convex(V) | VC | VS | VV |
| Straight(S) | SC | SS | SV |
| Concave (C) | CC | CS | CV |

### 6.5: Land Use, Vegetation and Veld Condition

Land use mapping was undertaken on the 1984 1:30 000 aerial photographs using a Chinagraph pencil under a mirror stereoscope. Four land use classes are mapped: urban, forest, grazing and arable land. Abandoned arable land is classified as grazing land. The forests of the study area are easily delimited due to the sharp boundaries that exist between grassland and the continuous canopy produced by the evergreen and deciduous trees of the forest community. These sharp boundaries are said to be maintained by the frequent fires occurring in the surrounding grassland which restrict the establishment of young trees outside the parent forest (Hill, Kaplan and Scott, 1977). Land use data were transferred to 1:50 000 maps using the same methods described in section 6.1. Urban areas are excluded from the final analysis. Based on the theory (Chapter 2) it is expected that forested areas with their high biomass-will be the least susceptible to erosion, whilst arable lands with monoculture and a low biomass will be most susceptible to erosion.

Vegetation maps for the area are available in various forms. Hill Kaplan and Scott (1977) produced a vegetation survey of the entire Keiskamma River Basin which is the major single basin occurring in Ciskei. The Amatole Basin and Middledrift portion of the research area fall into this region. Assigning erosion hazard ratings to different vegetation types is difficult due to the effect that man has on individual vegetation types directly through bush clearing and indirectly through overgrazing. The carrying capacities recommended for different vegetation types are based on the susceptibility of that vegetation type to overexploitation. This will, in turn determine the susceptibility of the area to erosion. Carrying capacity indices are therefore used as surrogate erosion hazard indices. The assumption being that the lower the carrying capacity of the vegetation type, the higher the erosion hazard. The carrying capacities used are those recommended in Hill, Kaplan and Scott (1977). Vegetation maps for the Buffalo River Basin were prepared by Gibbs-Russel and Robinson (1982). Data for the Roxeni Basin are not readily available and field mapping was carried out in this area. Carrying capacities for the Yellowwoods basin are obtained from Willis and Trollope (1982) (Table 6.7). Table 6.8 lists the vegetation types, Acocks synonyms and carrying capacity values used for the Amatole, Middledrift and Roxeni study areas.

**TABLE 6.7: CARRYING CAPACITY FOR DIFFERENT VEGETATION TYPES IN THE YELLOWWOODS CATCHMENT** (After Willis and Trollope, 1982).

| Veld Type | Vegetation Unit | Carrying Capacity (ha/LSU) |
|---|---|---|
| Valley Bushveld | Woody Invasion Community | 7,6 |
| Eastern Province Thornveld | Grassland Community | 6,7 |
| | Woody Invasion into Grassland | 8,5 |

**TABLE 6.8: VEGETATION TYPES AND CARRYING CAPACITY**
(Hill, Kaplan and Scott, 1977).

| Physiognomic type | Acocks Equivalent | Carrying Capacity ha/LSU |
|---|---|---|
| **TALL EVERGREEN FORESTS** | | |
| Medium to tall *Podocarpus-Xymalos* Evergreen forest | Dohne Sourveld (44b) | 0* |
| Medium to short *Schotia-Celtis Vepris-Calodendrum*. Other species of Evergreen forest. | Dohne Sourveld (44b) | 0 |
| Short to medium *Scutia-Buddleia Rhus-Grewia-Plumbago*. Other species of evergreen thicket. | Dohne Sourveld (44b) | 0 |
| **VERY SHORT TO MEDIUM THICKETS** | | |
| Short to medium *Scutia-Grewia-Harpephyllum*. *Hippobromus*. Other species evergreen thicket. | Dohne Sourveld (44b) | 15 |
| Short *Scutia-Maytenus-Grewia*. Other species evergreen thicket. | Valley Bushveld proper, Southern variation (23b) | 13,5 |
| Mosaic of short *Scutia-Maytenus-Grewia* evergreen thicket and *Acacia karroo* short open shrubland. | Valley Bushveld proper, Southern variation (23b) | 6,5 |
| Short *Calpurnia-Diospyros*. Evergreen secondary shrubland. | Dohne Sourveld (44b) | 10 |

* Values of 0 indicate that no grazing or browzing occurs.

TABLE 6.8: *Continued*

| | | |
|---|---|---|
| ***ACACIA KARROO* COMMUNITIES** | | |
| *Acacia karroo-Scutia*. Short woodland to open woodland. | Eastern Province (7a) and False thornveld of the Eastern Cape (21) | 7 |
| *Acacia karroo*. Short open shrubland and wooded grassland. | Eastern Province thorn-veld (7a) and False thorn-veld of the Eastern Cape (21) | 5 |
| Open shrubland, Wooded *Themeda-Elyonurus* grassland and *Acacia* karroo short open shrubland. | Valley bushveld. Proper southern variation (23b) | 5 |
| *Acacia karroo*. Short open shrubland and wooded *Themeda-Hyparrhenia* Grassland. | False thornveld of the Eastern Cape (21) Dohne Sourveld (44b) | 5,5 |
| Aloe-*Acacia*. Short open shrubland and wooded grassland | False thornveld of the Eastern Cape (21) | 11 |
| | Valley bushveld proper. Southern Variation (23b) | |
| **GRASSLANDS, WOODED GRASSLANDS AND SECONDARY DWARF SHRUBLANDS.** | | |
| Medium *Themeda-Hyparrhenia -Elyonurus* grassland and grassland | Portions of: False thorn-veld of Eastern Cape (21) Alexandria Forest (2) Eastern Province thornveld (northern forms) (7) Dohne Sourveld (44b) | 4 |
| *Eragrostis-Sporobolus* grassland | Portions of: False thorn veld of Eastern Cape (21) Alexandria Forest (2) Eastern Province thorn-veld (northern forms) (7) Dohne Sourveld (44b) | 6 |
| *Themeda* - other species grassland | False thornveld of the the Eastern Cape (21) | 4,5 |
| *Themeda-Cymbopogon-Digitaria* wooded grassland | False thornveld of the Eastern Cape (21) | 4,5 |
| Dwarf *Senecio-Chrysocoma* shrubland | False thornveld of the Eastern Cape (21) | 9,5 |
| Dwarf *Chrysocoma* shrubland | Valley bushveld proper, southern variation (23b) and in part False thornveld of the Eastern Cape (21) | 11 |

Recent vegetation assessments in the area have included veld condition scoring (V.C.S.) (Chapter 2). Information on V.C.S. for the Amatole Basin (Mentis, 1981) and for the Yellowwoods Basin (Willis and Trollope, 1982) was used to try to overcome the problems associated with short term changes in vegetation composition and cover within vegetation units.

Pasture scientists have for some time made use of indicator species in veld assessment (Trollope, 1986). The dominance of certain species of plants over others indicates the degree of overstocking and veld degradation. An index (Increaser II.Bench$^{-1}$) was derived using the ratio of increaser II species (those which dominate in poor veld and increase with overstocking) to benchmark increaser II species for that site (see Chapter 2). Data were obtained for the Amatole Basin from Mentis (1981) and for the Yellowwoods basin from Willis and Trollope (1982).

**6.6: Population, Footpath and Stock Density**

The total population for each of the villages was obtained from the census data collected by Ciskei's Directorate of Planning (1984). Location boundaries are used to define the area of influence of the villages. Population densities are determined for each of the locations found in the study area. Table 6.9 summarizes the population density data obtained. These population density values are used as a surrogate to represent the degree of erosion hazard due to man's direct impact on the environment.

In the initial stages of the study an attempt was made to map footpath networks from the same 1:30 000 air photographs used to map soil erosion. It soon became clear that a large degree of subjectivity existed. To avoid the possibility of a bias creeping into this analysis, the paths shown on the 1:50 000 topographical sheets are used. The density of paths is determined by calculating the length of path per km$^2$. The technique used is similar to that used for the measurement of stream drainage density (Strahler, 1975) and gully density (Jones and Keech, 1966).

Stock data were obtained from the Ciskei department of agriculture's veterinary services section for all the dipping tank service areas in the study area. All stock inspectors responsible for the dipping were interviewed to ascertain the exact extent of the area served by the dipping tanks. In most areas, the division is along the same boundaries as those used in the population survey (i.e.location boundaries). In some areas more than one location shares a common dipping tank. The stock data collected are presented in Table 6.10.

**TABLE 6.9: POPULATION DENSITY IN THE STUDY AREA**
(Ciskei Directorate of Planning, 1984)

| Location | Population Density People.km$^{-2}$ |
|---|---|
| YELLOWWOODS | |
| Frankfort | 91 |
| Peelton North | 216 |
| Peelton South | 27 |
| Skobeni | 373 |
| Tyutu | 315 |
| Ndevana | 1151 |
| ROXENI | 44 |
| MIDDLEDRIFT | |
| Ann Shaw | 23 |
| Burnshill | 95 |
| Cildara | 125 |
| Cwaru | 89 |
| Hegu | 86 |
| Lenye | 8 |
| Middledrift | 97 |
| Mfiki | 282 |
| Lugudwini | 21 |
| Lower Regu | 90 |
| Upper Regu | 106 |
| Trust land | 98 |
| Zali | 160 |
| Zibi | 146 |
| Fort Cox | 32 |
| AMATOLE | 73 |

**TABLE 6.10: ANIMAL STOCK DENSITIES FOR THE STUDY AREA**

| | STOCKING RATE (HA PER STOCK UNIT) | | |
| --- | --- | --- | --- |
| LOCATION | SHEEP AND GOATS (Small stock units) | CATTLE AND EQUINES (Large stock units) | ALL STOCK [a](Mature stock units) |
| [b] YELLOWWOODS | | | |
| Sesake | 4,43 | 4,96 | 4,27 |
| Frankfort | 3,42 | 5,30 | 4,34 |
| Peelton North | 0,78 | 6,32 | 2,93 |
| Peelton South | 1,70 | 5,07 | 3,36 |
| Ndevane | 2,44 | 4,88 | 2,44 |
| [c] ROXENI | 1,04 | 9,94 | 4,29 |
| [c] MIDDLEDRIFT | | | |
| Mfiki | 3,26 | 30,25 | 13,00 |
| Ann Shaw | 2,16 | 15,56 | 7,68 |
| Burnshill | 4,64 | 6,49 | 5,41 |
| Cwaru | 1,49 | 19,12 | 6,75 |
| Lugudwini | 1,92 | 8,70 | 5,26 |
| Zibi | 0,63 | 11,05 | 3,16 |
| Zali | 0,69 | 13,95 | 3,59 |
| Cildara | 0,62 | 8,58 | 2,87 |
| Lenye | 4,35 | 3,48 | 3,13 |
| Fort Cox | 0,78 | 3,47 | 2,12 |
| [c] AMATOLE | 2,44 | 5,57 | 4,20 |

a One mature stock unit is equivalent to 7 small stock units
b As at February 1985
c As at June 1985

Table 6.11 provides a summary of all the data and data sources used in the study. The ease with which data are available varies greatly, with, for example geological data being readily available at a suitable scale and rainfall erosivity requiring detailed analysis of an extensive data set. Detail also varies, with, for example very detailed vegetation maps available at 1:10 000 and MAP data available for less than 30 stations within the entire Ciskei region. The next chapter considers the various methods of analysis which are to be employed in using the data collected to test the study hypothesis.

TABLE 6.11 : SUMMARY OF DATA SOURCES USED IN THE STUDY

| DATA | SOURCE |
|---|---|
| SOIL EROSION | Field survey and 1:30 000 aerial photographs (Aircraft Operating Company, 1984) |
| RAINFALL | South African Weather Bureau |
| ALTITUDE | 1:50 000 topocadastral series, South Africa |
| EROSIVITY | Derived from original breakpoint and daily rainfall data (South African Weather Bureau) |
| SOIL ERODIBILITY | SLEMSA values applied to maps of Hill, Kaplan and Scott (no date a, b and 1977) and ARDRI (1981) |
| SOIL TYPE | Hill, Kaplan and Scott (no date a, b and 1977) and ARDRI (1981) |
| GEOLOGY | 1:50 000 geological sheets, Geological Survey of South Africa |
| SLOPE ANGLE | 1:50 000 topocadastral series, South Africa |
| SLOPE LENGTH | 1:50 000 topocadastral series, South Africa |
| LS | 1:50 000 topocadastral series, South Africa |
| PROFILE SLOPE SHAPE | 1:50 000 topocadastral series, South Africa |
| LATERAL SLOPE SHAPE | 1:50 000 topocadastral series, South Africa |
| COMBINED SLOPE SHAPE | 1:50 000 topocadastral series, South Africa |
| SLOPE ASPECT | 1:50 000 topocadastral series, South Africa |
| LAND USE | 1:30 000 aerial photographs (Aircraft operating company,1984) and field surveys |
| VELD TYPE | Hill, Kaplan and Scott (1977), Gibbs-Russel and Robinson (1982) and field survey |
| VELD CARRYING CAPACITY | Gibbs-Russel and Robinson (1982), Willis and Trollope (1982), Hill, Kaplan and Scott (1977) and field surveys |
| VELD CONDITION SCORE | Gibbs-Russel and Robinson (1982), Willis and Trollope (1982) Hill, Kaplan & Scott (1977) and field surveys |
| POPULATION DENSITY | Ciskei Directorate of Planning (1984) |
| DISTANCE TO NEAREST VILLAGE | 1:50 000 topocadastral sheets, South Africa |
| FOOTPATH DENSITY | 1:50 000 topocadastral sheets, South Africa |
| LIVESTOCK DENSITY | Ciskei Department of Agriculture's Veterinary services dipping tank statistics |

# CHAPTER SEVEN

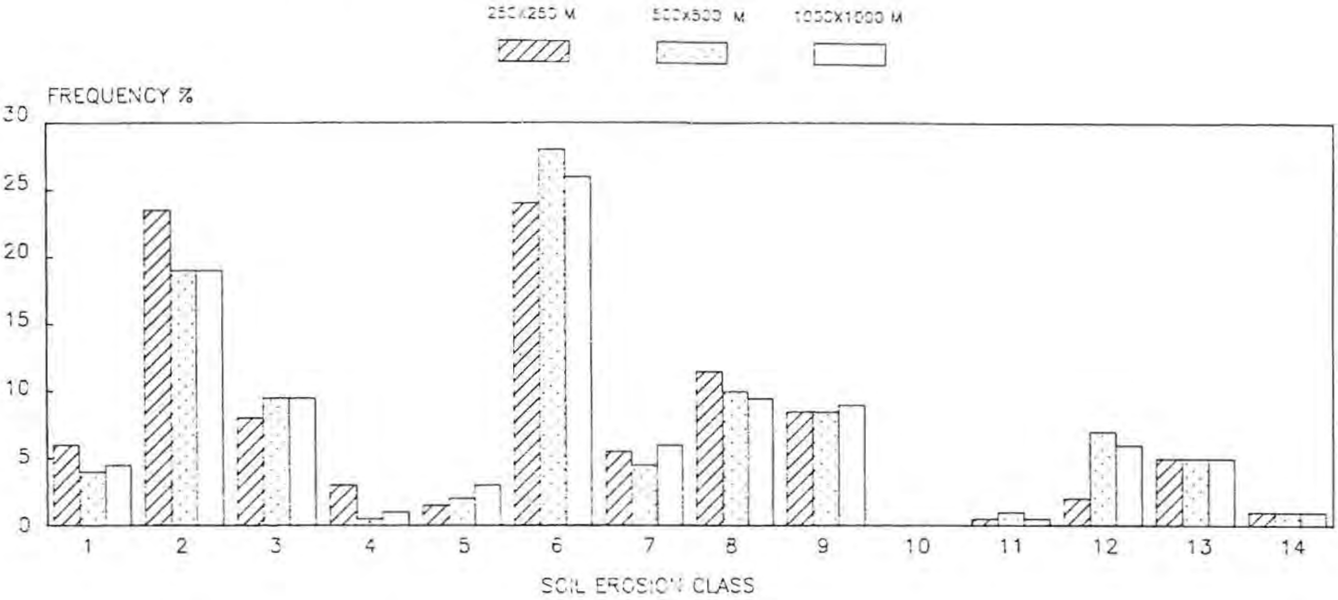
# DATA ANALYSIS

## 7.1: Extraction of Data for Analysis

The use of geographical information systems for the quantitative comparison of mapped data is discussed in Chapter 3. Data on soil erosion and soil erosion promoting factors were extracted from the original maps using a 500m square grid point sampling system . These data were then entered into a computer data file in matrix form. An extract of the data file is given the Appendix (p168).

Before deciding on the final sample interval of 500m square it was necessary to ascertain the extent to which different sample sizes accurately represent the population under study. In general, it can be stated that the larger the sample, the more representative it will be (Dixon and Leach, 1977). However, restrictions on analysis time preclude the use of excessively large populations. A second general point on sampling is that the greater the variability of the population, the larger the sample needed to accurately represent it (Dixon and Leach, 1977).

If the grid cells of a geographical information system are small relative to source map regions, the description attributed to any sample point is likely to be unreliable (Cocks and Walker, 1987). A method of identifying cell size errors is to compare descriptions of the same source data after being encoded to various cell sizes (Wehde, 1979). A pilot study was undertaken in the Yellowwoods Basin using different grid sizes (1000m, 500m, and 250m) to evaluate the effect of sample size on the final results. The spatial variability of the different variables differs considerably, with, for example, mean annual $EI_{30}$ showing a low variability and slope angle having a high variability. If these variables were being examined in isolation, $EI_{30}$ would require a low sampling frequency and slope angle a considerably higher sampling frequency. Soil erosion is the key variable to this study and has a relatively high spatial variability. It was therefore decided to restrict the pilot study to soil erosion. Figure 7.1 presents histograms showing the effect of varying sampling frequencies on the distribution of soil erosion classes in both the original mapped form and the modified classes. The histograms depicted in Figure 7.1 show very little difference between sample distributions at the three different sample a.Original mapped form:




b.Regrouped data:

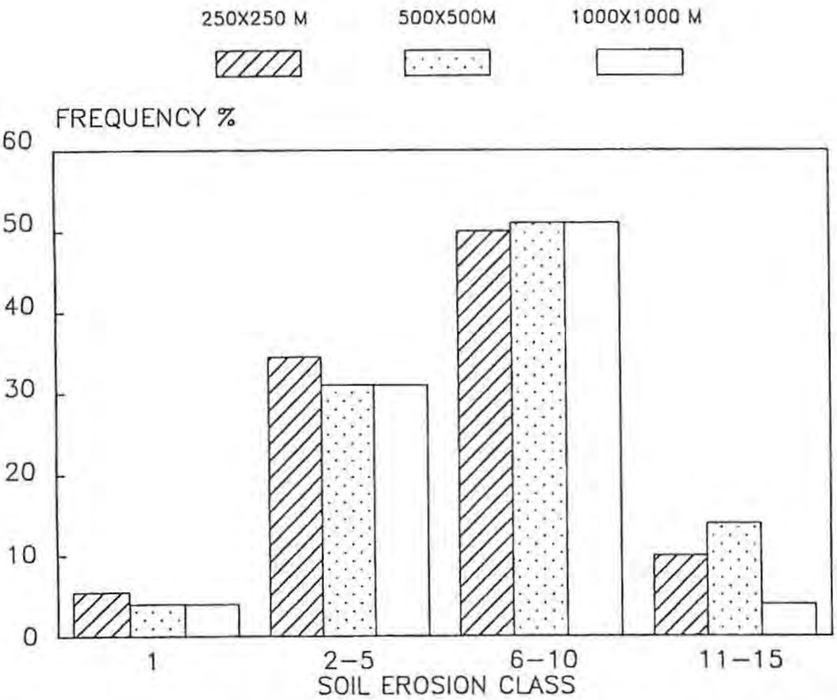



**FIGURE 7.1: THE EFFECT OF VARYING SAMPLING FREQUENCIES ON THE DISTRIBUTION OF SOIL EROSION CLASSES IN THE YELLOWWOODS BASIN.**

frequencies. The 500m by 500m frequency was selected because it yielded data volumes well within the capacity of the non-parametric statistics software package used and because standard 1cm by 1cm transparent graph paper could be used for grid overlays at the 1:50 000 scale.

A grid sampling system was chosen for the study with the grid being placed randomly over the catchment and then sampling from all grid points within the area defined by the catchment boundary. Random sampling is not employed due to the possibility of certain variables which are not evenly distributed across the entire area (e.g. soil type) being missed out completely. A systematic sample is not equivalent to a random sample where the environment sampled exhibits some periodicity which concurs within the sampling frame, for example evenly spaced crops (Dixon and Leach, 1977). None of the variables to be considered in this study exhibit this type of characteristic and the sampling method can therefore be treated as being random (Dixon and Leach, 1977).

### 7.2: Hypothesis Testing

Various BMDP statistical software options (Dixon, 1985) are used for testing the research hypothesis. The major consideration in selecting statistical tests is the measurement scale at which the different variables are recorded. As the scale of measurement of the dependent variable (erosion) is ordinal, the use of statistical tests is limited to non-parametric statistics. Chi-square tests are used to test relationships between erosion and variables measured at the nominal and ordinal scale (e.g. geology, slope aspect and veld-type) and Spearman Rank correlations (Rs) are used to test relationships which involve variables measured at higher levels (ordinal and interval scale, e.g. erodibility and population density). The significance of the relationships are assessed at the 5% probability level.

The overall aim of the study is to identify the most important factors affecting the spatial distribution of soil erosion in Ciskei and to develop an erosion hazard assessment technique applicable to as wide a range of conditions as possible. The results of the bivariate analyses will be used as guidelines for the selection of variables to be included in the multivariate analyses and the testing of the research hypothesis. The use of multivariate statistical analyses is not new to soil erosion studies. Although individual variables might be weakly related to soil erosion, grouped variables often reveal stronger relationships (Stocking, 1972a). For example, the effect that vegetation cover has on reducing raindrop impact and splash erosion might mean that heavily wooded steep slopes are well protected from erosion. A bivariate analysis of the relationship between slope angle and soil erosion might suggest that steep slopes are less eroded than gentle slopes. A multivariate analysis capable of assessing the combined effect of slope steepness and vegetation cover would provide a more adequate assessment of the combined effect of both vegetation cover and slope steepness on soil erosion. Recourse to multivariate techniques becomes even more essential when one considers the wide range of factors which could effect the soil erosion process. Various different types of multivariate statistics have been used in soil erosion studies, for example, multiple regression (Stocking, 1972a), discriminant analysis (Dickenson, *et al*., 1985), factor analysis (Dyer and Marker, 1979) and cluster analysis (Higginson,1973; Istok and Boersma,1986). Although no reference has been found in the literature to the use of multiway frequency table analysis (also referred to as contingency table analysis) in soil erosion studies, Wrigley (1976) provides a useful introductory summary to the application of this technique in geography. Multiway frequency tables are appropriate where data are categorical, discrete but ordered or continuous but grouped into intervals (Dixon, 1985). All of these requirements can be met by the data set used in this study. Most of the other multivariate techniques mentioned earlier have more stringent data requirements which cannot be met by the available data.

"The mere act of drawing up a contingency table represents a conscious structuring of a multifarious reality prior to analysis in which the variation present is subdivided according to distinct categorical variables" (Fingleton, 1984, p1). In the same way as scattergrams, pie charts and economic time series charts are used as data display devices, the contingency table offers an organising framework through which to view reality. Two-way frequency tables with associated histograms and statistical tests are used in this study to assess bivariate relationships. Where applicable (independent variable measured at the ordinal scale or higher) Spearman Rank correlation analyses are applied to the uncategorised data so that the strength and direction of relationships can be assessed. Multiway tables are used to identify variable combinations to test the study hypothesis. The categories derived in this way are ranked according to their mean erosion scores. The resultant rankings are used as erosion hazard indices and are correlated with observed soil erosion by way of Spearman's Rank correlation.

Three BMDP programs were used in the analysis of the data. BMDP1D was used to screen the data and to transform it to a form suitable for further analysis. The program also computes descriptive statistics for the data set which are useful in deciding on category boundaries. BMDP4F is used for determining the frequency of occurrence of the various erosion classes in relation to the independent variables and for creating two-way and multi-way frequency tables. BMDP4F is also used for determining the degree of association between groups. BMDP3S is used to determine Spearman's Rank correlation coefficients for uncategorised data. All of these programs are described in Dixon (1985).

# CHAPTER EIGHT

## DISCUSSION OF RESULTS OF BIVARIATE ANALYSES.

The results of the bivariate analyses will be used as guidelines for the selection of primary variables for use in the testing of the research hypothesis and for eventual inclusion in the erosion hazard assessment model. Table 8.1 summarizes the results of the statistical analyses of the relationship between soil erosion and the 24 independent variables. Variations in sample populations given in Table 8.1 are due to gaps in the data set.

The results depicted in Table 8.1 show that the one variable which appears to have the most marked effect on the spatial variation in soil erosion is land use. Figure 8.1 and Table 8.2 show the relationship between soil erosion and the three land use types (forestry, arable land and grazing land). Included in the histograms is the distribution that would occur (expected) if the three sub-populations defined by land use did not differ from the parent population.

The relatively low proportion of soil erosion in areas covered by forest is well in keeping with the literature reviewed (e.g. Gerlach, 1976; Zachar, 1982). Even though forested areas received more attention than other land use areas in terms of ground truthing, it could be argued that litter or dense vegetation cover might obscure erosion evidence. This fact combined with the obvious difference between forested land and other land uses led to the decision to repeat the bivariate analyses excluding forested land. The results of the repeated analyses are summarized in Table 8.3.

Many of the differences in the extent of soil erosion observed in the various environments are very slight. It is the differences in the tails of the distributions which are important (i.e. the presence or absence of severe erosion and whether or not there are areas of no erosion). It is evident from field observation that heavy soil erosion is often confined to small portions of otherwise relatively homogeneous catchments. The remainder of the discussion in this chapter focusses on those bivariate relationships which are statistically valid. The discussion follows the same format adopted in previous chapters.

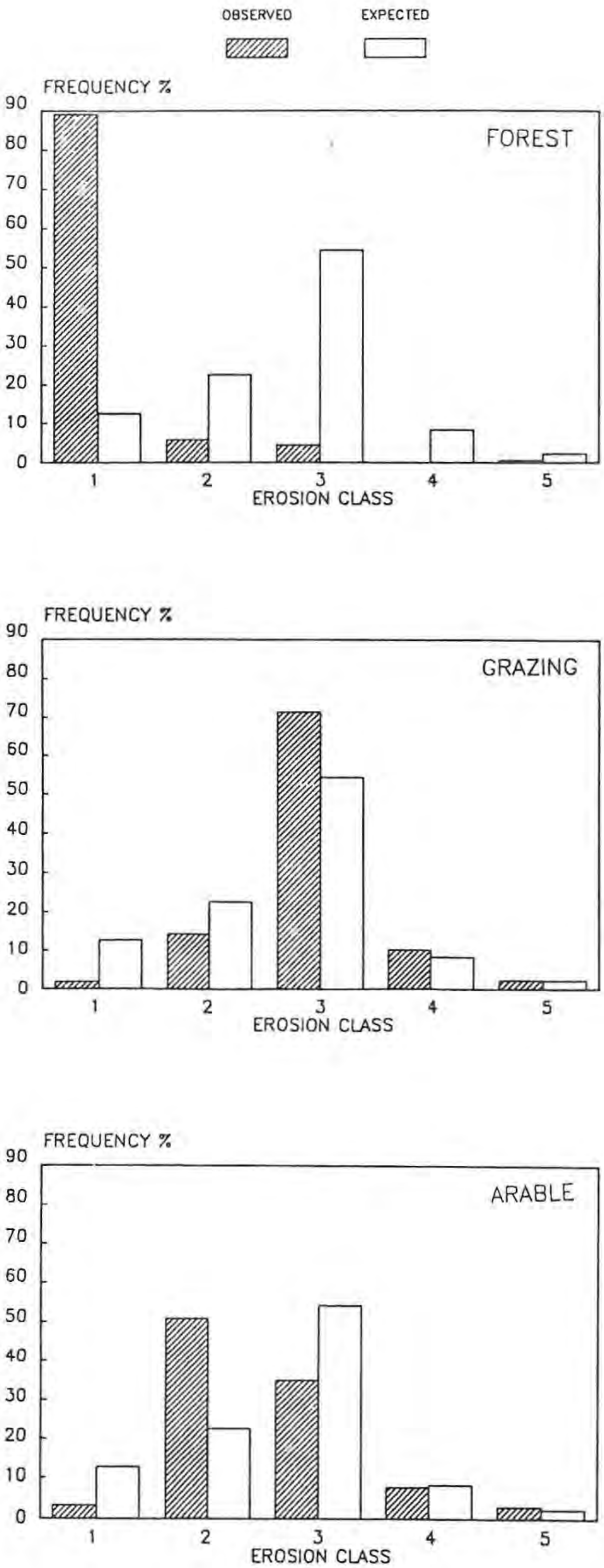



FIGURE 8.1: THE RELATIONSHIP BETWEEN SOIL EROSION AND LAND USE.

TABLE 8.1 RESULTS OF THE STATISTICAL TESTS

| SAMPLE POPULATION | INDEPENDENT VARIABLE | CHI-SQUARE | SPEARMAN RANK |
|---|---|---|---|
| 1334 | MEAN ANNUAL PRECIPITATION | | -0,48 |
| 1290 | ALTITUDE | | -0,34 |
| 1334 | RAINFALL EROSIVITY | | -0,44 |
| 1309 | SOIL ERODIBILITY | | 0,02(2) |
| 1304 | SOIL TYPE | 301,2(1) | |
| 1334 | GEOLOGY | 48,7 | |
| 1288 | SLOPE STEEPNESS | | -0,30 |
| 1288 | SLOPE LENGTH | | 0,12 |
| 1288 | L.S. FACTOR | | -0,29 |
| 1288 | PROFILE SHAPE | 58,9 | |
| 1288 | LATERAL SHAPE | 48,0 | |
| 1324 | THREE DIMENSIONAL SHAPE | 129,4 | |
| 1334 | SLOPE ASPECT | 53,2 | |
| 1321 | LAND USE | 1147,1 | |
| 1180 | VELD TYPE | 435,4 | |
| 859 | VELD CARRYING CAPACITY | | 0,06(2) |
| 485 | VELD CONDITION SCORE | | 0,20 |
| 481 | INCREASER II. $BENCH^{-1}$ | | 0,09(3) |
| 1130 | POPULATION DENSITY | | 0,14 |
| 1332 | DISTANCE FROM VILLAGE | | -0,21 |
| 1329 | FOOTPATH INTENSITY | | 0,11 |
| 1237 | LARGE STOCK UNIT DENSITY | | 0,29 |
| 1233 | SMALL STOCK UNIT DENSITY | | -0,31 |
| 1236 | MATURE LIVESTOCK UNIT DENSITY | | 0,12 |

(1) Expected Chi-square value <1 (possibly too many categories).

(2) Not significant at the 5% level.

(3) Not significant at the 1% level.

### 8.1: Soil erosion and climate

The climatic variable considered most important in explaining variation in soil erosion is rainfall, more specifically the kinetic energy of rainfall. The analysis of the relationship between rainfall erosivity and soil erosion in non-forested areas reveals a negative correlation ($R_s$ = -0,32) suggesting an inverse relationship between erosivity and soil erosion. Although erosivity values are likely to be important controls on soil loss through time at a given point in space, the effect of spatial variations in soil erosion due to variations in erosivity might be complicated by the effect of rainfall on vegetation. A strong correlation between MAP and vegetation cover in Ciskei was observed by Hill, Kaplan and Scott (1977). Zachar (1982) emphasises the fact that soil erosion does not always occur where the erosivity is highest but may occur instead where ecoclimatic conditions are unfavourable. Langbein and Schumm (1958), Douglas (1967) and Kirkby (1980) show that on a world scale, areas with an MAP of less than 300mm show an increase in erosion with increasing MAP. At MAP levels above 300mm the protective effect due to increased vegetation cover increases and soil erosion decreases. This inverted trend could then account for a decrease in erosion with increasing values of $EI_{30}$ where $EI_{30}$ is dependent on MAP. The dependence of $EI_{30}$ on MAP is high as discussed in Chapter 6. This is supported by a strong correlation (Rs = 0,86) between the two variables.

**TABLE 8.2: OBSERVED FREQUENCY DISTRIBUTION FOR EROSION ON DIFFERING LAND USES.**

| LAND USE | EROSION CLASS* | | | | | |
|---|---|---|---|---|---|---|
| | 1 (%) | 2 (%) | 3 (%) | 4 (%) | 5 (%) | TOTAL (n) |
| FOREST | 88,7 | 5,8 | 4,5 | 0,0 | 0,6 | 156 |
| GRAZING | 1,9 | 14,2 | 71,4 | 10,1 | 2,4 | 831 |
| ARABLE | 3,3 | 50,9 | 35,0 | 7,8 | 3,0 | 334 |
| TOTAL | 12,6 | 22,5 | 54,3 | 8,3 | 2,3 | 1321 |

* As defined in table 6.2

MAP in the area is dependent on the altitude (Rs = 0,70) with higher altitude regions receiving the highest precipitation. It follows therefore that either altitude or MAP could be used as an index of erosion hazard. The lower correlation (Rs = -0,16) between erosion and altitude in non-forested areas and the possibility that rain shadow effects could disrupt the MAP - altitude relationship favours the selection of MAP as an erosion hazard index. The relative importance of extreme rainfall in areas of Ciskei with low rainfall as opposed to areas of high rainfall is illustrated in Figure 5.3. The negative correlation between MAP and soil erosion lends support to the suggestion (Chapter 5.1) that low rainfall regions show a greater susceptibility to erosive storms than the higher rainfall regions.

**TABLE 8.3: RESULTS OF STATISTICAL TESTS EXCLUDING FORESTED LANDS**

| SAMPLE POPULATION | INDEPENDENT VARIABLE | CHI-SQUARE | SPEARMAN RANK |
|---|---|---|---|
| 1165 | MEAN ANNUAL PRECIPITATION | | -0,35 |
| 1129 | ALTITUDE | | -0,16 |
| 1165 | RAINFALL EROSIVITY | | -0,32 |
| 1141 | SOIL ERODIBILITY | | 0,04(2) |
| 1135 | SOIL TYPE | 204,2(1) | |
| 1165 | GEOLOGY | 55,2 | |
| 1129 | SLOPE STEEPNESS | | -0,10 |
| 1129 | SLOPE LENGTH | | 0,06(3) |
| 1129 | L.S. FACTOR | | -0,09 |
| 1129 | PROFILE SHAPE | 61,6 | |
| 1129 | LATERAL SHAPE | 22,3 | |
| 1156 | THREE DIMENSIONAL SHAPE | 112,5(1) | |
| 1165 | SLOPE ASPECT | 6,1(2) | |
| 1165 | LAND USE (Arable and grazing) | 185,0 | |
| 1015 | VELD TYPE | 154,7 | |
| 790 | VELD CARRYING CAPACITY | | 0,08(2) |
| 428 | VELD CONDITION SCORE | | 0,01(2) |
| 428 | INCREASER II. BENCH$^{-1}$ | | 0,06(2) |
| 988 | POPULATION DENSITY | | 0,01(2) |
| 1164 | DISTANCE FROM VILLAGE | | -0,02(2) |
| 1161 | FOOTPATH INTENSITY | | 0,06(3) |
| 1076 | LARGE STOCK UNIT DENSITY | | 0,29 |
| 1073 | SMALL STOCK UNIT DENSITY | | -0,21 |
| 1076 | MATURE LIVESTOCK UNIT DENSITY | | 0,12 |

(1) Expected Chi-square value <1 (possibly too many categories).
(2) Not significant at the 5% level.
(3) Not significant at the 1% level.

## 8.2: Soil erosion and parent material

The relationship between soil erosion and underlying material is investigated in terms of geology, soil type and soil erodibility. The results of the analysis indicate that soil erosion is less severe on soils underlain by dolerite than on those underlain by sedimentary rocks. This finding concurs with that of Berjak *et al.* (1986) and the field observations of Mountain (1952). The non-significant correlation coefficient (Rs = 0,04) obtained for the relationship between erosion and the SLEMSA erodibility coefficient justifies the exclusion of this index from any further analysis.

Tests on the relationship between soil type and erosion for non - forested soils reveal that soils with a high clay content and well structured A horizon (Milkwood, Mayo, Arcadia and Shortlands) tend to exhibit relatively low degrees of erosion. D'Huyvetter and Laker (1985) concur on the stability of Shortlands and Arcadia soils in the Amatole and Middledrift areas. Valsrivier and Sterkspruit soils are associated with areas of high erosion. Eloff (1973) agrees with respect to the susceptibility of these two soil types to erosion. D'Huyvetter and Laker (1985) identify the Valsrivier soils of the Amatole and Middledrift areas as being highly erodible. Mispah and Glenrosa soils predominate the study area and also exhibit a high degree of erosion, possibly due to their low permeability and the presence of a shallow restrictive horizon. Clovelly and Hutton soils do not vary much from the expected and, because they are relatively deep apedal soils without a restrictive horizon, are placed in a low erodibility group. Swartland and Westleigh soils, on the other hand, are duplex soils with relatively impermeable lower horizons and are placed in the high erodibility group. The data suggest that Oakleafs are relatively erosion prone (possibly due to their strong (92%) association with sedimentary rocks) and are placed in a higher erodibility group. The regrouping of soils (and associated erosion scores) is presented in Table 8.4 and Figure 8.2. Although no marked difference exists between group A and group B soils in the modal erosion class (class 3), group A soils are more common in erosion classes 1 and 2 whilst group B soils are more common in erosion classes 4 and 5.

Before deciding on the usefulness of a combined geology and soil type index to express the effect of parent material on soil erosion, an assessment must be made of the interdependence between these two variables. Table 8.5 summarizes the distribution of the various soil types on dolerite and sedimentary rocks. The table shows that no soil type is restricted to a particular geological group. The standardised deviates ((observed - expected) $/ \sqrt{\text{expected}}$) (Dixon, 1985) in columns 5 and 8 of Table 8.5 give an indication of the extent to which the observed distributions deviate from the expected distribution. Glenrosa, Sterkspruit and Oakleaf soils show a strong association with sedimentary rocks whilst Swartland, Westleigh, Arcadia and Milkwood soils show a stronger than expected affinity to dolerites. Mispahs and Valsriviers show very little deviation from the expected distribution. A multiway frequency table (Table 8.6) is used to illustrate the combined effect of geology and soil type on the distribution of soil erosion in the study area.

**TABLE 8.4: OBSERVED FREQUENCY FOR VARIOUS EROSION CLASSES ON REGROUPED SOIL TYPES (FORESTED LAND EXCLUDED).**

| SOIL GROUP | DOMINANT SOIL FORMS * | EROSION CLASS 1 (%) | 2 (%) | 3 (%) | 4 (%) | 5 (%) | TOTAL (n) | MEAN |
|---|---|---|---|---|---|---|---|---|
| A | HU, MY, CV, MW, AR, SD. | 4,6 | 29,0 | 61,2 | 5,1 | 0,0 | 217 | 2,67 |
| B | VA, WE, OA, MS, SS, SW, GS. | 1,7 | 24,2 | 60,2 | 10,7 | 3,2 | 918 | 2,90 |
| TOTAL | | 2,3 | 25,1 | 60,4 | 9,6 | 2,6 | 1135 | 2,83 |

* A full description of all soil forms is given by Macvicar, *et al.* (1977).

**TABLE 8.5: OBSERVED FREQUENCY FOR VARIOUS SOIL TYPES ON GEOLOGY**

| DOMINANT SOIL FORM | GROUP | GEOLOGY: DOLERITE N | % | STD DEVIATES | SEDIMENTARY ROCKS N | % | STD DEVIATES | TOTAL N | % |
|---|---|---|---|---|---|---|---|---|---|
| MS | B | 72 | 22 | 0,4 | 255 | 78 | -0,2 | 327 | 100 |
| GS | B | 13 | 7 | -3,9 | 160 | 93 | 2,0 | 173 | 100 |
| SW* | B | 6 | 50 | 2,2 | 6 | 50 | -1,1 | 12 | 100 |
| VA | B | 9 | 23 | 0,3 | 30 | 77 | -0,1 | 39 | 100 |
| SS | B | 38 | 14 | -2,6 | 237 | 86 | 1,4 | 275 | 100 |
| WE* | B | 11 | 69 | 4,2 | 5 | 31 | -2,1 | 16 | 100 |
| CV | A | 9 | 29 | 1,0 | 22 | 71 | -0,5 | 31 | 100 |
| HU | A | 23 | 30 | 1,7 | 54 | 70 | -0,9 | 77 | 100 |
| SD | A | 12 | 80 | 5,0 | 3 | 20 | -2,6 | 15 | 100 |
| OA | B | 6 | 8 | -2,5 | 69 | 92 | 1,3 | 75 | 100 |
| AR | A | 13 | 46 | 2,9 | 15 | 54 | -1,5 | 28 | 100 |
| MY* | A | 2 | 14 | -0,6 | 12 | 86 | 0,3 | 14 | 100 |
| MW | A | 23 | 55 | 4,8 | 19 | 45 | -2,5 | 42 | 100 |
| TOTAL | | 237 | 21 | | 887 | 79 | | 1124 | |

Although a number of frequencies are too low to make any conclusive statements it is clear from the table that the mean erosion score for all of the major soil types is higher when underlain by sedimentary rocks than when underlain by dolerites. Based on the foregoing evidence a combined geology and soil type index, "parent material" is derived. Table 8.7 outlines the parent material groups recommended for future analyses.

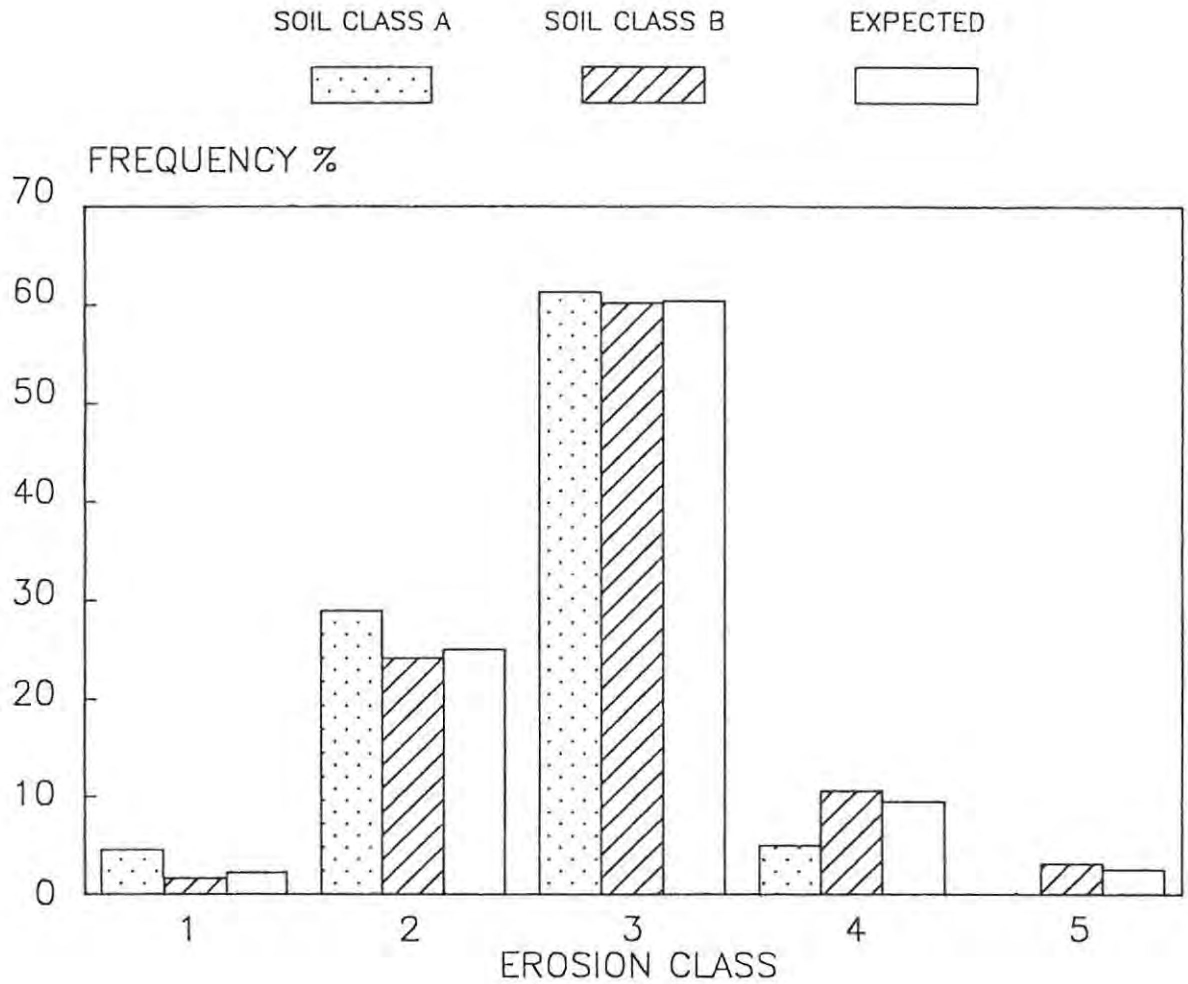



**FIGURE 8.2: THE RELATIONSHIP BETWEEN SOIL EROSION AND REGROUPED SOIL TYPES**

TABLE 8.6: THE COMBINED EFFECT OF GEOLOGY AND SOIL TYPE ON SOIL EROSION IN NON-FORESTED AREAS.

| GEOLOGY | SOIL | EROSION CLASS 1 (%) | 2 (%) | 3 (%) | 4 (%) | 5 (%) | TOTAL (n) | MEAN |
|---|---|---|---|---|---|---|---|---|
| | MS | 6,9 | 38,9 | 50,0 | 4,2 | 0,0 | 72 | 2,51 |
| | GS | 7,7 | 38,5 | 53,8 | 0,0 | 0,0 | 13 | 2,46 |
| | SW | 0,0 | 50,0 | 50,0 | 0,0 | 0,0 | 6 | 2,50 |
| | VA | 11,1 | 55,6 | 33,3 | 0,0 | 0,0 | 9 | 2,20 |
| | SS | 0,0 | 36,8 | 52,6 | 10,5 | 0,0 | 38 | 2,74 |
| DOLERITE | WE | 0,0 | 9,1 | 63,6 | 27,3 | 0,0 | 11 | 3,18 |
| | CV | 0,0 | 33,3 | 66,7 | 0,0 | 0,0 | 9 | 2,67 |
| | HU | 4,3 | 39,1 | 52,2 | 4,3 | 0,0 | 23 | 2,57 |
| | SD | 16,7 | 66,7 | 16,7 | 0,0 | 0,0 | 12 | 2,00 |
| | OA | 0,0 | 66,7 | 33,3 | 0,0 | 0,0 | 6 | 2,33 |
| | AR | 15,4 | 53,8 | 30,8 | 0,0 | 0,0 | 13 | 2,15 |
| | MY | 0,0 | 0,0 | 100,0 | 0,0 | 0,0 | 2 | 3,00 |
| | MW | 4,3 | 30,4 | 56,5 | 8,7 | 0,0 | 23 | 2,70 |
| TOTAL | | 5,5 | 39,7 | 49,4 | 5,5 | 0,0 | 237 | 2,55 |
| | MS | 2,4 | 7,5 | 74,9 | 12,9 | 2,4 | 255 | 3,05 |
| | GS | 0,6 | 33,8 | 55,0 | 5,6 | 5,0 | 160 | 2,81 |
| | SW | 0,0 | 33,3 | 66,7 | 0,0 | 0,0 | 6 | 2,67 |
| | VA | 0,0 | 13,3 | 50,0 | 13,3 | 23,3 | 30 | 3,47 |
| SEDIMENTARY | SS | 0,4 | 27,8 | 55,3 | 16,5 | 0,0 | 237 | 2,88 |
| ROCKS | WE | 0,0 | 40,0 | 60,0 | 0,0 | 0,0 | 5 | 2,60 |
| | CV | 4,5 | 9,1 | 86,4 | 0,0 | 0,0 | 22 | 2,82 |
| | HU | 0,0 | 14,8 | 74,1 | 11,1 | 0,0 | 54 | 2,96 |
| | SD | 0,0 | 66,7 | 33,3 | 0,0 | 0,0 | 3 | 2,33 |
| | OA | 1,4 | 21,7 | 60,9 | 4,3 | 11,6 | 69 | 3,03 |
| | AR | 20,0 | 33,3 | 46,7 | 0,0 | 0,0 | 15 | 2,27 |
| | MY | 0,0 | 25,0 | 75,0 | 0,0 | 0,0 | 12 | 2,75 |
| | MW | 0,0 | 42,1 | 57,9 | 0,0 | 0,0 | 19 | 2,58 |
| TOTAL | | 1,5 | 21,4 | 63,2 | 10,6 | 3,3 | 887 | 2,93 |

**TABLE 8.7: EROSION HAZARD RATING AND PARENT MATERIAL**

| PARENT MATERIAL GROUP | EROSION HAZARD | DESCRIPTION OF PARENT MATERIAL GROUP |
|---|---|---|
| 1 | 1<br>LOW | ALL DOLERITE SOILS AND SOILS WITH STRUCTURED HIGH CLAY CONTENT A HORIZONS (AR,MY,MW). |
| 2 | 2<br>MODERATE | GLENROSAS(GS) ON SEDIMENTARY ROCKS AND DEEP SOILS WITHOUT A RESTRICTIVE HORIZON (CV, HU, SD). |
| 3 | 3<br>HIGH | DUPLEX SOILS (SW,VA,WE,SS) ON SEDIMENTARY ROCKS. |
| 4 | 4<br>VERY HIGH | MISPAHS(MS) AND OAKLEAFS(OA) ON SEDIMENTARY ROCKS. |

The classification presented in Table 8.7 is based on a combination of the logical grouping of the soils, the data obtained thus far and an attempt to distribute data as evenly as possible within the various groups. The allocation of Glenrosas to parent material group 2 and the combination of Oakleafs with Mispahs disrupt what would otherwise be a logical classification of parent material. An explanation of these anomalies would require detailed field and laboratory work, both of which are beyond the scope of this study. Figure 8.3 shows the frequency distribution of soil erosion on the parent material groups defined in Table 8.7. Fairly obvious differences exist between groups 1 and 4. The only difference between groups 2 and 3 is the greater proportion of class 4 and higher proportion of class 3 erosion in group 3. The classification will be retained as defined in Table 8.7 with the option for category collapsing at a later stage.

### 8.3: Soil erosion and relief

No meaningful relationships were found between any of the three slope shape parameters (lateral shape, profile shape and three dimensional shape) and soil erosion. Slope length also failed to show any significant relationships with soil erosion. Slope aspect, LS, slope angle and altitude all showed significant relationships with erosion. The relationship between altitude and mean annual precipitation has already been discussed (8.1).

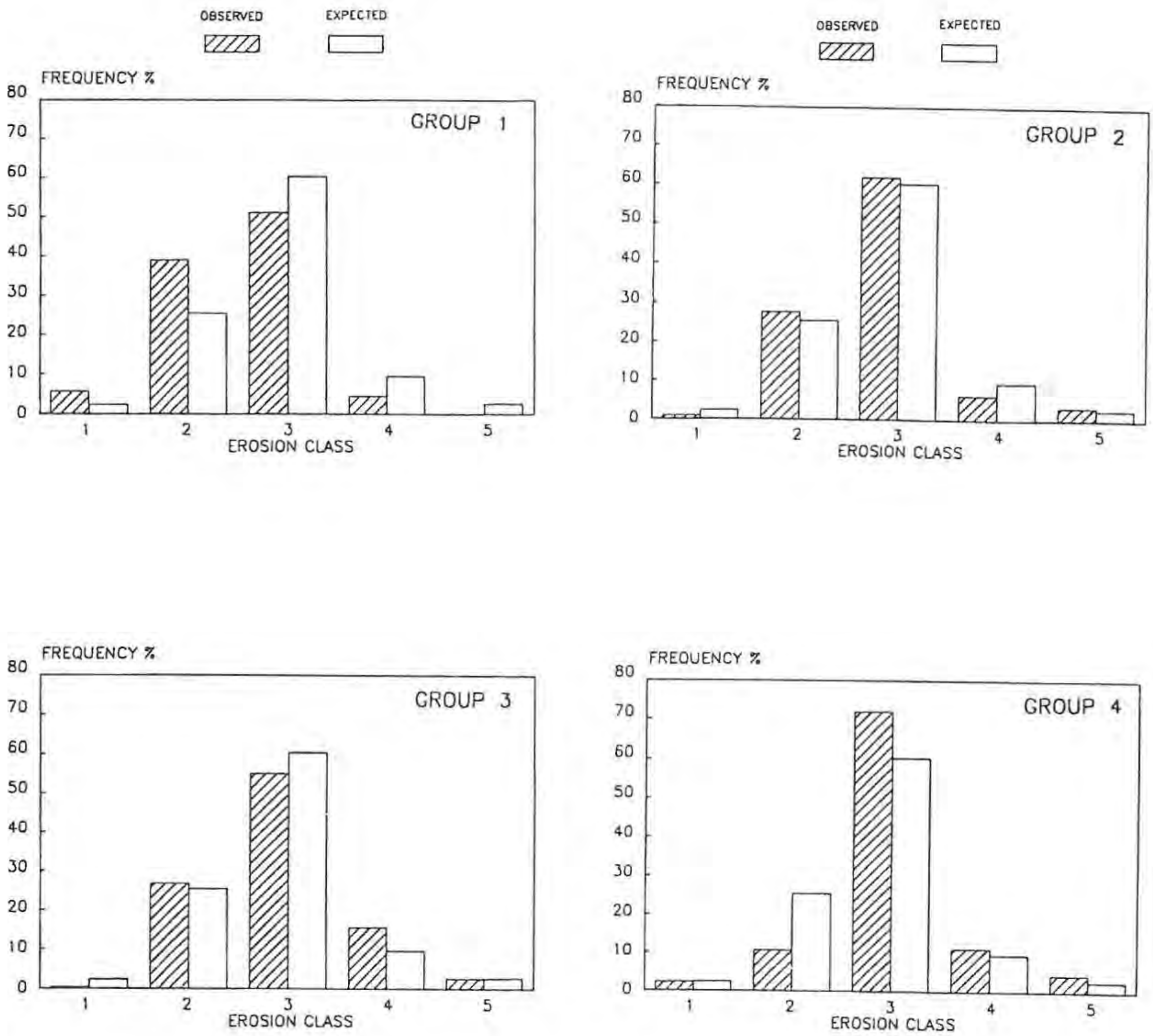



FIGURE 8.3: THE RELATIONSHIP BETWEEN SOIL EROSION AND PARENT MATERIAL.

LS and slope angle both vary inversely with soil erosion in non-forested areas (-0,09 and -0,10) which is contrary to what was expected from most of the literature reviewed. The lack of a relationship between slope length and erosion suggests that the LS correlation with erosion is due to the influence of slope angle in the LS equation (Chapter 2). The inverse relationship between soil erosion and slope angle is in keeping with the findings of Heusch (1970) and Odermeho (1986).

A relatively strong relationship exists between altitude and slope steepness (Rs = 0,60) as well as MAP and slope steepness (Rs = 0,49). It is, therefore highly likely that any relationship between slope steepness and erosion is really a result of the steeper slopes occurring at higher altitudes where there is more rainfall and a higher vegetation cover. This is in keeping with the conclusions of Hadley *et al.*'s (1985) review of erosion and sediment yield studies. These authors note that it is now recognised that the effect of slope characteristics on runoff and erosion depends on ground cover, canopy characteristics and soil management. Slope steepness and LS, like altitude might be useful indices but appear to be unlikely to make a pronounced additional contribution to the understanding of the distribution of erosion than that made by mean annual rainfall.

**8.4: Soil erosion and vegetation**

Four vegetation indices were tested in relation to soil erosion, namely veld type, Increaser II.Bench$^{-1}$ veld condition score and veld carrying capacity. Veld carrying capacity showed no meaningful relationship with erosion (Rs = 0,16 with forest and Rs = 0,08 without forest). Veld condition score (Rs = 0,20) showed a slightly more meaningful relationship when forested areas were included than did Increaser II.Bench$^{-1}$ (Rs = 0,09). The exclusion of forested areas rendered both of these assessment indices meaningless (Rs = 0,01 and 0,06 respectively). The paucity of data for these indices and the lack of a significant relationship make their applicability to other areas in Ciskei limited. However, veld type has been mapped widely and the results indicate a meaningful relationship. The lowest degree of erosion is associated with Dohne Sourveld and the highest degree of erosion is associated with Valley Bushveld and Eastern Province Thornveld (Table 8.8 and Figure 8.4). False Thornveld shows an intermediate degree of erosion.

An analysis of the relationship between veld type and mean annual precipitation reveals that the Dohne sourveld is found predominantly in areas where the mean annual precipitation exceeds 600 mm (only 17 cases in the data set occurred in areas where the MAP was less than 600 mm). It was therefore decided to restrict the use of Dohne Sourveld as an index to the higher rainfall areas ( $>600$ mm). Likewise, False Thornveld is more common in higher rainfall areas and Valley Bushveld, and Eastern Province Thornveld predominate in the lower rainfall areas. Table 8.9 summarizes the distribution of the veld types in two broad rainfall zones ($\leqslant 600$ mm and $>600$ mm). The limitations imposed on vegetation by rainfall will be used as a criterion for category collapsing at a later stage in the analysis.

**TABLE 8.8: OBSERVED FREQUENCY FOR DIFFERENT EROSION CLASSES ON VARIOUS VELD TYPES (FOREST EXCLUDED)**

| VELD TYPE: | EROSION CLASS | | | | | |
|---|---|---|---|---|---|---|
| | 1 (%) | 2 (%) | 3 (%) | 4 (%) | 5 (%) | TOTAL (n) |
| DOHNE SOURVELD | 5,5 | 43,2 | 48,6 | 2,2 | 0,5 | 183 |
| FALSE THORNVELD | 5,9 | 27,0 | 54,6 | 4,3 | 8,1 | 185 |
| VALLEY BUSHVELD | 2,2 | 13,0 | 70,7 | 12,5 | 1,6 | 184 |
| EASTERN PROVINCE THORNVELD | 0,0 | 19,9 | 65,7 | 14,5 | 0,0 | 463 |
| TOTAL: | 2,5 | 24,1 | 61,5 | 10,0 | 1,9 | 1015 |

**TABLE 8.9: OBSERVED FREQUENCY FOR DIFFERENT VEGETATION TYPES ON MEAN ANNUAL PRECIPITATION (FOREST INCLUDED)**

| | VELD TYPE | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| MEAN ANNUAL PRECIPITATION | Dohne Sourveld | | False Thornveld | | Valley Bushveld and E.P. Thornveld | | TOTAL | |
| | n | % | n | % | n | % | n | % |
| ≤600 mm | 18 | 2,7 | 89 | 13,3 | 560 | 84,0 | 667 | 100 |
| >600 mm | 257 | 39,8 | 266 | 41,2 | 123 | 19,0 | 646 | 100 |
| TOTAL: | 275 | 21,0 | 355 | 27,0 | 683 | 52,0 | 1 313 | 100 |

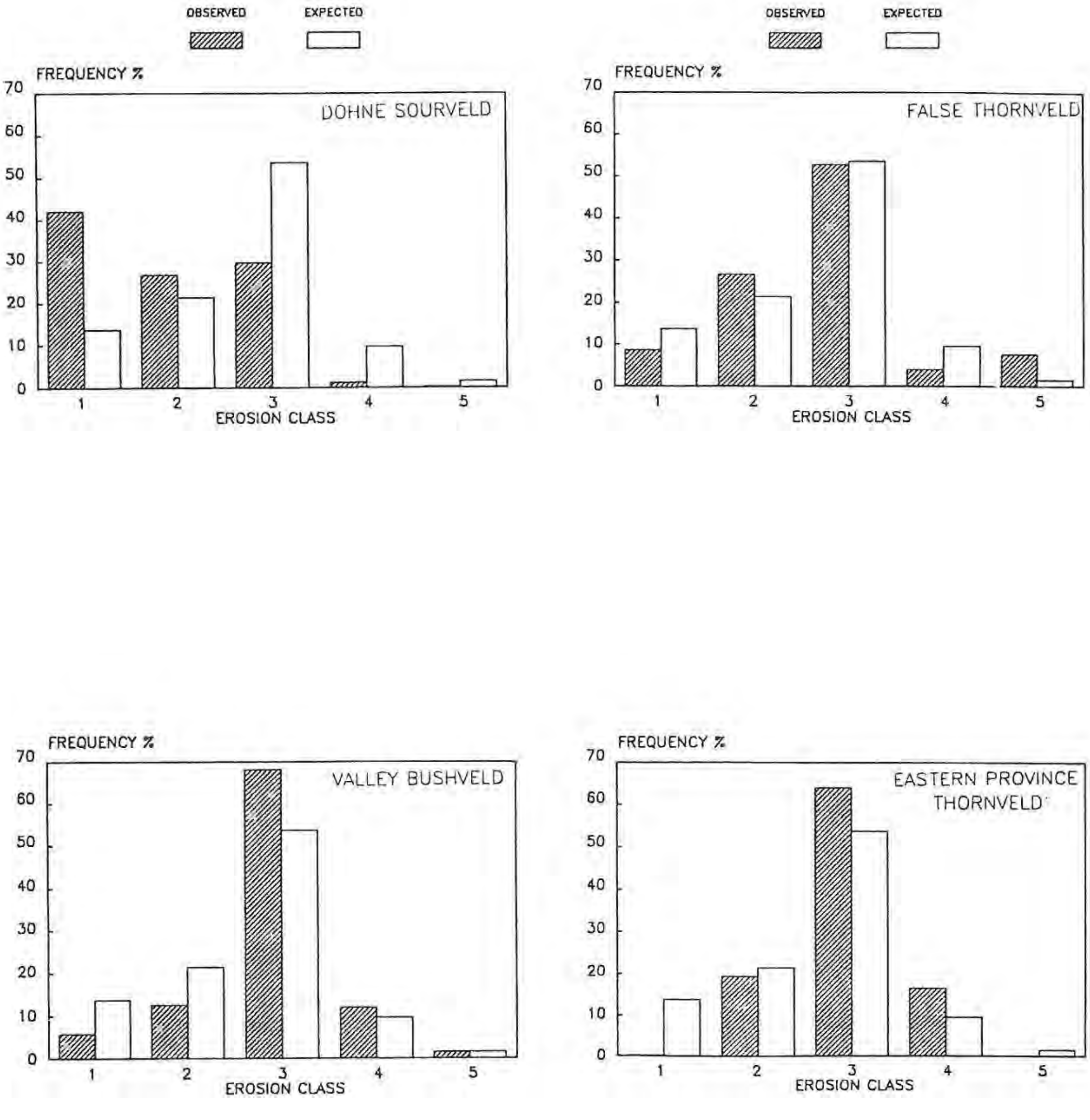



FIGURE 8.4: THE RELATIONSHIP BETWEEN SOIL EROSION AND VELD TYPE

### 8.5: Soil erosion and man

The relationship between areas of low erosion and forestry is discussed in section 8.1. Grazing land proved to be more heavily eroded than arable land (Figure 8.1). Difficulties involved in isolating areas which were previously cultivated but were left fallow following excessive erosion from grazing land reduces the usefulness of this attribute as an index.

The results show that there is a higher degree of soil erosion in areas with a high density of SSU (Rs = -0,31 including forest and -0,21 excluding forest) yet a relatively low degree of erosion in areas of high LSU density (Rs = 0,29 with forest and 0,29 without forest). No real trend emerges when mature livestock units (combined small and large stock units) is compared with erosion (Rs = 0,12 with forest and 0,12 without forest). Animals classified as large stock (cattle and equines) are predominantly grazing animals. It follows that high densities of large stock units will be restricted to areas with good grazing, i.e. a high grass cover. These areas would also have good vegetative protection. Small stock units, on the other hand, include a large proportion of goats which are mainly browsers and are suited to areas with relatively low grass cover and where bush encroachment (e.g. *Acacia karroo*) has occurred. The question as to whether there is a high amount of erosion because of the high density of stock units or *vice versa* could only be adequately answered with more detailed historical records of livestock populations.

Of the three remaining variables (population density, footpath intensity and distance to the nearest village) only footpath intensity correlates significantly with erosion once forested areas are excluded from the data. The correlation coefficient (Rs = 0,06) is so low that its usefulness as an index is dubious. These three indices will therefore not be considered as being of any primary importance in effecting soil erosion distribution. Land use is the only man-related variable which emerges as being significant in effecting soil erosion distribution in the study area.

### 8.6: Selection of primary independent variables

Multiple frequency table analysis is used to test the research hypothesis. The results of the bivariate analyses discussed in this section are used as guidelines for use in identifying the variables used in the final analysis. Forested lands are an obvious choice for inclusion in the final model. The first erosion hazard class, "low erosion hazard", can be defined as those areas included in the forestry category.

The results presented in Tables 8.1 and 8.2 show that a number of statistical relationships which were significant when forested areas were included in the analysis do not yield statistically significant results when forested areas are excluded from the analysis. The results presented in these tables are used as the basis for the selection of variables for use in the multivariate analysis that follows.

Variables to be excluded following the tests outlined in Table 8.2 are slope aspect, population density, V.C.S., Increaser II. $Bench^{-1}$, and distance from the nearest village. There are logical links between these variables and forested land. Forest tends to thrive on cooler, moister south-facing aspects, hence the reduction in the importance of slope aspect on excluding forested areas. Population density and distance from the nearest village also became non-significant indicators of erosion on exclusion of forested areas. Forested areas tend to occur in remote, high altitude areas where population densities are low, hence the reduction in importance of these two values on excluding forest. Both V.C.S. and Increaser II. $Bench^{-1}$ are indicators of the state of health of vegetation. The areas defined as forests in this investigation all have favourable V.C.S. and Increaser II. $Bench^{-1}$ ratings, hence the reduction in importance of these two indices on the exclusion of forest. The exclusion of forest from the analysis reduces the strength of the significant relationships found between erosion class and erosivity, slope steepness, LS, SSU, footpath intensity, altitude, mean annual precipitation and veld type. The interrelationships between erosivity, MAP, slope steepness, LS and altitude have already been discussed (8.1). Forested areas are found on steeply sloped, high altitude lands which have a high MAP and consequently a high erosivity value. Forested areas are found predominantly in Dohne Sourveld (88%). The exclusion of forested lands from the analysis would therefore have a consequent suppressing effect on the strength of the relationship between soil erosion and MAP, erosivity, slope steepness, LS and altitude. There is an improvement in the soil erosion - geology relationship on exclusion of forested lands. Geology therefore remains an important variable for consideration.

As a result of the analysis thus far the following, more specific version of the research hypothesis is proposed:

"The spatial variation in soil erosion is a function of land use, parent material, veld type and mean annual precipitation".

Although only four variables are identified in the hypothesis, it is possible that the lumping together of data in the analysis to this point has hidden some relationships. For example, it is possible that footpath density is particularly important in an area with a particular combination of the four variables represented in the hypothesis. The variables included in the hypothesis will therefore be considered to be "primary" variables. Where the number of observations within the data group characterised by a particular combination of the primary variables permits, further sub-categorisation on the basis of variables not included in the multivariate hypothesis will be used. These subcategories will only be retained if they show differences which are statistically significant at the levels set for the study.

# CHAPTER NINE

## RESULTS OF MULTIVARIATE ANALYSIS

In this chapter the relationship between the combined effects of land use, parent material, veld type and mean annual precipitation on soil erosion will be tested. The additive effect of other variables in combination with the primary variables included in the research hypothesis will also be considered where the sample permits. The strong relationship between areas of low erosion and forestry has been identified and discussed (Chapter 8) and forested areas have been designated a "low erosion hazard" class. The analysis that follows concentrates on non-forested areas initially with forested lands being included at the final stage.

A number of multiway frequency tables are constructed to obtain a clearer understanding of the data. The initial categories selected for two-way tables (Chapter 8) proved to be inadequate due to the uneven distribution in data when the various categories were combined. Where these low counts occurred categories were 'collapsed' to form new categories with higher frequencies. Table 9.1 represents the first of the multiway tables produced. The four groups used to define parent material are those outlined in Table 8.7. Two categories of mean annual precipitation (less than or equal to 600mm and greater than 600mm ) are used. The four dominant veld types are used and the five erosion classes are retained as in previous analyses.

Although a number of interesting trends emerge from the table, the major purpose of this categorisation is to provide a starting point for category collapsing and expansion for future model development. A mean annual precipitation cutoff point of 600 mm virtually excludes Dohne Sourveld from this class. In the same way, Eastern Province Thornveld dominates the lower rainfall class. This illustrates the interdependence between MAP and veld type.

Regrouping of data and ranking of the various combinations based on the mean of the product of the frequency of occurrence within an erosion class and the erosion score was undertaken. Forest was included as a unique class and added to the data set. The first "erosion hazard model" derived from this recategorisation process is outlined in Tables 9.2 and 9.3. Table 9.4 explains the notation used in Table 9.3 and subsequent tables.

**TABLE 9.1: THE RELATIONSHIP BETWEEN PARENT MATERIAL, MEAN ANNUAL PRECIPITATION, VELD TYPE AND SOIL EROSION FOR NON-FORESTED AREAS.**

| PARENT MATERIAL | MEAN ANNUAL PRECIPITATION | VELD TYPE | EROSION CLASS 1 (%) | 2 (%) | 3 (%) | 4 (%) | 5 (%) | TOTAL (n) |
|---|---|---|---|---|---|---|---|---|
| GROUP1 | LE 600mm | DOHNE SOURVELD | 0,0 | 60,0 | 40,0 | 0,0 | 0,0 | 5 |
| | | FALSE THORNVELD | 0,0 | 30,8 | 61,5 | 7,7 | 0,0 | 13 |
| | | VALLEY BUSHVELD | 0,0 | 28,1 | 65,6 | 6,3 | 0,0 | 32 |
| | | E.P. THORNVELD | 0,0 | 29,2 | 62,5 | 8,3 | 0,0 | 96 |
| | | TOTAL | 0,0 | 30,1 | 62,3 | 7,5 | 0,0 | 146 |
| | GT 600mm | DOHNE SOURVELD | 27,3 | 27,3 | 45,5 | 0,0 | 0,0 | 11 |
| | | FALSE THORNVELD | 12,3 | 54,4 | 33,3 | 0,0 | 0,0 | 57 |
| | | VALLEY BUSHVELD | 20,0 | 40,0 | 40,0 | 0,0 | 0,0 | 20 |
| | | E.P. THORNVELD | 0,0 | 0,0 | 100,0 | 0,0 | 0,0 | 3 |
| | | TOTAL | 15,4 | 46,2 | 38,5 | 0,0 | 0,0 | 91 |
| GROUP2 | LE 600mm | DOHNE SOURVELD | 0,0 | 0,0 | 83,3 | 16,7 | 0,0 | 6 |
| | | FALSE THORNVELD | 0,0 | 0,0 | 71,4 | 0,0 | 28,6 | 14 |
| | | VALLEY BUSHVELD | 0,0 | 0,0 | 100,0 | 0,0 | 0,0 | 13 |
| | | E.P. THORNVELD | 0,0 | 8,3 | 71,7 | 20,0 | 0,0 | 60 |
| | | TOTAL | 0,0 | 5,4 | 76,3 | 14,0 | 4,3 | 93 |
| | GT 600mm | DOHNE SOURVELD | 2,3 | 50,6 | 44,8 | 2,3 | 0,0 | 87 |
| | | FALSE THORNVELD | 4,8 | 19,0 | 76,2 | 0,0 | 0,0 | 21 |
| | | VALLEY BUSHVELD | 0,0 | 0,0 | 100,0 | 0,0 | 0,0 | 3 |
| | | E.P. THORNVELD | 0,0 | 56,5 | 43,5 | 0,0 | 0,0 | 23 |
| | | TOTAL | 2,2 | 45,5 | 50,7 | 1,5 | 0,0 | 134 |
| GROUP3 | LE 600mm | DOHNE SOURVELD | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0 |
| | | FALSE THORNVELD | 0,0 | 0,0 | 0,0 | 0,0 | 100,0 | 3 |
| | | VALLEY BUSHVELD | 0,0 | 0,0 | 66,7 | 16,7 | 16,7 | 6 |
| | | E.P. THORNVELD | 0,0 | 19,8 | 61,0 | 19,2 | 0,0 | 182 |
| | | TOTAL | 0,0 | 18,8 | 60,2 | 18,8 | 2,1 | 191 |
| | GT 600mm | DOHNE SOURVELD | 2,2 | 64,4 | 33,3 | 0,0 | 0,0 | 45 |
| | | FALSE THORNVELD | 0,0 | 50,0 | 50,0 | 0,0 | 0,0 | 2 |
| | | VALLEY BUSHVELD | 0,0 | 0,0 | 100,0 | 0,0 | 0,0 | 1 |
| | | E.P. THORNVELD | 0,0 | 25,0 | 54,2 | 20,8 | 0,0 | 24 |
| | | TOTAL | 1,4 | 50,0 | 41,7 | 6,9 | 0,0 | 72 |
| GROUP4 | LE 600mm | DOHNE SOURVELD | 16,7 | 0,0 | 50,0 | 16,7 | 16,7 | 6 |
| | | FALSE THORNVELD | 3,5 | 5,3 | 64,9 | 12,3 | 14,0 | 57 |
| | | VALLEY BUSHVELD | 0,0 | 7,4 | 69,5 | 21,1 | 2,1 | 95 |
| | | E.P. THORNVELD | 0,0 | 2,0 | 89,8 | 8,2 | 0,0 | 49 |
| | | TOTAL | 1,4 | 5,3 | 72,5 | 15,5 | 5,3 | 207 |
| | GT 600mm | DOHNE SOURVELD | 9,5 | 0,0 | 90,5 | 0,0 | 0,0 | 21 |
| | | FALSE THORNVELD | 6,3 | 43,8 | 50,0 | 0,0 | 0,0 | 16 |
| | | VALLEY BUSHVELD | 0,0 | 0,0 | 100,0 | 0,0 | 0,0 | 13 |
| | | E.P. THORNVELD | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0 |
| | | TOTAL | 6,0 | 14,0 | 80,0 | 0,0 | 0,0 | 50 |

TOTAL OF THE OBSERVED FREQUENCY TABLE IS 984.

A Spearman rank correlation was used to test the strength of the relationship between the category ranks (Table 9.3) and erosion score for each of the data sampling points in the study area. A statistically significant correlation coefficient of 0,62 was obtained. Subsequent analysis of the variation occurring within the categories outlined in Table 9.3 was undertaken using frequency tables on additional variables not already included in the categorisation process. The resultant categorisation is outlined in Table 9.5. In creating the categories outlined in Table 9.5 an attempt was made to reduce all categories to a sample size closer to each other but above the recommended lower limit of 30 (Allen, 1982). The slightly lower sample of 1122 is due to the fact that certain areas have missing data for some of the additional variables. A Spearman Rank correlation analysis was applied to test the strength of the relationship between the erosion hazard ranks assigned in Table 9.5 and erosion score for each of the data sampling points in the study area. A statistically significant correlation coefficient of 0,66 was obtained.

**TABLE 9.2: PRELIMINARY MODEL COMPONENTS AND FREQUENCY OF OCCURRENCE OF EACH CATEGORY IN THE STUDY AREA**

| VELD TYPE | PARENT MATERIAL | MAP | (n) |
|---|---|---|---|
| FOREST | | | 156 |
| DOHNE SOURVELD | 1 OR 2 | NOT SPECIFIED | 109 |
| DOHNE SOURVELD | 3 OR 4 | NOT SPECIFIED | 72 |
| VALLEY BUSHVELD | 1 OR 2 | NOT SPECIFIED | 68 |
| VALLEY BUSHVELD | 2 OR 3 | NOT SPECIFIED | 115 |
| E.P. THORNVELD | 1 | NOT SPECIFIED | 99 |
| E.P. THORNVELD | 2 | NOT SPECIFIED | 83 |
| E.P. THORNVELD | 3 | NOT SPECIFIED | 206 |
| E.P. THORNVELD | 4 | NOT SPECIFIED | 49 |
| FALSE THORNVELD | NOT SPECIFIED | L.E. 600mm | 87 |
| FALSE THORNVELD | NOT SPECIFIED | G.T. 600mm | 96 |
| | | | 1140 |

The results show that the four variables selected in Chapter 8 (land use, parent material, veld type and mean annual precipitation) can be used to account for variations in soil erosion in the study area. The study hypothesis is therefore accepted. A more detailed analysis of the data shows that the inclusion of additional variables can result in a slightly improved explanation of spatial variations in soil erosion.

The more detailed categorisation of data outlined in Table 9.5 was examined using a series of two-way tables and Chi-square tests. Any subdivision of a category yielding Chi-square values not significant at the 5% probability level were discarded and the original, undivided categories were retained thus ensuring the uniqueness of classes. This analysis showed that the difference in the extent of soil erosion on parent material groups 1 and 2 did not differ significantly from that on groups 3 and 4 (Chi-square = 0,4; expected = 2,46) in the Dohne Sourveld region. False thornveld regions receiving an MAP of less than or equal to 600mm did not reveal significantly different patterns of erosion on the different parent material groups as outlined in Table 9.5 (Chi-square = 4,6; expected = 0,62; not significant at the 5% probability level).

**TABLE 9.3: DISTRIBUTION OF EROSION CLASS ON VARIOUS EROSION HAZARD CATEGORIES**

| CATEGORY | | | | EROSION CLASS | | | | | TOTAL FREQUENCY | MEAN | RANK |
|---|---|---|---|---|---|---|---|---|---|---|---|
| L | P | A | M | 1 (%) | 2 (%) | 3 (%) | 4 (%) | 5 (%) | (n) | | |
| 1 | * | * | * | 89,1 | 5,8 | 4,5 | 0,0 | 0,6 | 156 | 1,17 | 1 |
| 2,3 | * | 2 | 2 | 9,4 | 44,8 | 45,8 | 0,0 | 0,0 | 96 | 2,36 | 2 |
| 2,3 | 1,2 | 1 | * | 4,6 | 45,9 | 46,8 | 2,8 | 0,0 | 109 | 2,48 | 3 |
| 2,3 | 3,4 | 1 | * | 5,6 | 40,3 | 51,4 | 1,4 | 1,4 | 72 | 2,53 | 4 |
| 2,3 | 1,2 | 3 | * | 5,9 | 25,0 | 66,2 | 2,9 | 0,0 | 68 | 2,66 | 5 |
| 2,3 | 1 | 4 | * | 0,0 | 28,3 | 63,6 | 8,1 | 0,0 | 99 | 2,80 | 6 |
| 2,3 | 2 | 4 | * | 0,0 | 21,7 | 63,9 | 14,5 | 0,0 | 83 | 2,93 | 7 |
| 2,3 | 3 | 4 | * | 0,0 | 20,4 | 60,2 | 19,4 | 0,0 | 206 | 2,99 | 8 |
| 2,3 | 4 | 4 | * | 0,0 | 2,0 | 89,8 | 8,2 | 0,0 | 49 | 3,06 | 9 |
| 2,3 | 3,4 | 3 | * | 0,0 | 6,1 | 73,0 | 18,3 | 2,6 | 115 | 3,17 | 10 |
| 2,3 | * | 2 | 1 | 2,3 | 8,0 | 63,2 | 9,2 | 17,2 | 87 | 3,31 | 11 |
| TOTAL | | | | 14,3 | 22,0 | 53,2 | 8,7 | 1,8 | 1140 | | |

* All sub-categories

All of the other divisions employed in Table 9.5 (i.e divisions resulting in additional classes to Table 9.3) are statistically significant (Chi-square exceeded expected and probability less than 5%). A regrouping of the data based on these tests is presented in Table 9.6. A Spearman's rank correlation analysis of the relationship between the hazard rankings (Table 9.6) and erosion class yielded a statistically significant coefficient of 0,66. This coefficient is the same as that obtained for the more detailed categorisation of the data as depicted in Table 9.5. The additional variables included in Table 9.5 are therefore superfluous as they add nothing to the explanation of soil erosion patterns. The following chapter (Chapter 10) provides a discussion of these results in the light of the theoretical background, followed by the formulation and testing of an erosion hazard model.

**TABLE 9.4: MODEL NOTATION**

| CATEGORY CODE | NUMBER | EXPLANATION |
|---|---|---|
| L | 1 | Forestry |
| L | 2 | Grazing land |
| L | 3 | Arable land |
| P | 1 | Parent material class 1 |
| P | 2 | Parent material class 2 |
| P | 3 | Parent material class 3 |
| P | 4 | Parent material class 4 |
| A | 1 | Dohne Sourveld |
| A | 2 | False Thornveld |
| A | 3 | Valley Bushveld |
| A | 4 | Eastern Province Thornveld |
| M | 1 | MAP LE 600mm |
| M | 2 | MAP GT 600mm |
| S | 1 | Slope angle LE 15% |
| S | 2 | Slope angle GT 15% |
| LS | 1 | Laterally convex slopes |
| LS | 2 | Laterally concave slopes |
| SL | 1 | Slope length LE 650m |
| SL | 2 | Slope length GT 650m |
| D | 1 | Distance to nearest village LE 2km |
| D | 2 | Distance to nearest village GT 2km |
| H | 1 | Population density LE 85 people per $km^2$ |
| H | 2 | Population density GT 85 people per $km^2$ |

**TABLE 9.5: DISTRIBUTION OF EROSION CLASS ON FIRST REVISION OF EROSION HAZARD CATEGORIES**

| CATEGORY | | | | | | | | | EROSION CLASS | | | | | TOTAL FREQUENCY | MEAN | RANK |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| L | P | A | M | S | LS | SL | D | H | 1 (%) | 2 (%) | 3 (%) | 4 (%) | 5 (%) | (n) | | |
| 1 | * | * | * | * | * | * | * | * | 89,1 | 5,8 | 4,5 | 0,0 | 0,6 | 156 | 1,17 | 1 |
| 2 | 1 | 2 | 2 | * | * | * | * | * | 12,3 | 54,4 | 33,3 | 0,0 | 0,0 | 57 | 2,21 | 2 |
| 2 | 1,2 | 1 | * | 1 | * | * | * | * | 3,2 | 61,9 | 34,9 | 0,0 | 0,0 | 63 | 2,32 | 3 |
| 3 | 1 | 4 | * | * | * | * | * | * | 0,0 | 55,3 | 42,1 | 2,6 | 0,0 | 38 | 2,47 | 4 |
| 2 | 3,4 | 1 | * | * | * | * | * | * | 5,6 | 40,3 | 51,4 | 1,4 | 1,4 | 72 | 2,53 | 5 |
| 2 | 2,3,4 | 2 | 2 | * | * | * | * | * | 5,1 | 30,8 | 64,1 | 0,0 | 0,0 | 39 | 2,59 | 6 |
| 2 | 3 | 4 | * | * | 2 | * | * | * | 0,0 | 46,2 | 43,6 | 10,3 | 0,0 | 39 | 2,64 | 7 |
| 2 | 2 | 4 | * | * | * | * | 2 | * | 0,0 | 34,4 | 65,6 | 0,0 | 0,0 | 32 | 2,66 | 8 |
| 2 | 1,2 | 3 | * | * | * | * | * | * | 5,9 | 25,0 | 66,2 | 2,9 | 0,0 | 68 | 2,66 | 9 |
| 2 | 1,2 | 1 | * | 2 | * | * | * | * | 7,3 | 22,0 | 63,4 | 7,3 | 0,0 | 41 | 2,71 | 10 |
| 2 | 3 | 4 | * | * | 1 | 1 | * | * | 0,0 | 27,7 | 57,4 | 14,9 | 0,0 | 47 | 2,87 | 11 |
| 2 | 1 | 4 | * | * | * | * | * | * | 0,0 | 11,5 | 77,0 | 11,5 | 0,0 | 61 | 3,00 | 12 |
| 2 | 3,4 | 3 | * | * | * | * | * | 1 | 0,0 | 13,2 | 76,3 | 7,9 | 2,6 | 38 | 3,00 | 13 |
| 2 | 4 | 4 | * | * | * | * | * | * | 0,0 | 2,0 | 89,8 | 8,2 | 0,0 | 49 | 3,06 | 14 |
| 3 | 3 | 4 | * | * | 2 | * | * | * | 0,0 | 9,5 | 73,0 | 17,5 | 0,0 | 63 | 3,08 | 15 |
| 2 | 1,2 | 2 | 1 | * | * | * | * | * | 0,0 | 14,8 | 66,7 | 3,7 | 14,8 | 27 | 3,19 | 16 |
| 2 | 2 | 4 | * | * | * | * | 1 | * | 0,0 | 9,3 | 62,8 | 27,9 | 0,0 | 43 | 3,19 | 17 |
| 2 | 3 | 4 | * | * | 1 | 2 | * | * | 0,0 | 7,7 | 61,5 | 30,8 | 0,0 | 52 | 3,23 | 18 |
| 2 | 3,4 | 3 | * | * | * | * | * | 2 | 0,0 | 2,6 | 71,4 | 23,4 | 2,6 | 77 | 3,26 | 19 |
| 2 | 3,4 | 2 | 1 | * | * | * | * | * | 3,3 | 5,0 | 61,7 | 11,7 | 18,3 | 60 | 3,37 | 20 |
| TOTAL | | | | | | | | | 14,5 | 21,8 | 53,2 | 8,6 | 1,8 | 1122 | 2,61 | |

TABLE 9.6: DISTRIBUTION OF EROSION CLASS ON SECOND REVISION OF EROSION HAZARD CATEGORIES.

| CATEGORY | | | | | | | | | EROSION CLASS | | | | | TOTAL FREQUENCY | MEAN | RANK |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| L | P | A | M | S | LS | SL | D | H | 1 (%) | 2 (%) | 3 (%) | 4 (%) | 5 (%) | (n) | | |
| 1 | * | * | * | * | * | * | * | * | 89,1 | 5,8 | 4,5 | 0,0 | 0,0 | 156 | 1,17 | 1 |
| 2 | 1 | 2 | 2 | * | * | * | * | * | 12,3 | 54,4 | 33,3 | 0,0 | 0,0 | 57 | 2,21 | 2 |
| 3 | 1 | 4 | * | * | * | * | * | * | 4,9 | 58,8 | 35,3 | 1,0 | 0,0 | 102 | 2,32 | 3 |
| 3 | 1 | 4 | * | * | * | * | * | * | 0,0 | 55,3 | 42,1 | 2,6 | 0,0 | 38 | 2,47 | 4 |
| 2 | 2,3,4 | 2 | 2 | * | * | * | * | * | 5,1 | 30,8 | 64,1 | 0,0 | 0,0 | 39 | 2,59 | 5 |
| 2 | 3 | 4 | * | * | 2 | * | * | * | 0,0 | 46,2 | 43,6 | 10,3 | 0,0 | 39 | 2,64 | 6 |
| 2 | 2 | 4 | * | * | * | * | 2 | * | 0,0 | 34,4 | 65,6 | 0,0 | 0,0 | 32 | 2,66 | 7 |
| 2 | 1,2 | 3 | * | * | * | * | * | * | 5,9 | 25,0 | 66,2 | 2,9 | 0,0 | 68 | 2,66 | 8 |
| 2 | * | 1 | * | 2 | * | * | * | * | 6,8 | 21,9 | 65,8 | 4,1 | 1,4 | 73 | 2.71 | 9 |
| 2 | 3 | 4 | * | * | 1 | 1 | * | * | 0,0 | 27,2 | 57,4 | 14,9 | 0,0 | 47 | 2,87 | 10 |
| 2 | 1 | 4 | * | * | * | * | * | * | 0,0 | 11,5 | 77,0 | 11,5 | 0,0 | 61 | 3,00 | 11 |
| 2 | 3,4 | 3 | * | * | * | * | * | 1 | 0,0 | 13,2 | 76,3 | 7,9 | 2,6 | 38 | 3,00 | 12 |
| 2 | 4 | 4 | * | * | * | * | * | * | 0,0 | 2,0 | 89,8 | 8,2 | 0,0 | 49 | 3,06 | 13 |
| 3 | 3 | 4 | * | * | 2 | * | * | * | 0,0 | 9,5 | 73,0 | 17,5 | 0,0 | 63 | 3,08 | 14 |
| 2 | 2 | 4 | * | * | * | * | 1 | * | 0,0 | 4,3 | 62,8 | 27,9 | 0,0 | 43 | 3,19 | 15 |
| 2 | 3 | 4 | * | * | 1 | 2 | * | * | 0,0 | 7,7 | 61,5 | 30,8 | 0,0 | 52 | 3,23 | 16 |
| 2 | 3,4 | 3 | * | * | * | * | * | 2 | 0,0 | 2,6 | 71,4 | 23,4 | 2,6 | 77 | 3,26 | 17 |
| 2 | * | * | 1 | * | * | * | * | * | 2,3 | 8,0 | 63,2 | 9,2 | 17,2 | 87 | 3,30 | 18 |
| TOTAL | | | | | | | | | 14,6 | 21,8 | 53,2 | 8,6 | 1,8 | 1121 | 2,61 | |

## CHAPTER TEN

## DISCUSSION OF RESULTS OF MULTIVARIATE HYPOTHESIS TESTING

Following the division made on the basis of forested and non-forested lands, the primary variable used in all categories of erosion hazard classification is veld type. Veld type is therefore referred to as the first order of classification. The section that follows discusses the results of the analyses presented in Chapter 9. For convenience, the chapter is divided according to veld type.

### 10.1: Erosion Hazard in Dohne Sourveld

The data presented show that the areas covered by Dohne Sourveld tend to exhibit least erosion. This is particularly true when one adds the portion of forested land (88%) classified as Dohne Sourveld. Over 90% of the Dohne Sourveld occurring in the study sample is associated with areas where the mean annual precipitation exceeds 600mm. It was shown in Chapter 8 that erosion tends to be lower in these areas of higher precipitation. Acocks (1975) describes this veld type as being restricted to areas above 600m above sea level where mean annual rainfall exceeds 650mm. Acocks (1975) also suggests that this veld type can show susceptibility to erosion in drier areas where erodible subsoils exist. No evidence of high erosion in lower rainfall areas could be found in the Dohne Sourveld regions included in the study area. The initial subdivision of Dohne Sourveld on the basis of parent material showed a slight yet statistically non-significant difference in erosion. The only additional parameter for which statistically differing subcategories could be found is slope angle. Slopes steeper than 15% show a greater degree of erosion than the gentler slopes (Chi-square = 25; expected = 0,42). This is contrary to the results obtained when the relationship between slope steepness and erosion was examined for all veld types combined.

This is not altogether surprising as the importance of a variable like slope might become obscured by other variables (such as MAP and veld type) when the distribution of erosion is considered in conjunction with the multiplicity of other variables that might effect soil erosion. The low erosion values recorded for the Dohne Sourveld are to be expected as this veld type comprises a dense, sour grassveld with basal cover averaging 30% (Acocks, 1975). The lack of any significant differences within the Dohne Sourveld category (except for slope angle) shows its relative resilience to other factors and its inherently low erosion hazard. Table 10.1 summarizes the relative differences in erosion hazard within the Dohne Sourveld.

**TABLE 10.1: RELATIVE EROSION HAZARD RATING FOR DOHNE SOURVELD (EXCLUDING FORESTS).**

| EROSION HAZARD | DESCRIPTION |
|---|---|
| 1 LOW | Slopes LE 15% |
| 2 MEDIUM | Slopes GT 15% |

### 10.2: Erosion Hazard in False Thornveld of the Eastern Cape

False Thornveld shows diverse levels of soil erosion. Mean annual precipitation relates strongly to soil erosion in this veld type with areas with a mean annual rainfall in excess of 600mm being significantly less severely eroded than those in areas where the mean annual rainfall is less than or equal to 600mm (Chi-square = 54,9; expected = 3,85). It is likely that the lower rainfall areas are particularly prone to overgrazing, and invasion by thorn bushclump veld (*Acacia karroo*) as described by Aucamp (1980). Acocks (1975) concurs on the vulnerablilty of this veld type to soil erosion in its unstable state. Where overgrazing does not occur, this veld type retains a dense *Themeda* sward which is less prone to soil erosion. The nature of the underlying parent material also has a significant effect on soil erosion within this veld type, with parent material group 1 soils (those on dolerite) being less erosion prone than parent material group 2,3 and 4 soils in the higher rainfall areas (Chi-square = 8,9; expected = 3,7). No significant differences exist between the various parent material groups in the lower rainfall category. The low rainfall False Thornveld category exhibits the highest degree of soil erosion found in the study area. Table 10.2 summarizes the relative differences in soil erosion for the various subcategories found within the False Thornveld.

TABLE 10.2: EROSION HAZARD RATING FOR THE FALSE THORNVELD (EXCLUDING FORESTS).

| EROSION HAZARD | DESCRIPTION |
|---|---|
| 1 LOW | MAP GT 600mm and parent material class 1 |
| 2 MEDIUM | MAP GT 600mm and parent material class 2,3 or 4 |
| 3 HIGH | MAP LE 600mm |

**10.3 Erosion Hazard in Valley Bushveld**

The dominant factor affecting the variation in soil erosion in Valley Bushveld is parent material. Soil erosion in this veld type on parent material groups 1 and 2 is significantly lower than that occurring on parent material groups 3 and 4 (Chi-square = 28,5; expected =1,1). The latter class can be further subdivided on the basis of the population density in the area, with areas with higher population densities being more heavily eroded than those with a lower population density (85 people. kilometre$^{-2}$ was used as the dividing line as this division produced the most equitable split in the data) (Chi-square = 8,1; expected = 1,0). Acocks (1975) describes this veld type as being an extremely dense, semi-succulent, thorny scrub in its undamaged state. Clearing and overgrazing leads to invasion by prickly pear and *Euphorbia bothae*. It is likely that vegetation cover reduction occurs to a greater extent in areas of denser population as is indicated by the data set. Table 10.3 summarizes the relative differences in soil erosion hazard sub-categories found within the Valley Bushveld.

**10.4 : Erosion Hazard in Eastern Province Thornveld**

Soil erosion in areas of Eastern Province Thornveld can be divided into four classes based on the underlying parent material (Table 9.3). All of the parent material groups differ significantly in soil erosion at the accepted probability levels. Due to the high occurrence of this veld type in the study area (37% of the total area excluding forest) a more detailed

TABLE 10.3: EROSION HAZARD RATING FOR THE VALLEY BUSHVELD (EXCLUDING FORESTS)

| EROSION HAZARD | DESCRIPTION |
|---|---|
| 1 LOW | Parent material group 1 or 2 |
| 2 MEDIUM | Parent material group 3 or 4<br>Population density LE 85. $km^{-2}$ |
| 3 HIGH | Parent material group 3 or 4.<br>Population density GT 85. $km^{-2}$ |

subdivision was sought. Significant differences within the categories outlined in Table 9.3 were found on the basis of: a) land use, with grazing land showing a greater degree of erosion than arable lands; b) lateral slope shape, with laterally convex slopes being more erosion prone than laterally concave slopes; c) distance from the nearest village, with areas closer to villages being more eroded than those distant to the village, and d) slope length, with longer slopes being more heavily eroded than shorter slopes. Further subdivisions made on the categories outlined in Table 9.3 were based on the indices which yielded the highest significant Chi-square values. Surprisingly large differences existed between arable and grazing lands on parent material group 1. Grazing land showing a higher degree of erosion than arable lands, possibly due to the effect of compaction on reducing infiltration capacity and increasing runoff on these high clay-content soils. The trend is reversed for laterally concave slopes on parent material group 3, where arable lands exhibit a higher degree of erosion than grazing land. In the literature it was noted that the study by Hawley *et al.* (1983) suggested that Jackson's (1984) relationship between soil erosion and lateral slope shape was more likely to apply to cultivated land than to natural veld. The higher erosion of laterally concave slopes on cultivated soil of a relatively high erodibility is, therefore to be expected.

There is, however, a general tendency for greater erosion on laterally convex slopes than on laterally concave slopes underlain by parent material group 3. This is contrary to the theories of Jackson (1984) and Birch (1986). This apparent anomaly could possibly be accounted for by variations in soil moisture with lateral slope shape. Higher soil moisture levels and higher vegetation densities are likely to occur on laterally concave slopes in close proximity to water courses (Anderson and Kneale, 1980; Hawley, *et al.* 1983; Henninger, *et al.*, 1986). This is particularly true in areas of natural veld and where dryland cultivation occurs. Further, more detailed investigation would be required before coming to any final conclusions on the relationships between slope shape and erosion in these areas. The relationship between distance to the nearest village and soil erosion is as expected. Those areas closer to the village being more prone to wood collection, overgrazing and compaction (Chapter 2) than those distal to the village. Although previous analyses (Chapter 8) showed no meaningful relationship between slope length and soil erosion, it is apparent that laterally convex slopes underlain by parent material group 2 soils of the Eastern Province Thornveld can be subdivided on the basis of slope length. Slopes longer than 650m being significantly more erosion prone than those shorter than 650m. The resulting classification of erosion hazard within the Eastern Province Thornveld is given in Table 10.4.

**TABLE 10.4: EROSION HAZARD RATING FOR EASTERN PROVINCE THORNVELD (EXCLUDING FORESTS).**

| EROSION HAZARD | DESCRIPTION |
|---|---|
| 1 VERY LOW | Arable land, parent material group 1. |
| 2 LOW | Grazing land, parent material group 3, laterally concave. |
| 3 LOW - MEDIUM | Parent material group 2, more than 2 km from nearest village. |
| 4 MEDIUM | Parent material group 3, laterally convex, slope length LE 650m. |
| 5 MEDIUM - HIGH | Grazing land, parent material group 1. |
| 6 HIGH | Parent material group 4. |
| 7 HIGH - VERY HIGH | Arable land, parent material group 3, laterally concave. |
| 8 VERY HIGH | Parent material group 2, closer than 2km from nearest village. |
| 9 SEVERE | Parent material group 3, laterally convex, slope length GT 650m. |

## CHAPTER ELEVEN

## FORMULATION OF EROSION HAZARD MODEL

In this chapter an erosion hazard model will be developed based on the results (and discussions) thus far. Verification of the model will be undertaken by applying it to the catchments selected for model verification (Figure 5.12).

### 11.1: The erosion hazard model

Table 11.1 summarizes the input data required for the application of the erosion hazard model. The methods used to obtain the input data are described in Chapter 6. A spider diagram summarizing the proposed soil erosion hazard model is presented in Figure 11.1. The model is to be used in conjunction with the model inputs outlined in Table 11.1 and the parent material submodel as described in Chapter 8. In previous chapters erosion hazard has been referred to in relative terms. The model which has been put forward is able to distinguish between areas of differing degrees of relative erosion, the two extremes being forested lands and False Thornveld receiving on average less than or equal to 600mm of rainfall per year. Between these two extremes lie 16 groups characterised by a variety of erosion hazard indices which, when combined, define distinctive categories (Table 9.6). Because of the amount of 'noise' present in the data, it is not possible to allocate precise erosion class values to each of the erosion hazard categories. The categories do, however, show definable variations in the distribution of erosion classes found in that category. Figure 11.2 presents a series of cumulative frequency curves for the various soil erosion hazard categories. Although histograms have been used as a method of presenting data in previous chapters, it would be difficult to represent all of the data in one Figure using histograms, hence the use of cumulative frequency curves. Similarities in erosion frequency distribution between the various soil erosion hazard groups outlined in Figure 11.2 were sought in an attempt to develop a more simple and manageable alternative to the proposed high resolution soil erosion hazard model. Forestry (L1) stands out alone and will therefore be designated a 'low' soil erosion hazard category. This category is dominated (89%) by erosion class 1, ie 'no visible signs of erosion' (Figure 11.2).

Ranks 2 (L2 P1 A2 M2), 3 (L2 A1 S1) and 4 (L3 P1 A4) are all dominated ( >50%) by erosion class 2 (sheet and rill erosion only) (Figure 11.2 and Table 9.6). These ranks (2-4) will be

TABLE 11.1: INPUT DATA REQUIRED FOR THE EROSION HAZARD MODEL.

| | |
|---|---|
| Land use | Forestry |
| | Arable |
| | Grazing |
| Veld Type | Dohne Sourveld |
| | False Thornveld |
| | Eastern Province Thornveld |
| | Valley Bushveld |
| Geology | Dolerite |
| | Beaufort Group Sedimentary Rocks |
| Dominant Soil Type | Arcadia |
| | Mayo |
| | Milkwood |
| | Clovelly |
| | Hutton |
| | Shortlands |
| | Swartland |
| | Valsrivier |
| | Westleigh |
| | Sterkspruit |
| | Mispah |
| | Oakleaf |
| MAP | LE 600mm |
| | GT 600mm |

If Dohne Sourveld and parent material *group 1 or 2, then slope angle is required.

If Eastern Province Thornveld and:

a) Parent material group 3, then lateral shape is required,
b) Parent material group 2, then distance to nearest village is required,
c) Parent material group 3 and laterally convex, then slope length is required.

If Valley Bushveld and parent material group 3, then the population density is required.

* Derived from geology and soil type using Table 8.7.

grouped together in a 'moderate' soil erosion hazard category. Ranks 5 (L2 P2,3 and 4 A2 M2), 7 (L2 P2 A4 D2), 8 (L2 P1 and 2 A3), 9 (L2 A1 S2), 10 (L2 P3 A4 LS1, SL1), 11 (L2 P1 A4) and 12 (L2 P3 and 4 A3 H1) are all dominated by erosion class 3 ('evidence of gullys'). These ranks also show a positive skewness with a greater incidence of erosion class 2 (11-46%) than erosion class 4 (0-15%) (Figure 11.2). Rank 6 (L2 P3 A4 LS2) will be included in this category because of the skewing effect of the inordinately high percentage of erosion class 4 associated with this group (Figure 11.2). Ranks 5-12 are combined to form a 'high' soil erosion hazard category.

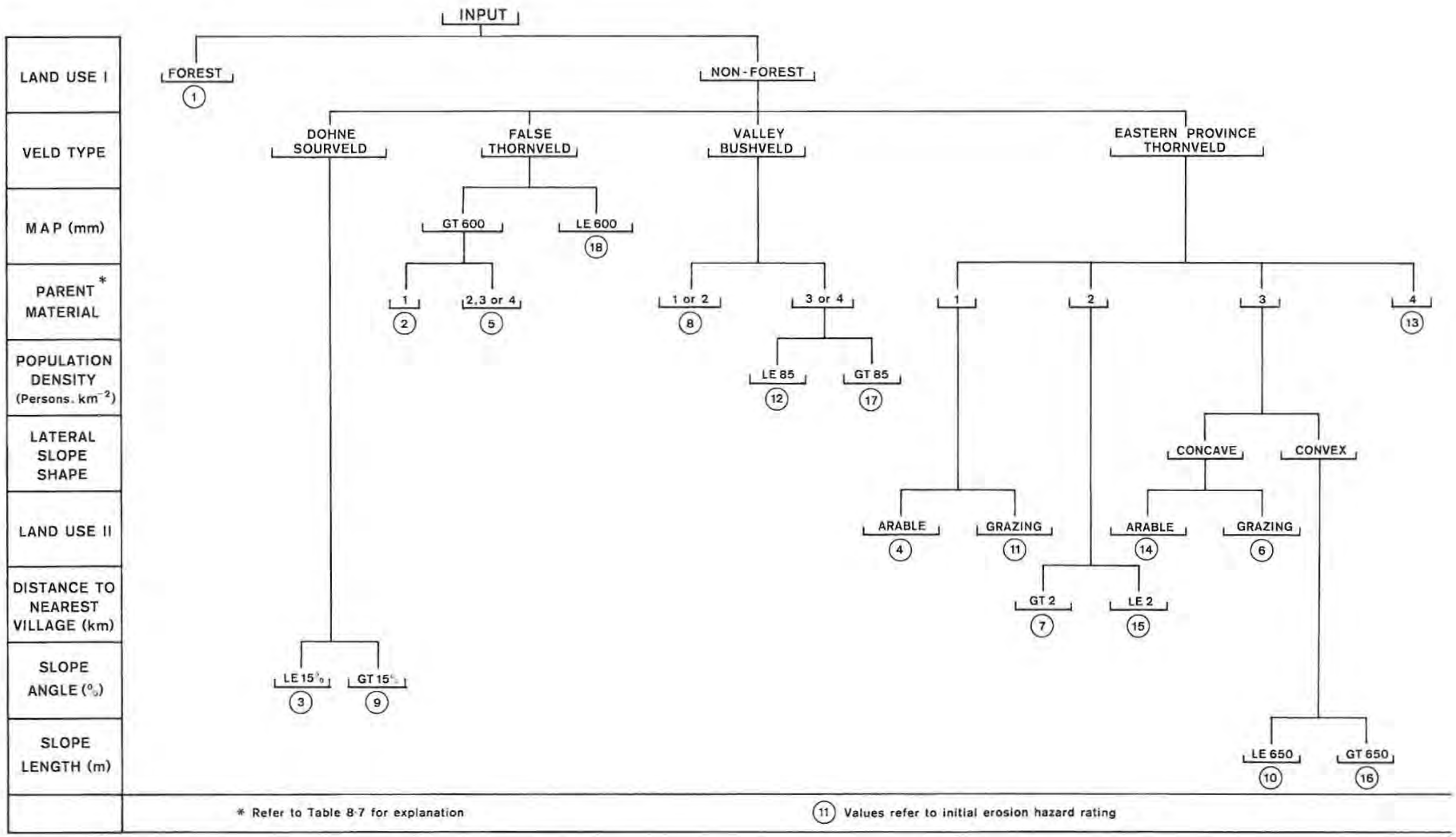



FIGURE 11.1: AN INITIAL SOIL EROSION HAZARD ASSESSMENT MODEL FOR CISKEI.

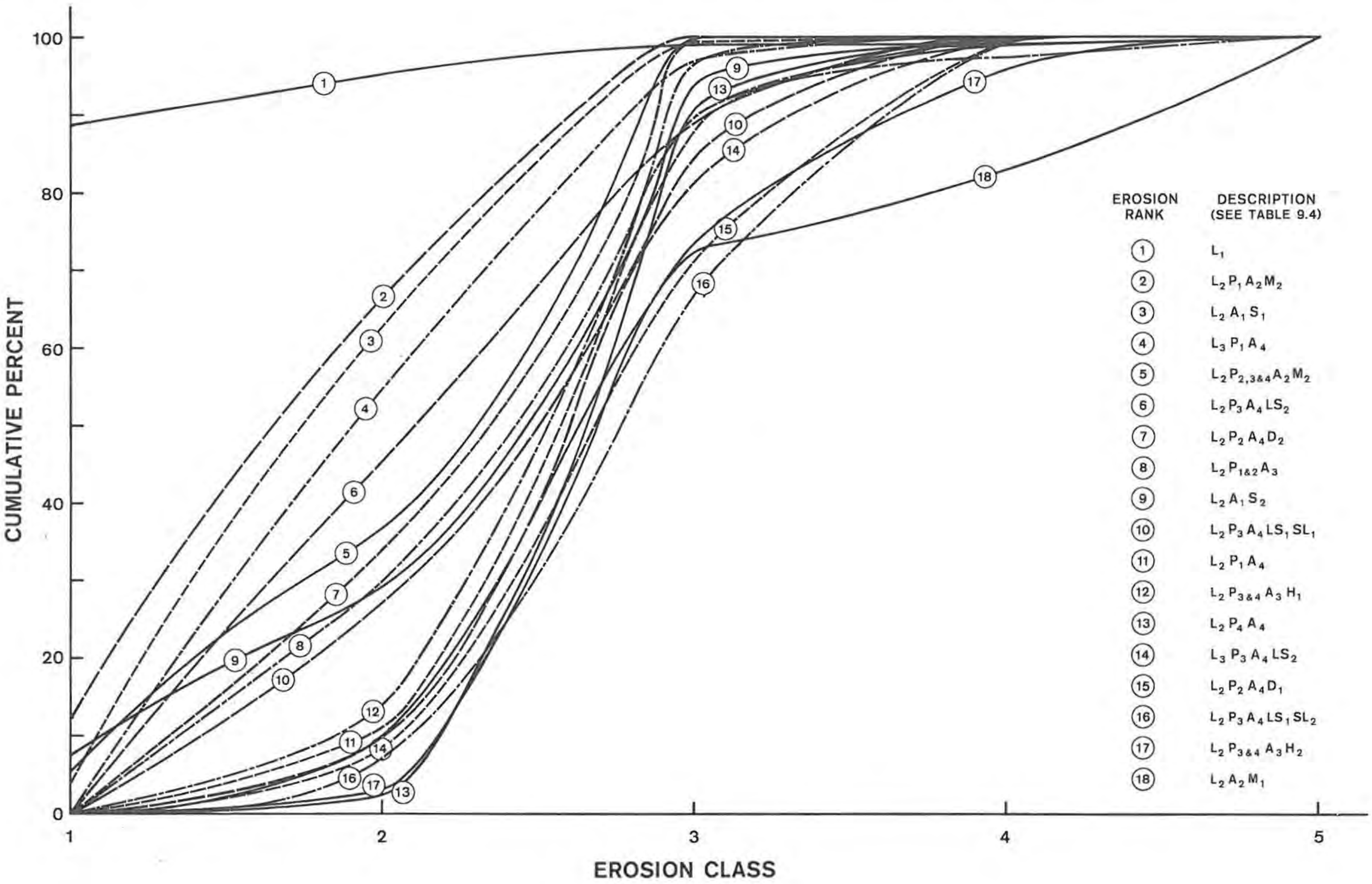



FIGURE 11.2: CUMULATIVE FREQUENCY DISTRIBUTION OF SOIL EROSION FOR THE VARIOUS SOIL EROSION HAZARD CATEGORIES

The remaining ranks are all characterised by the dominance of class 3 with erosion classes 4 ('intricate gullys') or 5 ('severe gullys') being subdominant (Figure 11.2). These classes are combined to form a 'very high' erosion hazard class. Figure 11.3 comprises histograms showing the frequency distribution of soil erosion within each of the four soil erosion hazard classes in the study area. Table 11.2 summarizes the characteristics of each of the four classes. Although a relatively cumbersome set of criteria ermerge for the allocation of soil erosion hazard classes, this is unavoidable due to the apparent multiplicity of factors effecting soil erosion. A flow diagram (Figure 11.4) is used to present a more simple overview of the low resolution version of the model.

### 11.2: Model Verification

The erosion hazard model described in the previous section is tested in the four catchments selected in Chapter 5, i.e. Gwali, Tyatora, Rabula and Thamara. A 250m square grid is used to collect the data required for model inputs. A total number of 3053 data points make up the data set. The techniques used for the assessment of erosion and land use from aerial photoraphs are those outlined in Chapter 6. The 1984 1:30 000 aerial photographs flown by Aircraft Operating Company were used. The independent variables required as model inputs were derived using the techniques outlined in Chapter 6. Soil, geology and veld type data were derived from Hill, Kaplan and Scott (1977 and 1979). Mean annual precipitation was obtained from South African Weather Bureau data (as described in 6.2) and population density data from the census data collected by Ciskei's Directorate of Planning (1984). The remaining input data are all obtained from 1:50 000 topocadastral sheets. A geographical information system was set up and all data were entered into a computer data file in matrix form. Various tests were used to assess the efficiency of the proposed model.

Table 11.3 provides a comparison of the data obtained when applying the model to the verification catchments with that obtained from the study catchments. Two of the initial erosion hazard submodels (ranks 6 and 15 of the original data set (Table 9.6)) are not present in the verification catchments. There are an additional three categories with an exceptionally low frequency of occurrence (less than 10 observations). The data presented in Table 11.3 show a strong similarity in mean erosion score for the study and verification catchments. This is illustrated by a scatterplot (Figure 11.5) and a Pearson correlation coefficient of 0,95. A comparison of the ranked mean erosion scores obtained for the study and verification data sets

### TABLE 11.2: EROSION HAZARD CATEGORY DESCRIPTION

| EROSION HAZARD CLASS | EROSION HAZARD INDICATOR PARAMETERS | DESCRIPTION OF EROSION |
|---|---|---|
| A. Low erosion hazard | 1. Forestry Areas | No visible signs of erosion |
| B. Moderate erosion hazard | 1. Cultivated and arable False Thorn-veld with Parent Material = 1 and mean annual precipitation greater than 600 mm. | Predominantly sheet and rill erosion with some evidence of gullies. |
| | 2. Cultivated and arable Dohne Sourveld with slopes less than or equal to 15%. | |
| | 3. Cultivated Eastern Province Thorn-veld with Parent material group 1. | |
| C. High erosion hazard | 1. Cultivated and False Thornveld with Parent Material = 2,3, 4 and mean annual precipitation greater than 600 mm. | Obvious to severe rill and sheet erosion with evidence of gullies throughout. Intricate gullies in places. (Less than 20% gullies). |
| | 2. Arable Eastern Province Thornveld with Parent Material = 3 and concave lateral slope shape. | |
| | 3. Cultivated and arable Eastern Province Thornveld with Parent Material = 2 and greater than 2 km from the nearest village. | |
| | 4. Cultivated and arable Valley Bush -veld with Parent Material = 1 and 2. | |
| | 5. Cultivated and arable Dohne Sour -veld with slope angle greater than 15%. | |

TABLE 11.2: *Continued*

| | | |
|---|---|---|
| | 6. Cultivated and arable Eastern Province Thornveld with Parent Material = 3 laterally convex slope shapes and slope length less than or equal to 650 m. | |
| | 7. Arable Eastern Province Thornveld with Parent Material = 1. | |
| | 8. Cultivated and arable Valley Bushveld with Parent Material = 3 and 4 and population density less than or equal to 85 people.km$^{-2}$ | |
| D. Very high erosion hazard | 1. Cultivated and arable Eastern Province Thornveld on Parent Material group 4. | Obvious to severe sheet and gully erosion with more than 20% of the area dissected by gullies. |
| | 2. Cultivated Eastern Province Thornveld on Parent Material group 3 and slope length greater than 650m. | |
| | 3. Cultivated and arable Eastern Province Thornveld on Parent Material group 2 and distance to nearest village less than or equal to 2 km. | |
| | 4. Cultivated and arable Eastern Province Thornveld on Parent Material group 3, length of slope greater than 650m. and laterally convex. | |
| | 5. Cultivated and arable Valley Bushveld on Parent Material 3 and 4 and population density greater than 85 people.km$^{-2}$ | |
| | 6. Cultivated and arable False Thornveld with mean annual precipitation less than or equal to 600mm. | |

(Table 11.3) shows that the application of the model at the higher level of resolution (using the full range of 18 possible erosion hazard categories) cannot be achieved with total confidence due to overlapping of adjacent classes at this level. This observation is supported by a plot of the data in ranked form (Figure 11.6). A Spearman rank correlation coefficient of 0,91 shows that the relationship between the two ranked sets of data is nevertheless strong.

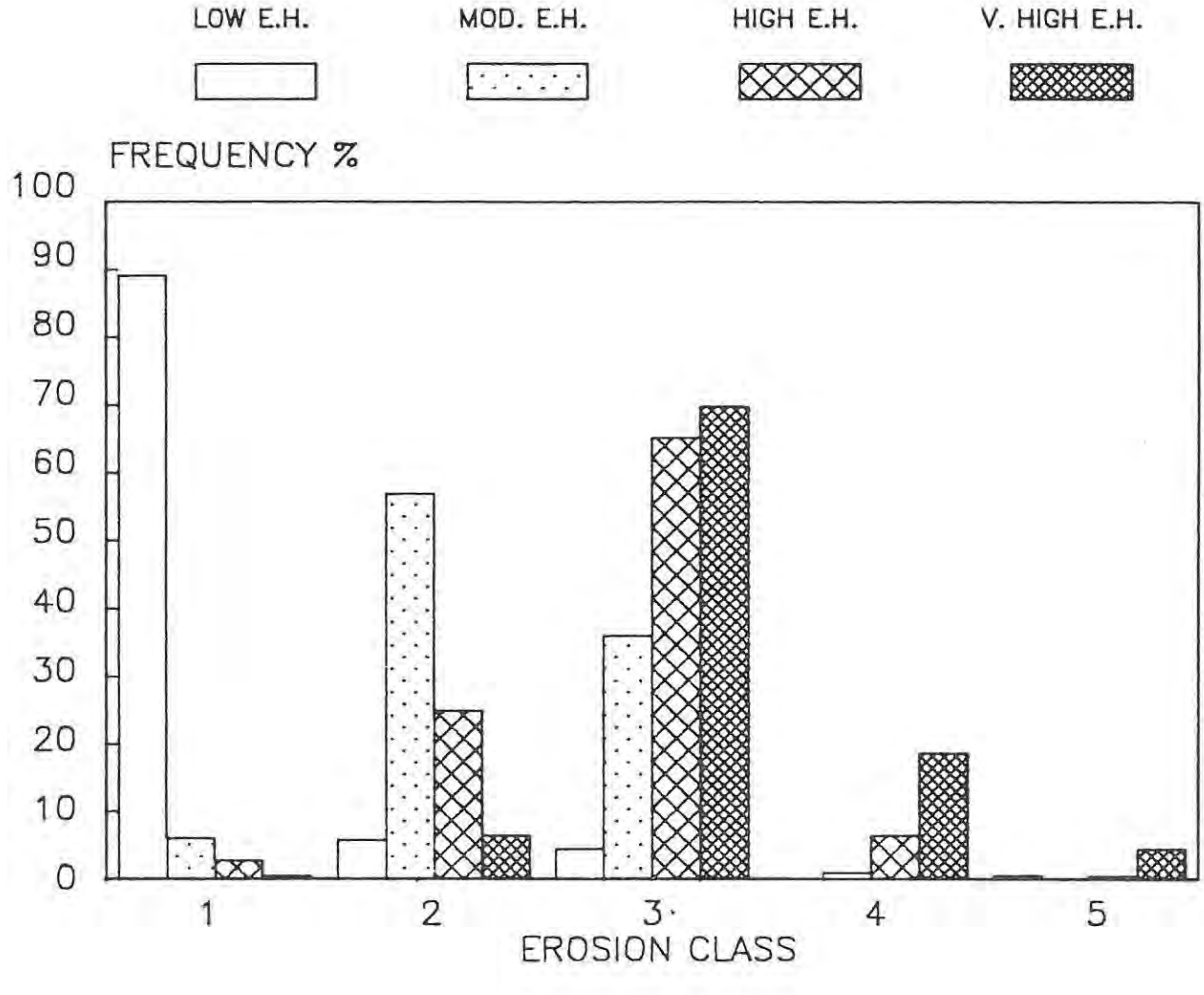



FIGURE 11.3: FREQUENCY DISTRIBUTION OF SOIL EROSION ON THE FOUR FINAL SOIL EROSION HAZARD CATEGORIES

If the model is applied using the lower level of resolution (i.e. the four clases suggested in Figure 11.4) then no overlap occurs between adjacent erosion hazard groups and the model performs adequately. A closer examination of Figure 11.6 and Table 11.3 reveals that the inconsistencies in rankings are confined to hazard groups two and three and do not overlap into adjacent groups. Table 11.4 summarizes the data using the lower resolution model and Figure 11.7 comprises a set of histograms comparing the four erosion hazard groups obtained for the study area to those obtained for the verification area.

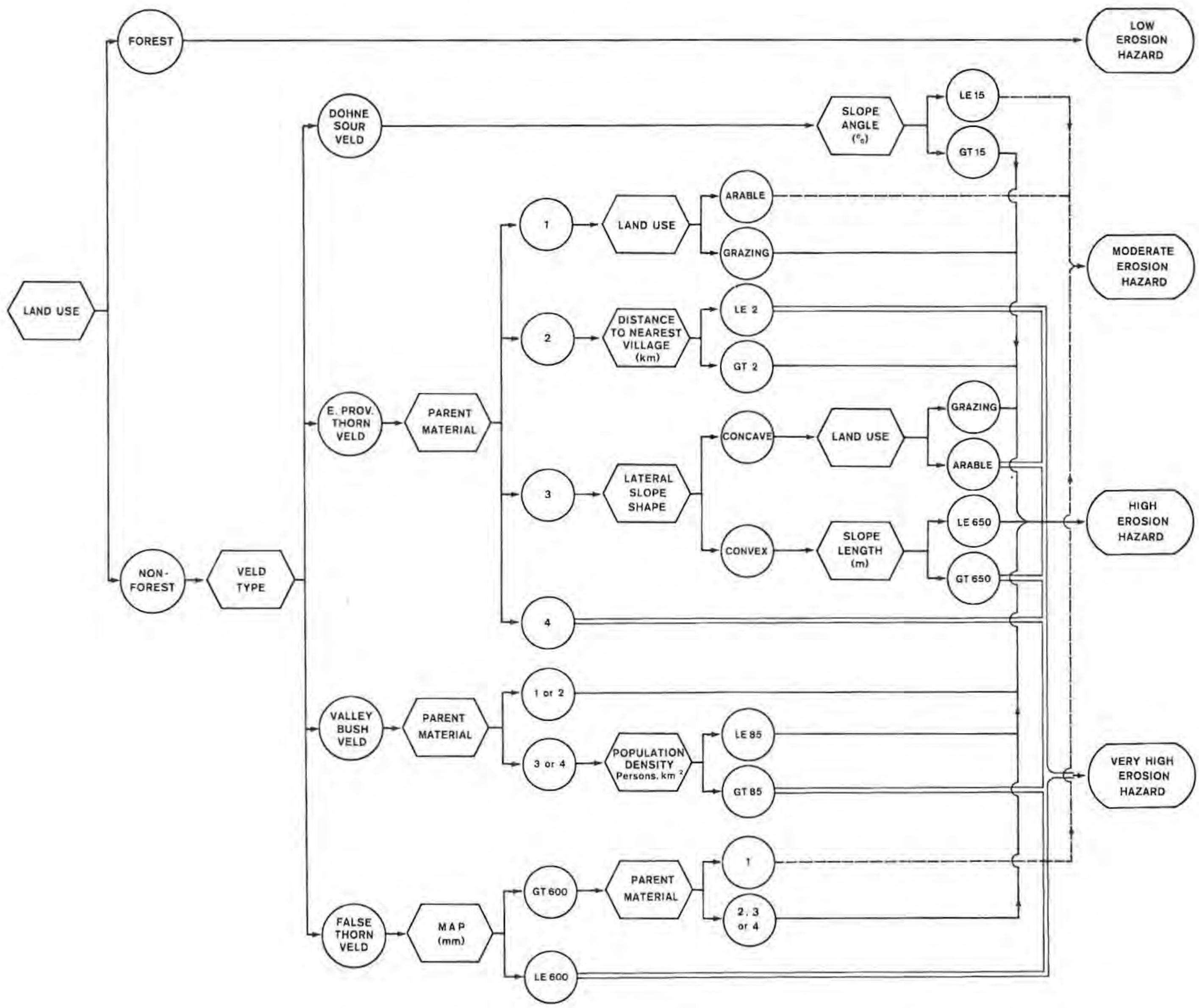



FIGURE 11.4: FINAL SOIL EROSION HAZARD MODEL FOR CISKEI

TABLE 11.3: FREQUENCY OF OCCURRENCE OF SOIL EROSION HAZARD CLASSES ON VERIFICATION AND STUDY CATCHMENTS

| EROSION HAZARD GROUP | EROSION CLASS 1 (%) | | 2 (%) | | 3 (%) | | 4 (%) | | 5 (%) | | TOTAL FREQUENCY | | MEAN | | EROSION HAZARD | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | s* | v* | s | v | s | v | s | v | s | v | s | v | s | v | s | v |
| LOW EROSION HAZARD | 89,1 | 97,0 | 5,8 | 2,8 | 4,5 | 0,2 | 0,0 | 0,0 | 0,6 | 0,0 | 156 | 541 | 1,17 | 1,03 | 1 | 1 |
| MODERATE EROSION HAZARD | 12,3 | 0,0 | 54,4 | 73,7 | 33,3 | 26,3 | 0,0 | 0,0 | 0,0 | 0,0 | 57 | 19 | 2,21 | 2,26 | 2 | 4 |
| | 4,9 | 2,3 | 58,8 | 76,4 | 35,3 | 21,3 | 1,0 | 0,0 | 0,0 | 0,0 | 102 | 216 | 2,32 | 2,19 | 3 | 3 |
| | 0,0 | 0,0 | 55,3 | 100,0 | 42,1 | 0,0 | 2,6 | 0,0 | 0,0 | 0,0 | 38 | 1 | 2,47 | 2,00 | 4 | 2 |
| HIGH Erosion Hazard | 5,1 | 0,0 | 30,8 | 42,8 | 64,1 | 52,4 | 0,0 | 1,2 | 0,0 | 3,6 | 39 | 334 | 2,59 | 2,66 | 5 | 8 |
| | 0,0 | - | 46,2 | - | 43,6 | - | 10,3 | - | 0,0 | - | 39 | - | 2,64 | - | | - |
| | 0,0 | 5,1 | 34,4 | 35,9 | 65,6 | 59,0 | 0,0 | 0,0 | 0,0 | 0,0 | 32 | 39 | 2,66 | 2,54 | 6 | 6 |
| | 5,9 | 0,0 | 25,0 | 31,1 | 66,2 | 67,7 | 2,9 | 0,5 | 0,0 | 0,7 | 68 | 418 | 2,66 | 2,70 | 7 | 9 |
| | 6,8 | 0,0 | 21,9 | 29,7 | 65,8 | 69,6 | 4,1 | 0,7 | 1,4 | 0,0 | 73 | 296 | 2,71 | 2,71 | 8 | 10 |
| | 0,0 | 0,0 | 27,2 | 50,0 | 57,4 | 50,0 | 14,9 | 0,0 | 0,0 | 0,0 | 47 | 2 | 2,87 | 2,50 | 9 | 5 |
| | 0,0 | 8,3 | 11,5 | 20,8 | 77,0 | 70,8 | 11,5 | 0,0 | 0,0 | 0,0 | 61 | 24 | 3,00 | 2,63 | 10 | 7 |
| | 0,0 | 0,0 | 13,2 | 31,6 | 76,3 | 67,1 | 7,9 | 0,0 | 2,6 | 1,3 | 38 | 79 | 3,00 | 2,71 | 11 | 11 |
| VERY HIGH EROSION HAZARD | 0,0 | 0,0 | 2,0 | 20,0 | 89,8 | 80,0 | 8,2 | 0,0 | 0,0 | 0,0 | 49 | 20 | 3,06 | 2,80 | 12 | 12 |
| | 0,0 | - | 9,5 | - | 73,0 | - | 17,5 | - | 0,0 | - | 63 | - | 3,08 | - | | - |
| | 0,0 | 0,0 | 4,3 | 18,4 | 62,8 | 78,3 | 27,9 | 2,0 | 0,0 | 1,2 | 43 | 244 | 3,19 | 2,86 | 13 | 13 |
| | 0,0 | 0,0 | 7,7 | 0,0 | 61,5 | 100,0 | 30,8 | 0,0 | 0,0 | 0,0 | 52 | 3 | 3,23 | 3,00 | 14 | 14 |
| | 0,0 | 0,0 | 2,6 | 10,7 | 71,4 | 65,7 | 23,4 | 20,0 | 2,6 | 3,6 | 77 | 140 | 3,26 | 3,16 | 15 | 15 |
| | 2,3 | 0,1 | 8,0 | 8,6 | 63,2 | 68,8 | 9,2 | 16,0 | 17,2 | 6,5 | 87 | 677 | 3,30 | 3,20 | 16 | 16 |

*s = study data, v = verification data

TABLE 11.4: FREQUENCY OF OCCURRENCE OF SOIL EROSION HAZARD CLASSES ON VERIFICATION AND STUDY CATCHMENTS USING FOUR EROSION HAZARD GROUPS.

| EROSION HAZARD GROUP | EROSION CLASS | | | | | | | | | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 (%) | | 2 (%) | | 3 (%) | | 4 (%) | | 5 (%) | | | |
| | s* | v* | s | v | s | v | s | v | s | v | s | v |
| 1. Low Erosion Hazard | 89,1 | 97,0 | 5,8 | 2,8 | 4,5 | 0,2 | 0,0 | 0,0 | 0,6 | 0,0 | 156 | 541 |
| 2. Moderate Erosion Hazard | 6,1 | 2,1 | 56,9 | 76,7 | 36,0 | 21,2 | 1,0 | 0,0 | 0,0 | 0,0 | 197 | 236 |
| 3. High Erosion Hazard | 2,8 | 0,3 | 24,9 | 34,0 | 65,2 | 63,7 | 6,5 | 0,7 | 0,5 | 1,3 | 371 | 1192 |
| 4. Very High Erosion Hazard | 0,5 | 0,1 | 6,5 | 11,3 | 69,8 | 70,8 | 18,6 | 13,0 | 4,5 | 4,8 | 397 | 1084 |

* s = Study data, v = verification data

Both Table 11.3 and Figure 11.7 show that there is a difference in spread of data over the five erosion classes for the two data sets. This is borne out by Chi-square tests which indicate that there are significant differences between the data obtained for the study areas and that obtained for verification areas within each of the erosion hazard groups. Table 11.5 indicates that 'between erosion hazard group' differences are well in excess of the 'within erosion hazard group' differences. The large Chi-square values obtained when testing for 'between erosion hazard group' differences illustrates the uniqueness of the groups.

The histograms (Figure 11.7) show that areas defined as erosion hazard group 1 are dominated by erosion class 1, i.e., no visible signs of erosion. Erosion hazard group 2 is dominated by erosion class 2 (sheet and rill erosion only). Erosion hazard group 3 is dominated by erosion class 3 with erosion class 2 being subdominant (i.e. positively skewed). Erosion hazard group 4 is also dominated by erosion class 3 with class 4 being subdominant (i.e. negatively skewed).

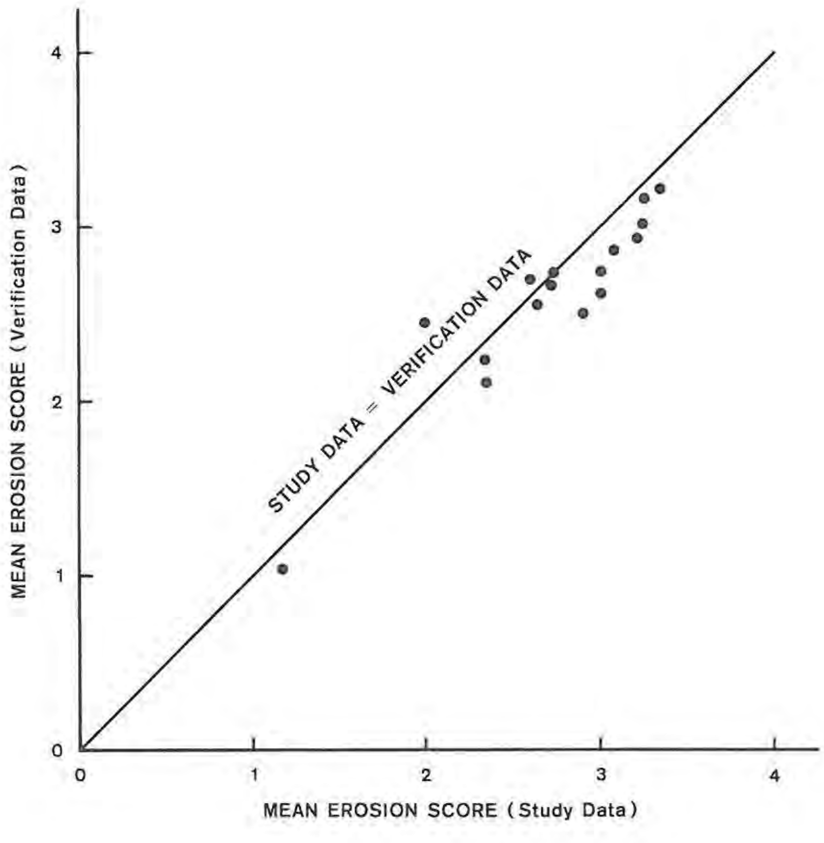



FIGURE 11.5: MEAN EROSION SCORE FOR VERIFICATION DATA VS MODEL DATA

The comparative analysis of data obtained from the study and verification catchments show a close correlation between the two data sets. Inconsistencies in the ranking of erosion classes lends support to the use of the lower resolution four-way classification of hazard groups rather than the more complex 18-way classification derived in the initial stages. A gratifying aspect of the analysis is the perfect agreement between the ranked erosion scores in the six most serious erosion classes. It is these areas which would probably receive most attention by users of the model.

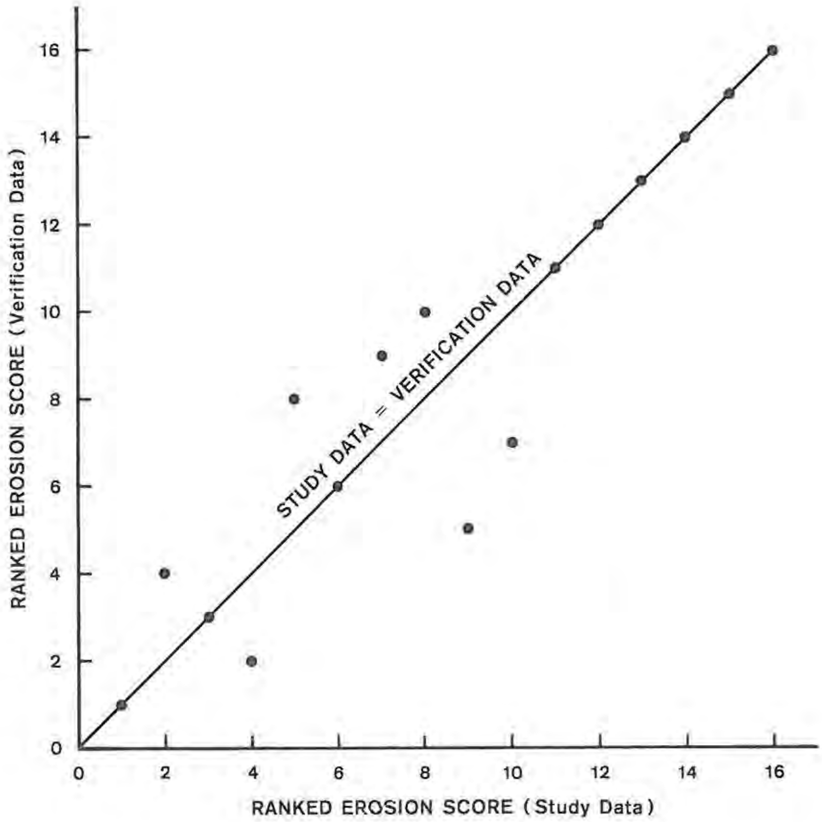



FIGURE 11.6: THE RELATIONSHIP BETWEEN RANKED VERIFICATION DATA AND RANKED MODEL DATA

**TABLE 11.5: A CHI-SQUARE MATRIX COMPARING STUDY AND VERIFICATION DATA.**

| HAZARD CLASS VERIFICATION DATA | HAZARD CLASS STUDY DATA | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| 1 | 27,0 | 310,4 | 1147,0 | 1082,7 |
| 2 | 605,4 | 21,4 | 96,9 | 308,9 |
| 3 | 861,4 | 335,5 | 76,3 | 88,2 |
| 4 | 836,4 | 165,4 | 278,6 | 15,2 |

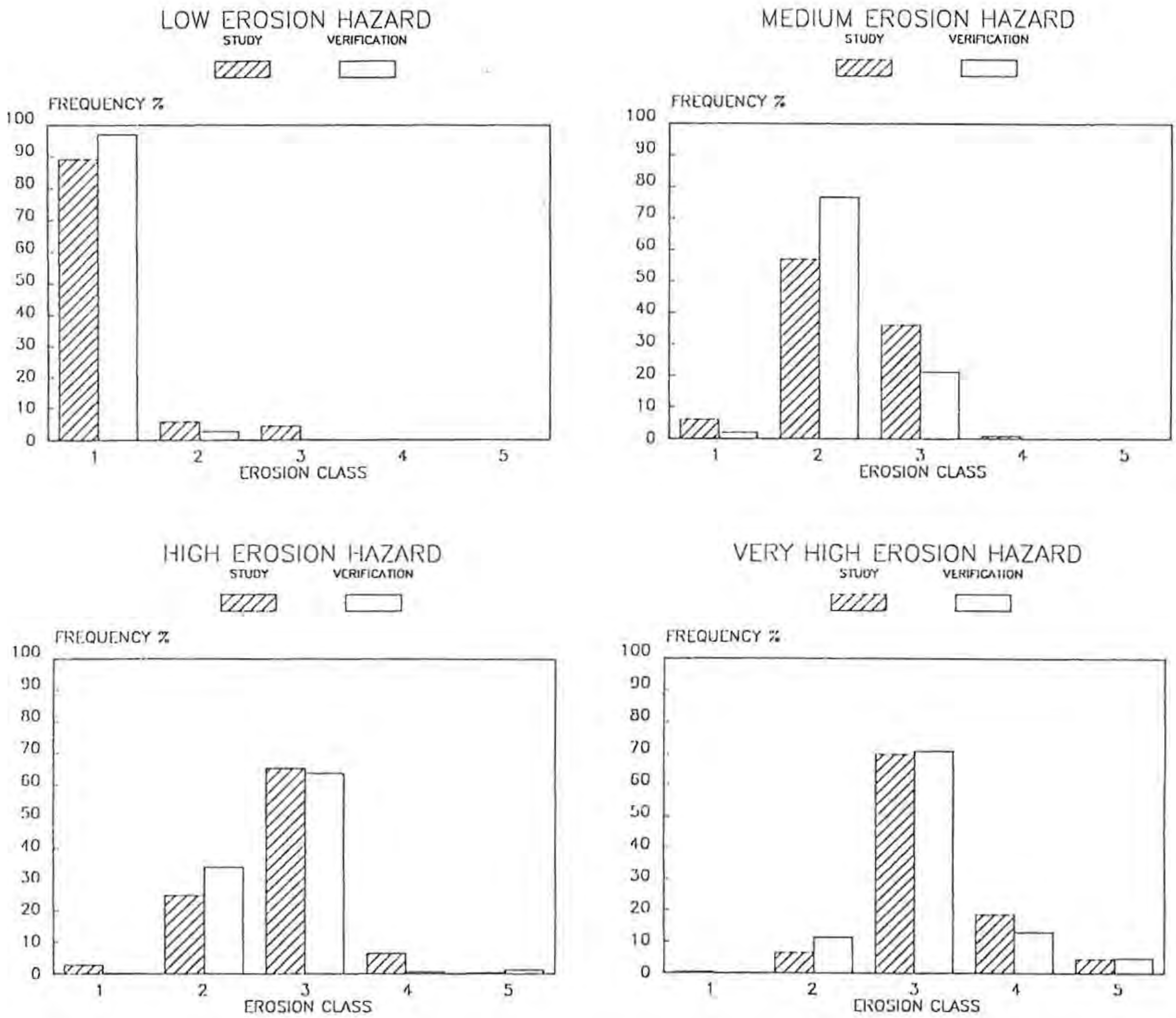



FIGURE 11.7: A COMPARISON OF THE STUDY AND VERIFICATION DATA FOR THE FOUR EROSION HAZARD GROUPS

# CHAPTER TWELVE

# CONCLUSIONS

The key question to this thesis as stated in Chapter 4 was: "What factor or combination of factors can be used to explain the spatial variation in soil erosion in Ciskei?". The expressed aim of the study being to develop an erosion hazard assessment technique for Ciskei which makes use of readily available data as its inputs. It was envisaged that the derived model would be relatively easy to apply and would be capable of identifying areas of varying erosion risk. Such a tool would be of use to rural development planners and soil conservators. In this chapter, the major findings of the thesis will be reviewed in the light of the study aims. The limitations of the model as well as topics identified for future research will be discussed.

Twenty four independent variables for which quantitative data are readily available have been identified as possible erosion hazard indices. Bivariate analyses reveal that many of these indices show no simple relationship with observed soil erosion. Those that did correlate with soil erosion show very weak relationships. A number of generally accepted indices yielded relationships contrary to the expected (for example $EI_{30}$, slope steepness and large stock density) illustrating the multiplicity of the soil erosion phenomenon. The primary factors selected from the results of the initial bivariate tests were land use, veld type, parent material and mean annual precipitation. All of these variables are easy to define with the data being readily available for large areas of Ciskei.

Subsequent multivariate analyses using multiway frequency tables resulted in the identification of additional sets of criteria for each of the four different veld types encountered in the study area. The additional variables selected are, population density in the Valley Bushveld; slope steepness in the Dohne Sourveld; and lateral slope shape, distance to the nearest village and slope length in the Eastern Province Thornveld. The resultant model was simplified to four levels of erosion hazard and summarized in the form of a flow diagram (Figure 11.4). A separate set of catchments was selected for testing validity of the model. The results obtained from the model testing exercise showed that the model could perform satisfactorily outside the area in which it was derived.

The general conclusion to the study is that readily available data can be used to identify areas of differing levels of erosion susceptibility at the macroscale. The most important variables identified by the study for incorporation in the model are rainfall, soils, geology, veld type and the presence or absence of forest. It should be noted that man has no influence on three of these variables (rainfall, geology and soils) and very little direct influence on the remaining two variables. It can be concluded therefore that spatial variations in soil erosion observable at the macroscale are largely controlled by natural environmental conditions.

Traditionally applied erosion hazard indices such as soil erodibility, rainfall erosivity and slope steepness would provide misleading results if applied independently in the region. The use of mean annual $EI_{30}$, for example, would identify the high-lying, high rainfall areas of the Amatole mountain range as being at high erosion risk. This study has shown that as long the forested status of these areas is conserved, they will in fact show the lowest degree of erosion susceptibility in the area. On the other hand, areas with low mean annual rainfall and low annual kinetic energies are associated with some of the most heavily eroded regions of the Eastern Province Thornveld.

A number of areas requiring further research are identified as a direct result of this study:

i) The application of the derived model to the rest of the central Ciskei and the production of a series of erosion hazard maps for the entire region. These maps can be accompanied by a key indicating the type and extent of erosion which is likely to be associated with each category.

ii) Testing, modifying (if necessary) and applying the model to other areas in and around Ciskei.

iii) The collection of more data on erosion rates in Ciskei. This could be obtained from reservoir survey data or from sequential mapping based on air photographs or satellite imagery (e.g. SPOT).

iv) An historical analysis of stock density in relation to spatial variations in soil erosion.

v) An examination of the relationship between seasonal variations in rainfall aggressiveness and soil erosion in both time and space.

The approach adopted in this study is pragmatic and based on the current understanding of soil erosion processes and the availability of data. This type of approach is necessary for the development of erosion hazard assessment techniques in the short term. Although detailed process studies are essential in achieving a full understanding of soil erosion processes, the empirical approach adopted by this study is not necessarily incompatible with process studies and could be updated as process studies supply more information about the physical mechanisms that control the rates and mechanics of soil erosion. Three particular areas are identified for more detailed process studies in Ciskei:

i) An examination of the relative importance of rill, sheet and gully erosion in terms of soil loss.

ii) A more detailed examination of the relationship between soil erodibility and underlying geology.

iii) A more detailed study of the effect of lateral slope shape on soil erosion in cultivated lands compared with natural veld conditions.

The aspects for further research listed above do not represent an exhaustive list, numerous other possibilities exist. A number of these recommendations stem from a recognition of the limitations of this project.

The area for which the model is applicable is an important limitation to the study. Although it was initially thought that a model could be developed for the entire Ciskei region, limitations of time and data availability precluded this possibility. The derived model is restricted in use to Dohne Sourveld, False Thornveld, Valley Bushveld and Eastern Province Thornveld between the Winterberg/Amatole escarpment and the coastal belt. The model is further restricted to the twelve soil forms outlined in Table 11.1. These are the most common soil forms of the region and neither the study nor the test catchments contained any significant amount of other soil forms. The area to which the study and the model is applicable comprises 54% of the Ciskei area. Although the study was restricted to Ciskei, it is possible that the model could be applicable to areas in the Cape Province and Transkei to the west and east of Ciskei. This would require further investigation. A further important restriction regarding the application of the model is scale. The model is designed for application at the macroscale. Most of the data used to derive and test the model is available in mapped form at a scale of 1:50 000. The model is therefore most suited to 1:50 000 mapping of erosion hazard. Model performance at other scales will have to be tested prior to application. The 1:50 000 scale does seem to be the most commonly used scale for mapping in the various resource surveys completed for Ciskei to date (e.g. Hill, Kaplan and Scott, 1977 and 1979). Further justification for use of this scale is the fact that a common problem with third world countries is the lack of adequate data for higher resolution mapping (Millington, *et al.*, 1982).

Because of the scale limitation, potential users should be warned that the delineation of an area as a low erosion hazard region does not justify haphazard planning within that region. The reason for forested areas being identified as low erosion hazard regions is due to the very presence of good vegetation cover. Badly planned harvesting of timber in these regions is likely to alter the potential for erosion in these areas. In the same way, areas classified as having a high susceptibility to erosion could be utilized productively if adequate conservation measures are applied at the local scale.

The derived soil erosion hazard assessment model is simple to operate and has input requirements which are easily met at low cost and is capable of rapid implementation. It can be applied without the aid of computers, or where large areas are to be mapped it is well suited to computerisation. The rapidly growing population of Ciskei and the government's intention to upgrade the output of subsistence farmers in an already overpopulated region increases the necessity for an adequately planned soil conservation policy. It is evident from the study that much of the data required for the application of well established techniques (for example, the Universal Soil Loss Equation) is not readily available in many parts of the region. It is, therefore, necessary to apply techniques which are appropriate to the region with respect to both data availability and model applicability. It is hoped that this study will fill that gap and will be able to make a positive contribution towards the efficient management of Ciskei's most valuable natural resource, the soil.

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# APPENDIX

## EXTRACT FROM DATA STORAGE FILE

```
C DATA FOR AMATOLE CATCHMENT
C HEADINGS FOR COLUMNS ARE AS FOLLOWS:
VAR. 1 (1,4)     GRID
VAR. 2 (6,7)     EROSION STATUS   MIN(1) MAX(13)
VAR. 3 (9)       GEOLOGY          MIN(1) MAX(2)
VAR. 4 (12,15) MLU                MIN(4.20) MAX(4.20)
VAR. 5 (18,21) LSU                MIN(5.57) MAX(5.57)
VAR. 6 (23,26) SSU                MIN(2.44) MAX(2.44)
VAR. 7 (28,29) LAND USE           MIN(1) MAX(3)
VAR. 8 (31,34) SL                 MIN(15) MAX(2195)
VAR. 9 (37,41) S%                 MIN(1.61) MAX(171.83)
VAR.10 (44,48) LS                 MIN(0.21) MAX(619.60)
VAR.11 (50)     SLOPE ASPECT      MIN(1) MAX(2)
VAR.12 (52,54) SOIL ERODIBILITY        MIN(3) MAX(6.5)
VAR.13 (56,59) POPULATION              MIN(73) MAX(73)
VAR.14 (62)     SHAPE                  MIN(1) MAX(9)
VAR.15 (64,67) FOOTPATHS               MIN(0.00) MAX(3.16)
VAR.16 (69,72) VEGETATION              MIN(0.0) MAX(15.0)
VAR.17 (74,74) VCS                     MIN(5) MAX(70)
VAR.18 (77,79) INC II BENCH            MIN(1.2) MAX(5.2)
VAR.19 (81,83) EI30                    MIN(185) MAX(250)
VAR.20 (85,86) SOIL TYPE         MIN(1) MAX(27)
VAR.21 (88,91) ALTITUDE
VAR.22 (93 94) MAP(X 100MM)  MIN(4) MAX(14)
VAR.23 (96,98) DIST TO NEAREST VILLAGE
VAR.24 (100,101) ACCOCKS VEGETATION DS=44 FT=21 VB=23 MIN(21) MAX(44)
VAR.25 (103,105) DISTANCE TO NEAREST TOWN
MISSING DATA = -1
0112  1 2  4.20  5.57 2.44  1   62  12.90   2.89 1 4.0   73  3 0.00 -1    -1 -1   250  3 4675 12 8.9 44 8.9
0113  1 2  4.20  5.57 2.44  1  213   5.63   1.63 1 6.5   73  3 0.00  3.0 70 -1   250 22 4510 12 8.9 44 8.9
0210  1 2  4.20  5.57 2.44  1   -1     -1     -1 1 4.0   73  1 0.00 -1    -1 -1   245 22 0000 11 8.3 44 8.3
0211  1 2  4.20  5.57 2.44  1  184  12.50   4.74 1 4.0   73  6 0.00 -1    -1 -1   245 22 4225 12 8.3 44 8.3
0212  1 2  4.20  5.57 2.44  1  366  25.14  21.57 1 4.0   73  3 0.00 -1    -1 -1   245 22 4200 12 8.3 44 8.3
0213  1 2  4.20  5.57 2.44  1  244  26.23  18.98 1 4.0   73  8 0.00  0.0 -1 -1   245 27 4300 12 8.3 44 8.3
0214  1 2  4.20  5.57 2.44  1   -1     -1     -1 1 6.5   73  8 0.00 -1    -1 -1   250  2   -1 12 8.5 44 8.5
0308  1 1  4.20  5.57 2.44  1   -1     -1     -1 1 5.0   73  1 0.00 -1    -1 -1   245  3 0000 11 7.9 44 7.9
0309  1 1  4.20  5.57 2.44  1  152  25.00  13.77 1 5.0   73  1 0.00 -1    -1 -1   245  3 3950 11 8.0 44 8.0
0310  1 1  4.20  5.57 2.44  1  259  38.22  38.60 1 5.0   73  1 0.00 -1    -1 -1   245  3 3875 11 7.9 44 7.9
0311  1 1  4.20  5.57 2.44  1  457  31.73  36.52 1 4.0   73  6 0.00 -1    -1 -1   245 27 3825 11 7.7 44 7.7
0312  1 2  4.20  5.57 2.44  1  610  36.23  53.69 1 4.0   73  6 0.00 -1    -1 -1   245 27 3775 12 7.7 44 7.7
0313  1 2  4.20  5.57 2.44  1   93  48.39  35.79 1 4.0   73  8 0.00  0.0 -1 -1   245 27 4300 12 7.7 44 7.7
0314  1 2  4.20  5.57 2.44  1   93  33.33  18.01 1 4.0   73  8 0.00 -1    -1 -1   245 27 4450 12 7.7 44 7.7
0405  1 2  4.20  5.57 2.44  1   -1     -1     -1 1 4.0   73  1 0.46 10.0 14 -1   240 27 0000 11 7.3 44 7.3
0406  2 2  4.20  5.57 2.44  2  184  25.00  15.15 1 6.0   73  1 0.68 -1    -1 -1   240 18 3950 11 7.1 44 7.1
0407  2 2  4.20  5.57 2.44  2  244  31.15  25.81 1 6.0   73  1 0.00 -1    -1 -1   240 18 3800 11 7.1 44 7.1
0408  1 2  4.20  5.57 2.44  1  320  23.75  18.25 1 6.0   73  1 0.00 -1    -1 -1   245 18 3800 11 7.1 44 7.1
0409  1 2  4.20  5.57 2.44  1  411  20.19  15.62 1 6.0   73  1 0.00 -1    -1 -1   245 18 3775 11 7.3 44 7.3
0410  1 2  4.20  5.57 2.44  1  518  26.45  28.07 1 6.0   73  1 0.00 -1    -1 -1   245 22 3600 11 7.1 44 7.1
0411  1 1  4.20  5.57 2.44  1  762  28.08  37.88 1 4.0   73  6 0.00 -1    -1 -1   245 22 3600 11 7.1 44 7.1
0412  1 2  4.20  5.57 2.44  1  762  33.99  53.42 1 4.0   73  6 0.00  0.0 -1 -1   245 22 3700 11 7.1 44 7.1
0413  1 2  4.20  5.57 2.44  1  396  07.58 338.95 1 4.0   73  8 0.00  0.0 -1 -1   245 27 3050 11 7.0 44 7.0
0414  1 2  4.20  5.57 2.44  1  305  15.08   8.25 1 4.0   73  8 0.00  0.0 -1 -1   245 27 4400 11 7.1 44 7.1
0415  1 2  4.20  5.57 2.44  1   62  50.00  31.07 1 6.5   73  8 0.00 -1    -1 -1   245  2 4470 11 7.2 44 7.2
0505  1 2  4.20  5.57 2.44  1  152  55.92  60.04 1 6.0   73  1 1.13 10.0 14 -1   240 18 4025 11 6.8 44 6.8
0506  1 2  4.20  5.57 2.44  1  427  28.57  29.24 1 6.0   73  1 0.00  0.0 -1 -1   240 18 3300 11 6.7 44 6.7
0507  1 2  4.20  5.57 2.44  1  549  33.33  43.77 1 6.0   73  1 0.00  0.0 -1 -1   240 18 3500 11 6.7 44 6.7
0508  1 2  4.20  5.57 2.44  1  625  34.08  48.62 1 6.0   73  1 0.00  0.0 -1 -1   240 18 3350 11 6.7 44 6.7
0509  1 2  4.20  5.57 2.44  1  655  30.23  40.07 1 6.0   73  1 0.00  0.0 -1 -1   240 18 3400 11 6.9 44 6.9
0510  1 2  4.20  5.57 2.44  1  823  28.68  40.86 1 4.0   73  6 0.00  0.0 -1 -1   240 22 3300 11 6.7 44 6.7
0511  1 2  4.20  5.57 2.44  1 1036  35.33  66.83 1 4.0   73  6 0.00  0.0 -1 -1   245 22 3100 11 6.6 44 6.6
0512  1 1  4.20  5.57 2.44  1  823  35.12  58.91 1 4.0   73  9 0.00  0.0 -1 -1   245 22 3500 11 6.6 44 6.6
0513  1 1  4.20  5.57 2.44  1  732  37.57  62.86 1 4.0   73  6 0.00  0.0 -1 -1   245 22 3600 11 6.6 44 6.6
0514  1 2  4.20  5.57 2.44  1  488  88.52 250.21 1 4.0   73  8 0.00  0.0 -1 -1   245 27 3050 11 6.7 44 6.7
0515  1 2  4.20  5.57 2.44  1  274  20.07  12.62 1 4.0   73  8 0.00 -1    -1 -1   245 27 4300 11 6.8 44 6.8
0605  1 2  4.20  5.57 2.44  1  244  18.85  10.70 1 6.0   73  2 0.91 10.0 14 -1   240 18 3875 11 6.1 44 6.1
0606  1 2  4.20  5.57 2.44  1  610  45.25  80.89 1 6.0   73  6 0.00  0.0 -1 -1   240 18 3400 11 6.0 44 6.0
0607  1 2  4.20  5.57 2.44  1  853  28.60  41.42 1 4.0   73  6 0.00  0.0 -1 -1   240 22 3300 11 5.9 44 5.9
0608  1 2  4.20  5.57 2.44  1  914  26.59  37.63 1 4.0   73  6 0.00  0.0 -1 -1   240 22 3250 11 5.9 44 5.9
0609  1 2  4.20  5.57 2.44  1 1006  26.44  39.10 1 4.0   73  6 0.00  0.0 -1 -1   240 22 3175 11 6.0 44 6.0
0610  1 2  4.20  5.57 2.44  1 1097  26.34  40.57 1 4.0   73  1 0.00  0.0 -1 -1   240 22 3100 11 5.9 44 5.9
0611  1 2  4.20  5.57 2.44  1 1219  41.26  96.40 1 4.0   73  6 0.00  0.0 -1 -1   240 22 2900 11 5.8 44 5.8
0612  1 2  4.20  5.57 2.44  1 1219  28.71  49.84 1 4.0   73  9 0.00  0.0 -1 -1   240 22 3300 11 5.8 44 5.8
0613  1 1  4.20  5.57 2.44  1  853  57.51  67.28 1 4.0   73  6 0.00  0.0 -1 -1   240 22 3400 11 5.8 44 5.8
0614  1 1  4.20  5.57 2.44  1  610  37.38  56.85 1 4.0   73  3 0.00  0.0 -1 -1   245 22 3650 11 5.8 44 5.8
0615  1 2  4.20  5.57 2.44  1  457  40.04  58.05 1 4.0   73  6 0.00  0.0 -1 -1   245 27 3900 11 6.0 44 6.0
0616  1 2  4.20  5.57 2.44  1  184  27.72  18.18 1 4.0   73  8 0.00 -1    -1 -1   245 27 4300 11 6.3 44 6.3
0617  1 2  4.20  5.57 2.44  1   62  25.81   9.30 1 6.5   73  8 0.00 -1    -1 -1   245  2 4450 11 6.5 44 6.5
0705  1 1  4.20  5.57 2.44  1  244  44.67  49.96 1 4.0   73  2 0.00 10.0 14 -1   235 22 3700 11 5.5 44 5.5
0706  1 1  4.20  5.57 2.44  1  610  44.92  50.20 1 4.0   73  2 0.00  0.0 -1 -1   240 22 3350 11 5.4 44 5.4
0707  1 2  4.20  5.57 2.44  1 1067  32.80  59.26 1 4.0   73  6 0.00  0.0 -1 -1   240 22 3100 11 5.2 44 5.2
0708  1 2  4.20  5.57 2.44  1 1250  21.92  31.97 1 4.0   73  6 0.00  0.0 -1 -1   240 22 3150 11 5.3 44 5.3
0709  1 2  4.20  5.57 2.44  1 1250  25.60  41.16 1 4.0   73  1 0.00  0.0 -1 -1   240 22 3000 11 5.5 44 5.5
0710  1 2  4.20  5.57 2.44  1 1311  29.06  52.82 1 4.0   73  9 0.00  0.0 -1 -1   240 22 2800 11 5.2 44 5.2
0711  1 2  4.20  5.57 2.44  1 1524  31.96  67.95 1 4.0   73  9 0.00  0.0 -1 -1   240 22 2850 11 5.2 44 5.2
```