SOURCES OF SOIL EROSION IN THE HAZELMERE CATCHMENT KWAZULU-NATAL, SOUTH AFRICA.

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DECLARATION

The research reported herein was undertaken in the Discipline of Geography, University of Natal, School of Applied Environmental Sciences, Pietermaritzburg, under the supervision of Prof. H.R. Beckedahl and Dr. T. Hill. These studies represent original work by the author and have not otherwise been submitted in any form, for any degree or diploma, to any other University. Where use has been made of the work of others, it is dully acknowledged in the text.

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ABSTRACT

Sedimentation of reservoirs is of major concern, particularly in South Africa where water resources are scarce. When a reservoir is filled with sediments, it is not only the water storage capacity which is reduced but the reservoir site could be lost. An investigation into the sources of sediment that pose a threat to the economic life of the Hazelmere Dam, located on the Mdloti River, was undertaken with a view to determining the extent to which siltation problems within the catchment may be attributed to soil characteristics as opposed to being related to other factors such as potential land use practices. The study determined that soils of the catchment are naturally prone to erosion. From particle size analysis, it is evident that these soils are highly erodible, whereas chemical analysis suggest that some of these soils are dispersive. Soil erosion does not necessarily develop as a direct consequence of a single variable such as soil chemistry nor of soil physical properties only, but is multivariate in nature and may be associated with a combination of factors. Using the factors of slope, land use, geological type and rainfall, an erosion risk or hazard map of the Hazelmere catchment has been produced. The actual erodibility of soil as determined by the Eijkelkamp rainfall simulator was then compared to this risk map. It is evident that there is a relationship between soil loss and soil erosion risk. Furthermore, results of soil loss and land use showed that there is a relationship between the two factors, a similar relationship existed between land use and soil erosion risk where soil erosion risk increased with grazing and cultivation land uses.

This study has mainly focused on the scientific and technical aspects concerning the sources of sediment. However, it has also shown that some of the contributing factors and barriers to adequate soil conservation are related to socio-economic and socio-political factors.

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THE RESEARCH IN CONTEXT

1.1 INTRODUCTION

As human activity has intensified over time, particularly since the Industrial Revolution, so environmental hazards have increased. McGregor and Thompson (1995) argue that increasingly the burden of disaster falls on those least able to cope with it. In the case of South Africa, it is frequently the impoverished rural communities. A geomorphological hazard phenomenon in a developing area may well have more radical effects on the social system than a similar event in a developed area due to differences in the respective coping mechanisms. This implies that a problem of soil erosion in impoverished rural areas may have a greater impact than in developed areas (Blaikie, 1985).

South African soils are susceptible to erosion, due to a variety of physical factors as well as a consequence of human utilization of the land (Fuggle and Rabie, 1992). Soil erosion may well be the greatest environmental problem which is facing South Africa, yet the South African population appears to be complacent towards it (Blaikie, 1985). Soil erosion is perceived to be a serious and rapidly increasing threat to land productivity and environmental sustainability in the subcontinent (Brinkcate and Hanvey, 1996). It is a natural and inevitable process that can become a serious environmental and economic problem when accelerated by human activities. Water supplies and storage reservoirs, freshwater and coastal environments, agricultural and urban productivity can all be negatively impacted by upon by accelerated soil erosion (which is influenced by human activity through, for example, overgrazing, destruction of natural vegetation and changing the quality of the soil). However, research efforts to implement rehabilitation are hampered by the attitude of the South African public to the problem (Blaikie, 1985).

People live and depend on the soil, making it one of the most vulnerable natural resources upon which humans have had a major impact. Such an impact can occur with great rapidity in response to both land use change and to new technologies (Goudie, 1993). Loss of soil from the land surface is a natural process, it is only when the rate of soil loss exceeds the rate of soil formation, at a given location, that soil erosion is said to occur (Fuggle and Rabie, 1992).

Soil erosion is now more widespread than ever before, it has been expressed that if each soil conservationist stopped the movement of one grain of soil for each word that has been written on the topic, the problem of soil erosion would disappear (Gregory and Walling, 1981; 1987). Cognisance needs to be taken of the fact that much of the technical knowledge needed to solve erosion problems has been available for years but the actual solution requires a combination of social acceptance and political and economic incentives, which are frequently more difficult to stimulate (Gregory and Walling, 1981). This is emphasised by Blaikie (1985) who states that soil erosion has social and political components, as it is a result as well as a cause of under-development, by contributing to the failure to produce, invest and improve productivity. This is due to the fact that more attention is given to the consequences than the causes of soil erosion. It has been stated by Blaikie (1985) that there are well established differences between scientific or technical personnel and actual land users in the perception of the soil erosion threat. These diffreences may result in impaired attempts at soil conservation stemming from misunderstandings between policy makers and land users. This problem also contributes to the underdevelopment of the people and to the continued unproductivity of the land (Brinkate and Hanvey, 1996).

The continued interest in studies of soil loss has been displayed in the ever increasing demand for sustained resource utilization, particularly with reference to agricultural production in relation to the growing world population. Associated with this is the demand for sustained supplies of fresh water for both domestic and agricultural needs, although the recognition that the earth's resources pertaining to land use are finite and for all practical purposes are non-renewarable (Beckedahl, 1998).

1.1.1 The Indirect Cost of Erosion

When farmers lose topsoil they pay for it in reduced soil fertility, but unfortunately the costs of erosion are not confined to the agricultural land alone. As soil is carried from the agricultural land by runoff, it may be deposited in local streams, rivers, canals and reservoirs. The loss of topsoil that reduces land productivity may also reduce the potential for irrigation, electrical generation, and the navigability of waterways. One reason for the excessively rapid siltation rates is that multi-purpose dams are designed by engineers who sometimes fail to recognise that the impoundments they build are part of a watershed (Boardman *et al.,* 1990). It has to be noted that once the dam is built, it is part of the drainage system and it may have adverse effects on the drainage system of that river and the catchment.

1.1.2 Effect of Erosion on Vegetation and Soil

The effect of erosion on vegetation becomes evident when the soil profile becomes thinner and of poorer quality (Liggit, 1988). This leads to loss of plant nutrients, lower moisture holding capacity and poorer soil physical characteristics. Furthermore, plant growth is reduced and a vicious cycle ensues, since a decrease in plant cover leads to increased erosion. Erosion, land management and vegetation cover are interlinked. Poor grazing management may lead to reduced plant cover (Forster, 1973; Stocking, 1978; Lutchmiah, 1999) and may cause erosion. Acocks (1988) stated that, in South Africa, the reduced depth and quality of the soil makes the recovery of the vegetation slow and difficult even if given a rest.

Rainsplash is particularly effective in breaking down soil aggregates and causing surface sealing - the dispersion of fine soil particles (for example clay particles) which clog the surface pores of the soil, reducing infiltration and causing greater runoff. The breakdown of these aggregates, with the subsequent loss of organic matter and clay particles, leads to a coarsening of soil texture and deterioration in soil structure.

1.1.3 Effects of Erosion on Sedimentation, Water Supplies and Land Use

Soil erosion and sedimentation primarily involves the process of detachment and transportation of sediment by raindrop impact and deposition by runoff. Erosion leads to large volumes of soil being transported to the river systems, where it is considered a major pollutant since it increases the turbidity of water. Turbidity hinders the passage of sunlight through water and may decrease biological activity and reduce the capacity of the water to support desirable water dependent species (Forster and Meyer, 1977; Crosson, 1985).

Turbidity reduces the attractiveness of water for recreational activities and since dirty water is heavier than clean water, it increases the cost of pumping as well as the cost of purification and filtration. The amount of chlorine required for disinfection of water increases as turbidity increases. Low turbidity thus minimises the required dose, and reduces the formation of chlorinated organics and taste and odour problems. It is also argued that the sediment in water may damage the water purification equipment due to abrasion (Crosson, 1985). Sedimentation of reservoirs is of major concern, particularly in South Africa where water resources are scarce. When a reservoir is filled with sediment, it is not only its water storage capacity which is reduced but the reservoir site is also lost (Liggit, 1988). Most of the dams which provide the examples of the severity of siltation in South Africa are related to the incorrect land use practices within the catchment for example Hazelmere Dam in KwaZulu-Natal (Russow and Garland, 2000).

The effect of erosion on water supplies has been noted by Liggit (1988), Currie (1997), Russow and Garland (2000), who argue that numerous springs and streams in South Africa have dried up as a result of man's activity. Sheet and gully erosion both reduce the infiltration capacity of the soil and increase the amount of runoff. The decrease in the amount of infiltration has two major effects on river discharge:

i) The increase in runoff causes an increase in discharge during and immediately after rain; and
ii) there is a decrease in baseflow.

The first effect increases the sediment yield as it encourages greater sediment mobility in the valley side slopes, and greater erosional scour of the river channel itself. The second effect encourages deposition of sediment within slack water conditions within the channel itself reducing the river's storage capacity. The incidents of flooding can be increased due to both of these factors. The effect of erosion on land use includes the detrimental effect of farming marginal land, particularly where erosion has depleted the nutrient value of soil (Liggit, 1988).

1.1.4 Sediment Sources and Sinks

Sediment sources produce sediment whereas the sinks trap sediment. Sediment sources include agricultural lands, construction sites, roadways, disturbed forest lands, surface mines, and natural geologic - badlands. Sources may also be classified according to the dominant type of erosion: sheet (interrill), rill, gully, stream channel, or mass erosion. Typical sediment sinks are at the base of the catchment, these include reservoirs (Liggit, 1988).

According to Hupp and Bazemore (1993) the three principle sources of sediment are:

i) Soil erosion of upland areas from overland flow, including farmed areas;

ii) head-cut or knickpoint migration in degrading low-order systems; and

iii) remobilization of stored sediment through channel processes acting on flood plains or other storage sites, including channel migration, bank widening, and avulsion.

At the scale and scope of the present study, there is insufficient information from previous or ongoing studies, on soil erosion resulting from overland flow. However, incision of road cuttings and widening of gullies are poorly understood and may represent significant, if not major, sources of sediment. Similarly these two processes may strongly affect sediment delivery to reservoirs. Furthermore, rivers within the catchment function as both sediment sinks through flood-plain accretion and as sources through channel and bank erosion.

1.1.5 Soil Erosion Classifications

The process of soil formation and soil loss has been in existence since time immemorial. The threat that has been posed by the accelerated soil erosion has also not passed unnoticed through the ages. From time to time conservationists in Africa have tried to draw attention to the consequences of continued and unchecked degradation of the soil. The soil erosion classification systems identify the degree and intensity of erosion within a given area of land or agro-ecological unit. The identification of different classes is generally carried out through aerial photograph interpretation supported by field checks. The amount of field work is determined by the scale of available aerial photographs and that of the final map, see for example the work of Elwell and Stocking (1973); Chaleka *et al.* (1985) in Lesotho; Whitlow (1986); Stocking (1987); Whitlow (1992) in Zimbabwe and Morgan (1995) in Tanzania.

1.2 RATIONALE FOR THE PRESENT STUDY

Gullies dissect fields and cause difficulty in the use of land and in extreme cases land may have to be abandoned. Soil loss from fields and the resultant decrease in land productivity are on-site effects of soil erosion. The off-site effects occur as a result of transportation and/or the subsequent deposition of eroded sediment both down slope and along watercourses and is of particular importance as the impact is experienced along the entire river channel. The siltation of impoundments in KwaZulu-Natal such as Hazelmere Dam is a major concern, as it poses a serious threat to economic development in general, and to KwaZulu-Natal in particular due, to the reduced productivity or economic life of reservoirs. Siltation of weirs and adverse effects aquatic on flora and fauna in proximity to weirs as discussed earlier (Section 1.1.3) represents further concerns. Hazelmere Dam, completed in 1975 and located on the Mdloti River, has shown a steady increase in accumulated sediment, such that there are now concerns that the economic life of the impoundment may be curtailed (Currie, 1997; Russow and Garland, 2000). This increase in sediment has been attributed to many factors, some of which include physical characteristics, especially soil and slope conditions as noted by Russow and Garland (2000).

In most of the world's drainage basins or catchments the principal sources of sediments have not been identified and there are no bases from which to ascertain either from where or when the sediment load is being derived (Forster, 1980). Ideally, if it were possible to identify major source areas with relative ease, rehabilitation could then be focused there with considerable savings being achieved.

The present study has been undertaken within a broader research programme dealing with the relations between sediment production, sediment sources and different land use practices, see for example Read (2002). This work is aimed at investigating the relationship between sediment sources within the Hazelmere catchment and the soil characteristics of the catchment. Furthermore, this study will use a Geographic Information System (GIS) to integrate a range of digital data to obtain a better understanding of the spatial distribution of soil erosion within the Hazelmere catchment.

1.2.1 Aims and Objectives

The aim of this research is to identify, assess and characterise the soil properties within the catchment of the Mdloti River upstream of the Hazelmere Dam, with a view to determining the extent to which the siltation problems within the catchment (and specifically within Hazelmere Dam) may be attributed to soil characteristics as opposed to other factors related to erosion such as slope and land-use practice.

The objectives of the study are to:

i) Identify soil characteristics (physical and chemical) within the Hazelmere catchment;
ii) determine erodibility of the soil, using an Eijkelkamp rainfall simulator and the Wischmeier and Smith (1965) nomograph;
iii) assess the relationship between particle size distribution and erodibility of the soil;
iv) map the areas within the Hazelmere catchment, which are susceptible to soil erosion, based on the known factors affecting soil erosion; and
v) to use a Geographic Information System (GIS) to integrate digital data of actual soil erosion, land use, rainfall distribution, soil erosivity, geology and topography (slope) so as to obtain a better understanding of the spatial distribution of soil erosion in the Hazelmere catchment.

In order to contextualise this study, a review of the existing literature pertaining to soil erosion is presented in Chapter 2. The last part of that Chapter outlines some of the models used in soil erosion studies and its assessment. The environmental setting of the study area covering the physical environment and land use activities is reviewed in Chapter 3. Chapter 4 focuses on the methods and techniques used. The results are presented and discussed in Chapter 5. The final chapter provides a brief review of the implications of the findings of the research, and then concludes with recommendations that could be adopted to alleviate the sedimentation problems in the Hazelmere Dam.

The discussion thus far has outlined the problem of soil erosion, the possible consequences of soil erosion and the basis of this study. It is anticipated that the results obtained from the present research will facilitate an explanation of sediment sources within the Hazelmere catchment and its erosion resulting in the siltation of Hazelmere Dam. In order to achieve these aims, it is necessary first to consider the context of soil erosion for the better understanding of the factors and processes involved in the transportation and deposition of sediment.

CHAPTER 2

SOIL EROSION: A REVIEW OF EXISTING KNOWLEDGE

2.1 INTRODUCTION

If water resources are to be effectively managed and the problem of siltation understood, then we also need to understand erosion which results in turbidity of the water, and a decrease in water quality. This is the principle objective of this study of sediment sources in the Hazelmere catchment. It is necessary to first understand the factors that contribute to soil erosion, the processes and the mechanics of erosion and the models used to estimate soil erosion. This chapter focuses on the types of soil erosion, nature of soil erosion, factors affecting soil erosion and lastly the effects of land use on runoff and rainfall erosivity.

The term erosion originated from the Latin word *erodere,* which means 'eat away'. As defined by Zachar (1982), soil erosion refers to the destruction of soil by the action of water and wind. This follows the work of Ellison (1947) who defined erosion as a process of detachment and transportation of soil material by transporting agents. Soil loss as distinct from soil erosion refers to the process of removal of soil from the system without attention being paid to detachment and entrainment processes (Liggitt, 1988).

2.2 THE NATURE OF SOIL EROSION AND ITS HYDROLOGICAL CONTEXT

Soil erosion involves two important phases; the detachment of soil particles from the mass soil and their subsequent transportation by the erosive agents. Within the context of the present study, the two principal agents of this process are raindrops and flowing water. Raindrops in the form of rainsplash provide the initial impetus for detachment of particles from soil clods by impact and their movement by splashing or dispersion (Cooke and Doornkamp, 1990).

Overland flow, or runoff erosion, provides the means for transportation of sediments but as the water is successively concentrated into rills and gullies not only is the transport capacity of the flow increased but its detachment capability is also increased (Cooke and Doornkamp, 1990). Rills form where slopes become sufficiently steep for sheet wash to be unstable and incise into loose sediment or where slopes have pathways that are long enough to form unstable concentrated flows (Selby, 1993).

The processes of water erosion are closely related to the routes taken by water in its passage through vegetation cover and in the movement over the ground surface. During a rainstorm water reaches ground surface as a result of direct fall; this component of water is known as direct throughfall. The water that reaches the ground may be stored in small depressions on the surface or it may infiltrate the soil, thus contributing to soil moisture storage and some may percolate to groundwater. When the soil is saturated (cannot absorb more water) the excess moves laterally downslope contributing to surface runoff, thus resulting in soil erosion by overland flow or by rills and gullies (Holy, 1980; Morgan, 1995; Madikizela, 2000). The water within the soil either percolates down to the groundwater table, or moves laterally through the soil as subsurface or interflow and eventually contributing to surface flow either as baseflow of rivers or by exiting along spring lines and seepage zones.

2.3 PREVALENT TYPES OF SOIL EROSION FOUND IN SOUTHERN AFRICA

2.3.1 Rainsplash or Raindrop Erosion

The main cause of erosion in interrill areas is rainsplash. It has been realised that the amount of soil in runoff increased rapidly with raindrop energy and it has been noted that erosion can be reduced greatly by preventing raindrop impact (Selby, 1993). Raindrop energy is largely expended in detachment of soil particles so the amount of energy available for transport is less than from overland flow. Contributors on this subject include, Ellison (1947); Hudson (1961); and Morgan (1995) who highlight the importance of rainsplash. They explain that raindrops affect erosion in three ways:

i) They detach soil particles;

ii) transport soil particles through the air; and

iii) increase the turbulence of surface water, increasing its detachment and transportation capacities.

The actual response of soil to a given rainfall episode depends predominantly on the moisture content, the structural state of the soil and the intensity of the rain. Morgan (1995) describes three possible responses:

i) If the soil is dry and the rainfall intensity is high, the soil aggregates break down quickly (it should, however, be noted that if soil is dry infiltration is impeded);

ii) if the aggregates are initially moderately wetted or the rainfall intensity is low, micro-cracking occurs and the aggregates break down into smaller aggregates; and

iii) if the aggregates are initially saturated, infiltration capacity depends on the saturated hydraulic conductivity of the soil and large quantities of rain are required to seal the surface. However, soils with less than 15 per cent clay content are vulnerable to sealing if the intensity of the rain is high.

Raindrop erosion is controlled by the resistance of the soil and the amount, intensity and the duration of the rainfall. Depending on the stability of the soil aggregates, a large total rainfall may cause severe erosion if the intensity is low, and likewise an intense rainfall of short period may cause little erosion because of its small amount (Smithen, 1981; Seuffert, 1992). The erosive power of rain may be altered by the vegetation cover, erosive power can be negligible if there is vegetation to prevent raindrops from hitting the soil (Selby, 1993). This is the role played by vegetation in protecting the soil from erosion.

2.3.2 Rill Erosion

At low intensities of erosion, soil removal is generally more or less uniform but at higher intensities braids, rills or small gullies play an important role. Erosion in these channels is referred to as rill erosion (Bryan and Yair, 1982). Rills may be distinguished from gullies by their small size and ephemeral nature. Generally rills are considered to be small enough to be ploughed over during normal soil tillage. Where flow is concentrated into rills, Thornes (1980) reported that total sediment removed was several orders of magnitude greater than for unrilled flow. Most rill systems have no connection with the river system but occasionally a master rill may develop a permanent course which may lead to a river system. Erosion along the rills is usually non-uniform and is especially intense in headcuts, the headcut dimension depends on the flow, soil and slope (Forster and Meyer, 1977).

Most of the upland sediment load is transported downslope by flow in rills, if the sediment load exceeds the transport capacity, deposition occurs, usually at the base of concave slopes, in grass strips, or at other locations where flow loses significant transport capacity (Bryan and Yair 1982; Bryan, 1994). Rill erosion is then the primary agent for sediment transport on slopes with little vegetation. Most studies consider rills as a surface phenomenon formed from infiltration excess overland flow. Once the rills are formed, their migration upslope occurs by retreat of the headcuts on the steep banks at the top of the channel (Liggit, 1988).

The rate of the retreat is controlled by the cohesiveness of the soil, the height and the angle of the headwall slope, slope and the discharge and velocity of the flow (Morgan, 1995). Conversely the downslope extension of rills is controlled by the shear stress exerted by the flow and the strength of the soil, it should also be noted that the shear stress determines the rate of detachment of the soil particles by flow within the rill. Rill flow is non-selective in the particle size and it can carry large grains and even rock fragments up to 9cm in diameter (Morgan, 1995). With its considerable erosive power rill erosion accounts for the bulk of the sediment removed from hillslope. This depends on the spacing of the rills and the extent of the area affected. This is further justified by the study done by Govers and Poesen (1988) in Berlin farmland, who found that the material transported in rills accounted for 54 to 78 per cent of the total erosion.

2.3.3 Gully Erosion

In many respects, gully erosion is like rill erosion except for scale, a width greater than 0.3m, and a depth greater than 0.6m (Selby, 1993). Gullies are relatively permanent steep-sided water courses which experience ephemeral flows during rainstorms. They may be initiated in several ways and may not be associated with rills. Gully erosion usually takes place as a result of overland flow (Dunne, 1980). Overland flow occurs when the rate of infiltration has been exceeded (termed the Horton overland flow) or when the soil is saturated. The erosive force of Horton overland flow increases with both distance from the divide and with gradient (Harvey, 1971; Heede, 1982; Hadley *et al.*, 1985; Harvey *et al.*, 1985).

The two types of overland flow therefore produce gullies with different characteristics. Horton overland flow leads to gullies far from the divide and just below the steepest gradient of a slope, whilst saturation overflow may occur at any position on the slope wherever soil and topography combine to make soil saturation possible (Cooke and Doornkamp, 1990). In addition, Horton overland flow may produce gullies which are not connected to the main drainage network whereas saturation overland flow generally extends existing channel systems. However, overland flow is not the only way that gullies can form. Mass movement, landslides for example, may occur leaving bare areas which are susceptible to erosion. Piping, also know as tunnel erosion, may also lead to the formation of gullies (Stocking, 1978; Chakela *et al.*, 1985; Beckedahl *et al.*, 1988). Morgan (1980) notes that not all gullies form as a result of surface erosion, the investigations show that, as more water is removed from the hillside by subsurface flow in pipes and when there is enough rain to provide sufficient flow to flush out the soil in these, the ground surface subsides exposing the pipe network as gullies.

Many studies record the formation of gullies by pipe or tunnel collapse (Beckedahl *et al.*, 1988). Gullies can be classified according to their topographic position, they can thus be classified as valley floor and valley side gullies (Brady, 1992). The valley floor gullies can range from ephermeral gullies formed in topographic swales in the landscape during heavy rains to more permanent deeply incised channels which are three to four meters deep (Liggit, 1988; Moon and Dardis, 1988; Cooke and Doornkamp, 1990).

According to Morgan (1980) ephemeral gullies are formed when runoff concentrates in the valley bottom, particularly where the surrounding hillslopes are convexo-concave, and where most of the land is under arable farming, the soils are either loose or crusted and the peak discharges reach several cumecs. The valley side gullies develop more or less at right-angles to the main valley line, where local concentrations of surface runoff cut into the hillside, subsurface pipes collapse or local mass movements create a linear depression in the landscape (Morgan, 1980).

2.3.4 Stream Bank Erosion

While stream bank erosion was not intensively researched during this project it is important to briefly discuss its contribution to siltation of reservoirs. Also known as riverbank or fluvial erosion, this form of erosion is the wearing away of the banks on the outer curves of streams and rivers caused by continual undercutting and slumping. It has been pointed out by Liggit (1988) that streambank erosion occurs mainly laterally, unlike gullies where there is an important vertical component. It is associated with high runoff velocities from degraded catchments and is sometimes intensified by gullies eroding inland from the river banks. Reservoirs on a river may reduce the amount of sediment in the channel and lead to increased scouring below the dam. In a sample of 20 catchments in the United States Mitchell and Bubenzer (1980) found that eroding stream banks contributed approximately 33 percent to the total measured sediment load in the stream.

2.4 SOIL EROSION FORMS

2.4.1 Terracette Erosion

Terracette erosion is a step-like formation occurring mainly on steep slopes in areas with high rainfall. The formation comprises a multiple series of parallel steps where the vertical face of each step is bare of vegetation (SARCCUS, 1981). Terracette erosion is caused by small-scale slipping (aggravated by trampling from livestock) (Zachar, 1982) which, in the case of Hazelmere catchment, is widespread.

2.4.2 Creep Erosion

According to SARCCUS (1981) creep erosion is defined as the gradual viscous movement of soil downslope, 'lubricated' by rain water due to increased pore water pressure and under the influence of gravity. This natural phenomenon may be observed in the landscape as an accumulation of material against the up-slope side of stone walls, posts and trees leaning downslope and a distinct line of distortion in rock outcrops may be induced by human activity, for example cut embankments for roads and construction (Selby, 1993).

2.4.3 Mass Movement

Mass movement has been widely studied, but it has been neglected in the context of soil erosion. In some areas such as New Zealand and Tanzania mass movement has been found to be an important cause of soil erosion. Liggit (1988) and Morgan (1995) argue that the quantity of sediments moved from the hillsides into rivers by mass movement may often be far in excess of that contributed by gullies, rills and overland flow.

2.4.4 Subsurface or Pipe Erosion

An extensive body of literature on piping has been reviewed, see for example Jones (1981; 1990) and Beckedahl (1996; 1998). The factors that favour the formation or the initiation of pipes have been outlined by Jones (1981); Beckedahl *et al.* (1988); Noordstrom (1988) and Beckedahl (1998) as follows: (although not all of these need be present for pipe formation to occur).

i) High infiltration rates;
ii) a zone of soil moisture concentration within the soil profile;
iii) a zone of preferential lateral subsurface water movement in response to a hydraulic head;
iv) a high percentage of swelling clays and associated cracking within the soil profile;
v) high rainfall intensity;
vi) an erodible layer above an impermeable horizon;
vii) a change in vegetation cover of the slope, resulting in increased infiltration;
viii) a high cation exchange capacity (CEC), and high sodium absorption ratio (SAR); and
ix) biotic factors such as rodents burrows and root channel networks.

2.5 FACTORS AFFECTING EROSION

The usefulness of erosion assessment can be enhanced by identifying key factors involved in the erosion process. The factors that control soil erosion are the erosivity of the eroding agent, the erodibility of the material, the slope of the land and the nature of the vegetation in that area (Morgan, 1995).

In assessing soil erosion one of the approaches is to use the Universal Soil Loss Equation (USLE) which was developed by W. H. Wischmeier, D .D. Smith, with the U. S. Department of Agriculture, Agricultural Research Service and Purdue University in 1965 (Wischmeier and Smith, 1958; 1965).

The equation used is: $A= R * K * L * S * C * P$
Where A is a long - term average annual soil loss in tons per acre per year (t/ha/yr)

R is the rainfall erosivity factor, the factor represents the input that drives the sheet and rill erosion process. The potential ability of the rain to cause erosion.

K is the soil erodibility factor, a number which reflects the susceptibility of a soil type to erosion, it is the measure of the inherent erodibility of a given soil under the standard condition of the USLE plot maintained in continuous flow.

L is the slope length steepness factor, the ratio of soil loss from the field slope length to that from a 22,6 metre length under identical conditions. The ratio of soil loss from the field slope gradient to that from a 9% slope under otherwise identical conditions. The slope length and steepness factor can also be referred to as the algorithms reflecting rill and interrill erosion ratios.

C is the cropping and management factor, the ratio of soil loss from the area with specified cover and management to that from an identical area in tilled continuous fallow. This factor, according to Renard, *et al.* (1991), is perhaps the most important factor as it represents conditions that can be managed most easily to reduce erosion.

P is the conservation practice factor, the ratio of soil loss with the support practice like contouring, strip cropping or terracing to that with straight- row farming up and down slope. This factor mainly represents how surface conditions affect flow paths and flow hydraulics.

These factors provide a guideline to the investigation of the causes of soil erosion. In particular it allows the determination of those land use and management practice combinations that will provide the selected level of erosion control. However, limitations to these factors do exist. In particular, the effects of the different factors cannot be separated completely, for example the slope steepness is correlated to slope length as well as management factors. Moreover, individual analysis of factors may lead to missing interactions between factors and this derivation of the value A does not allow for any sort of non-linear reactions between the factors (Wischmeier and Smith, 1965).

As has been noted, assessment of soil erosion risk is based upon the principles and parameters defined in the universal soil loss equation (USLE). This model was developed as a means of computing field-scale assessments of soil loss by rainfall from agricultural land. More specifically, its purpose was to provide a basis for advising farmers on soil conservation measures. As such, the model was designed to be used at a specific (i.e. local) scale, and in an area where erosion was a product essentially of Hortonian overland flow (i.e. runoff occurred as a result of high-intensity storms in which precipitation rates exceeded the infiltration capacity of the soil) (Selby, 1993).

In this form, the USLE has been widely and successfully applied in the USA for many years. In so far as it specifies the basic factors involved in soil erosion by rainfall, it can also clearly provide the foundation for the analysis of soil erosion risk in other areas. For a number of reasons, however, the model could not be used in its original form. Amongst others, these included: firstly, the circumstances that the model was developed specifically for USA conditions, and Wischmeier (1960; 1977) himself, for example, has warned against its use elsewhere without appropriate verification, calibration and hence necessary modification. Secondly, the fact that the model was developed explicitly for use at the local scale, as a basis for practical farm advice, as opposed to the more general regional scale and broader policy applications required here, and thirdly, the stringent data demands of the original method, which would not be achievable for the Hazelmere catchment. Consequently, this study has chosen not to modify and adapt the model to meet the requirements of this project. Any simplification of the model is dangerous, in that it might undermine its integrity and reduce the quality of its performance. Moreover, without careful testing and calibration, the results of any changes introduced could not be assessed.

2.5.1 Other Soil Loss Estimators

Although USLE still remains a widely used practical tool for estimating soil erosion, there is, however, a revised model of USLE called Revised Universal Soil Loss Equation (RUSLE) (Renard, *et al.,* 1991). Some of the improvements in the RUSLE include:

i) Modifications to the slope length factor so that it varies with soil susceptibility to rill erosion.
ii) a nearly linear slope steepness relationship that reduces computed soil loss values for very steep slopes.
iii) a sub-factor method for computing values for the cover management factor.

The Soil Loss Estimator for Southern Africa (SLEMSA) is a model that was developed in Zimbabwe in the late 1960s (Abel and Stocking, 1987) to estimate soil loss by sheet erosion in the subtropical areas of southern Africa. The model was developed by H. A. Elwell (Elwell, 1971).

The equation is: $Z = C * K * S$

Where Z is mean annual soil loss, t/ha/yr;

K is mean annual soil loss, in t/ha/yr from conventionally tilled bare fallow on slope;

C is a correction factor which modifiers K according to crop characteristics; and

S the factor which corrects the product of C and K for slope conditions (Elwell, 1981; Garland, 1988).

Elwell (1981) states that, this model like any other model, cannot account for all the complex processes involved in erosion. The advantage of SLEMSA model lies in its simplicity and the use of locally available data and that a variety of models can be developed to suit different localities (Stocking, 1995; Duma, 2000).

A different soil loss estimator is Chemicals, Runoff, and Erosion from Agricultural Management System (CREAMS) generated as a collaborative model in Europe. CREAMS is a process based erosion prediction model (Knisel, 1980). CREAMS is structured as three separate components which are:

i) Hydrology;
ii) erosion/sedimentation.;
iii) chemistry;

The advantage of this model is that it enables the user to run independent operations for each of the three separate routines and to make comparisons while operating at a relatively low cost. Secondly, the user may want to run only the hydrology and erosion components rather than the chemistry component, this allows for that option. A major shortcoming of CREAMS is that it is partly based on the philosophies inherent in the USLE and thus has some of the same limitations as does the USLE (Foster, 1980).

The last soil loss estimator in relatively wide usage is the Water Erosion Prediction Project (WEPP) model. WEPP is a physically-based model (Nearing *et al.,* 1994). The equation used in the WEPP erosion model is:

$$D_i = K_i * I^2$$

Where D_i is the rate of interill sediment delivery to rill, K_i is an interill erodibility parameter, and I is the average rainfall intensity integrated over the duration of rainfall excess (Nearing *et al.,* 1994).

To understand soil erosion requires an extensive knowledge of the processes involved. This knowledge allows the formulation of the parameters within models and the selection of the most appropriate models to predict soil loss. Soil loss prediction becomes an important tool in attempting to combat soil erosion. The data from soil erosion prediction models is used to assess risks of soil erosion and the choosing of correct soil conservation practices (Hudson, 1981; Millington, 1992; Duma, 2000).

2.5.2 Rainfall Erosivity

Climate influences erosion in several ways. The climate factor represents the input that drives the sheet and rill erosion process, and the difference in climate represent differences in erosivity of that climate (Selby, 1993). The erosivity of a rain storm is a function of its intensity and duration, and of the mass, diameter and velocity of the raindrops. Raindrop size varies with rainfall intensity, and it is possible to calculate the energy conditions of different rainfall events as a comparative measure of erosivity resulting from rainsplash. The widely used parameter in South Africa is the EI_{30} index (Beckedahl *et al.,* 1988). This index is the product of the total kinetic energy of a storm and the maximum intensity lasting for 30 minutes, where (E) is the kinetic energy and (I) is rainfall intensity.

In order for the fluvial erosion to take place, there must be runoff, that is water moving across the soil surface. As previously stated, runoff occurs when the rate of precipitation exceeds the surface ability to absorb it (infiltration capacity). Cooke and Doornkamp

(1990) argue that the rate at which the runoff is generated depends solely on the disparity between the rate of precipitation and the infiltration capacity of the surface. As this disparity increases, the amount of runoff produced per unit of time increases. A direct relationship between runoff and erosion indicates that the rate and amount of erosion is affected by the intensity and duration of precipitation.

Renard, *et al*, (1991) found that in Illinois, (in United States of America) all factors (soil erosion factors) being the same, nearly twice as much erosion is expected in southern Illinois than in the northeast because of differences in climatic erosivity at the two locations. In the Hazelmere catchment such factors are likely to be important. The cyclone Demonia, which struck KwaZulu-Natal in January 1984, illustrated the potential of an extreme event to cause erosion. Data on rainfall erosivity are however, rare as rainfall intensity and duration need to be recorded by autographic rain gauges; a form of instrumentation not in use at many of the low-order weather stations in southern Africa (Beckedahl *et al.,* 1988).

2.5.3 Soil Erodibility

Some soils are naturally more susceptible to erosion than others (Forster and Meyer, 1977). The erodibility of the soil is defined as its vulnerability or susceptibility to erosion, and defines the resistance of the soil to both detachment and transport. It is a function of the physical and chemical characteristics of the soil as well as the management of the soil. The erodibility of soil depends on several soil properties, more importantly those that affect the detachment and the transportability by rainsplash and runoff and also those that affect the infiltration capacity. The most important are aggregate stability, the texture of soil particles and related chemical and organic characteristics, and the strength of the soil. The differences in the ease of detachment and transport are affected by soil structure, organic matter and particle size distribution. For example the particles in fine sand are easily detached, compared to clay, but once detached and in suspension, clay particles are more easily transported than sands. In general, erodible soils have a low clay content while clay soils tend not to be erodible.

The degree of aggregation of soil particles has an effect on soil loss because many aggregates are too large to be detached by low velocity runoff, so removal tends to be confined to smaller aggregates and separates (Hudson, 1981). Where larger aggregates occur, splash cannot take place until raindrops have broken them down. Land use and management on the other hand has long and short-term influences on erodibility.

Although practices like cultivating row crops, as opposed to planting permanent pasture on a steep slope, facilitates erosional processes in the short term, in the long term increased erosion over the cultivated area will cause the soil to take on the erodible properties of the lower soil layers as these become exposed (Stocking, 1987). It is argued that with good management practices (for example those that increase aggregation and soil organic matter content) erodibility of the soil may decrease over time. Conversely, it can increase, as progressive erosion removes the surface soil and as tillage brings up more erodible subsoil. Moreover, continued intense tillage breaks down soil structure and depletes organic matter, further increasing erodibility (Zachar, 1982).

2.5.4 Slope Steepness and Gravity

The erosive power of surface water flow depends on the energy of water which varies with the velocity and the turbulence of flow. The steeper the slope, the faster the flow and the greater the erosion. The relationship between slope length and erosion also operates through runoff but is more complicated (Toy, 1977).

Another aspect that affects soil loss is slope length, which affects the catchment area and thus the amount of water available. If the slope is long, there is a build up of the amount of the surface runoff and its velocity and depth increases. This leads to scour erosion which would not occur on a shorter length of slope or where the effective down-hill slope is reduced to the distance between channel terraces.

Where storms generate little runoff (for example, are of low intensity), long slopes of relatively gentle gradient give a greater opportunity for the runoff to infiltrate. Therefore, erosion may decrease with slope length for low intensity rainfall. On the other hand, for the high intensity rainfall there is a progressive increase of runoff in the downslope direction. Under such conditions erosion tends to be directly proportional to runoff, and it becomes clear that, for high intensity storms, as slope length increases, erosion increases (Toy, 1977).

Renard, *et al.* (1991), argue that soil loss is much more sensitive to changes in slope steepness than to changes in slope length. The influence of slope is complex, as the shape of the slope also affects the severity of erosion especially as very few slopes in reality are rectilinear. Soil loss is high on convex slopes, less on straight slopes and least on concave slopes (Morgan, 1995). In most cases the top of the slope is convex and is prone to erosion while the bottom of the slope is concave and is a site for deposition.

2.5.5 Vegetation Cover

Vegetation cover functions to retard soil erosion, for it protects the surface from raindrop impact, reduces the amount of water available for the runoff by trapping it and improving infiltration capacity, and reduce the velocity of the runoff (by increasing the surface roughness). It also often acts as a 'trap' for sediment already being transported. In addition to this, plant roots help to keep the soil in place. Hudson (1981) argues that the difference in soil erosion caused by differing management of the same soil is often very much greater than the difference in erosion from different soils under the same form of management.

This is further noted by Cooke and Doornkamp (1990), who argue that in a given locality where other variables are held constant, it can readily be demonstrated that different vegetation cover strongly influences soil loss. Cover and management cannot be separated because there are many interrelationships that exist between the two. Furthermore, the vegetation effect can be assessed in terms of crop management practices.

The effectiveness of plant cover in reducing erosion depends upon the height and continuity of the canopy, the density of the ground cover and the root density. The height is important in attaining the velocity of the drop, ground cover not only intercepts the rain but also dissipates the energy of running water, imparts roughness to the flow and thereby reduces its velocity (Liggit, 1988).

Vegetation dissipates the energy of running water by imparting roughness to the flow, thus reducing the velocity. The level of roughness with different forms of vegetation depends upon the morphology and the density of the plants as well as their height in relation to the depth of flow. The greatest reduction in the velocity of running water occurs where there is dense, spatially uniform vegetation covers. Vegetation can play a significant role in the reduction of soil erosion, provided that it extends over a sufficient proportion of the soil surface (Cooke and Doornkamp, 1990; Selby, 1993; Morgan, 1995).

From the preceding discussion it is evident that various forms of erosion have different causes. Rainsplash is normally the precursor to rill and gully erosion and it may worsen streambank erosion as it may increase runoff as a result of surface sealing and destruction of soil structure. The potential erosion hazard of an area is determined by the factors such as erosivity, erodibility and topography. The next chapter deals with the environmental setting of the Hazelmere catchment.

CHAPTER 3

ENVIRONMENTAL SETTING

3.1 LOCATION AND RELIEF

The catchment of the Mdloti River lies on the eastern seaboard of KwaZulu-Natal approximately 30 km north of Durban (between 29° 15′ 02" and 29° 45′ 53" S and 30° 47′ 29" and 31° 07′ 10" E) (Figure 3.1). The Mdloti River rises in the Noodsberg area, New Hanover District, of the KwaZulu-Natal midlands and flows in an eastward direction towards the Indian Ocean through the town of Verulam and the coastal town of Mdloti. Districts through which the Mdloti River flows include Ndwedwe and Inanda. The Mdloti River is bordered to the northeast by the Mvoti River catchment and to the south by the Umgeni River catchment.

The average gradient of the Mdloti River is 1 in 90 or slightly less than 1 percent (Currie, 1997). The catchment is characterised by gently undulating hills in the lower reaches of the catchment, ranging in elevation from 0 - 450 m above mean sea level (amsl) and becomes steeper and more rugged with distance inland (Currie, 1997). A narrow belt of vegetated sand dunes, arguably from the Berea Formation divides the interior from the ocean (King, 1982). The whole Hazelmere catchment is extensively incised and dissected by the Mdloti River and its tributaries which drain eastwards towards the Indian Ocean (Figure 3.2).

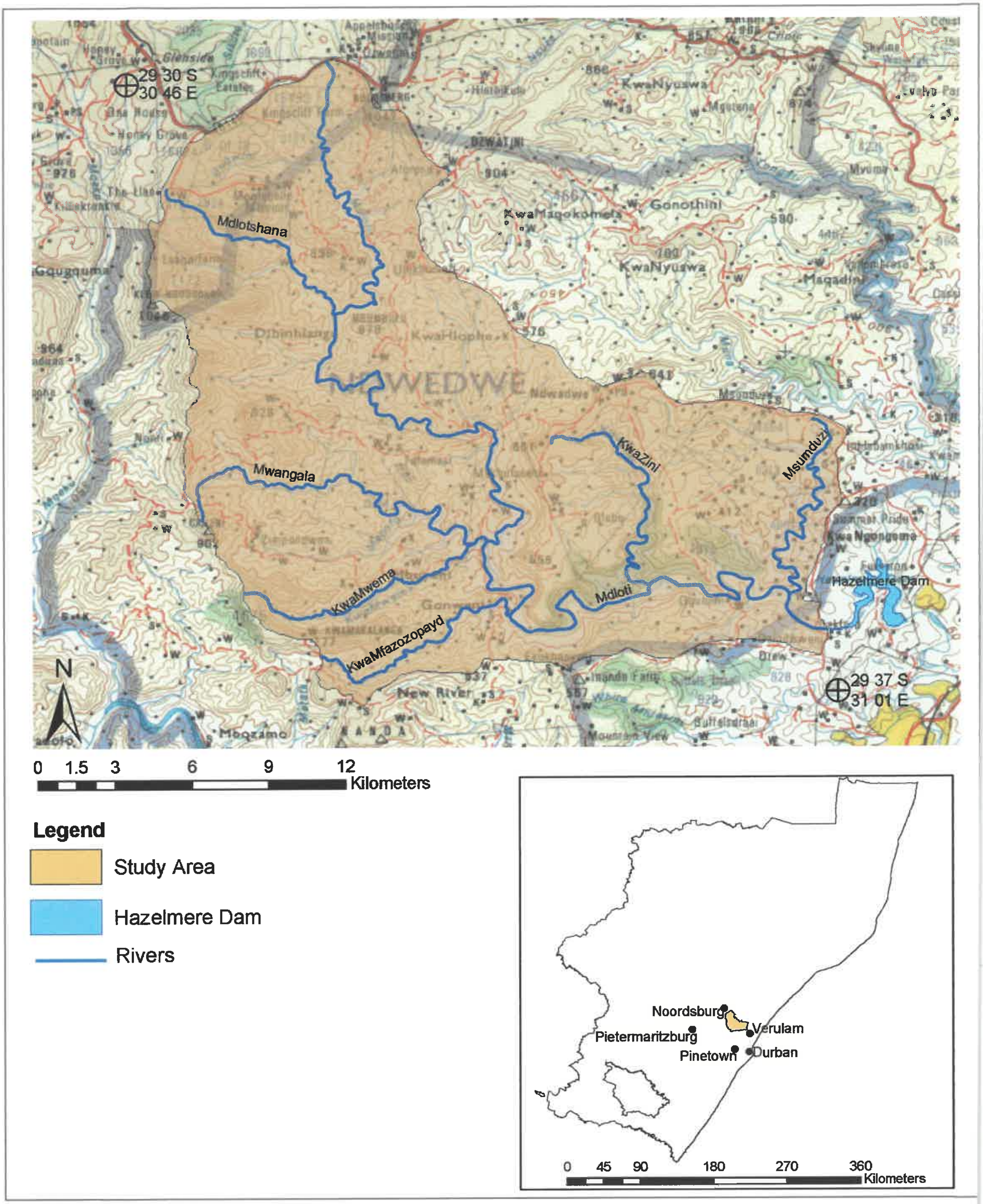


Figure 3.1 Location of Hazelmere catchment within KwaZulu-Natal.
(Source: South African Explorer, Municipality Demarcation Board and 1:250 000 South African Topographical Map)

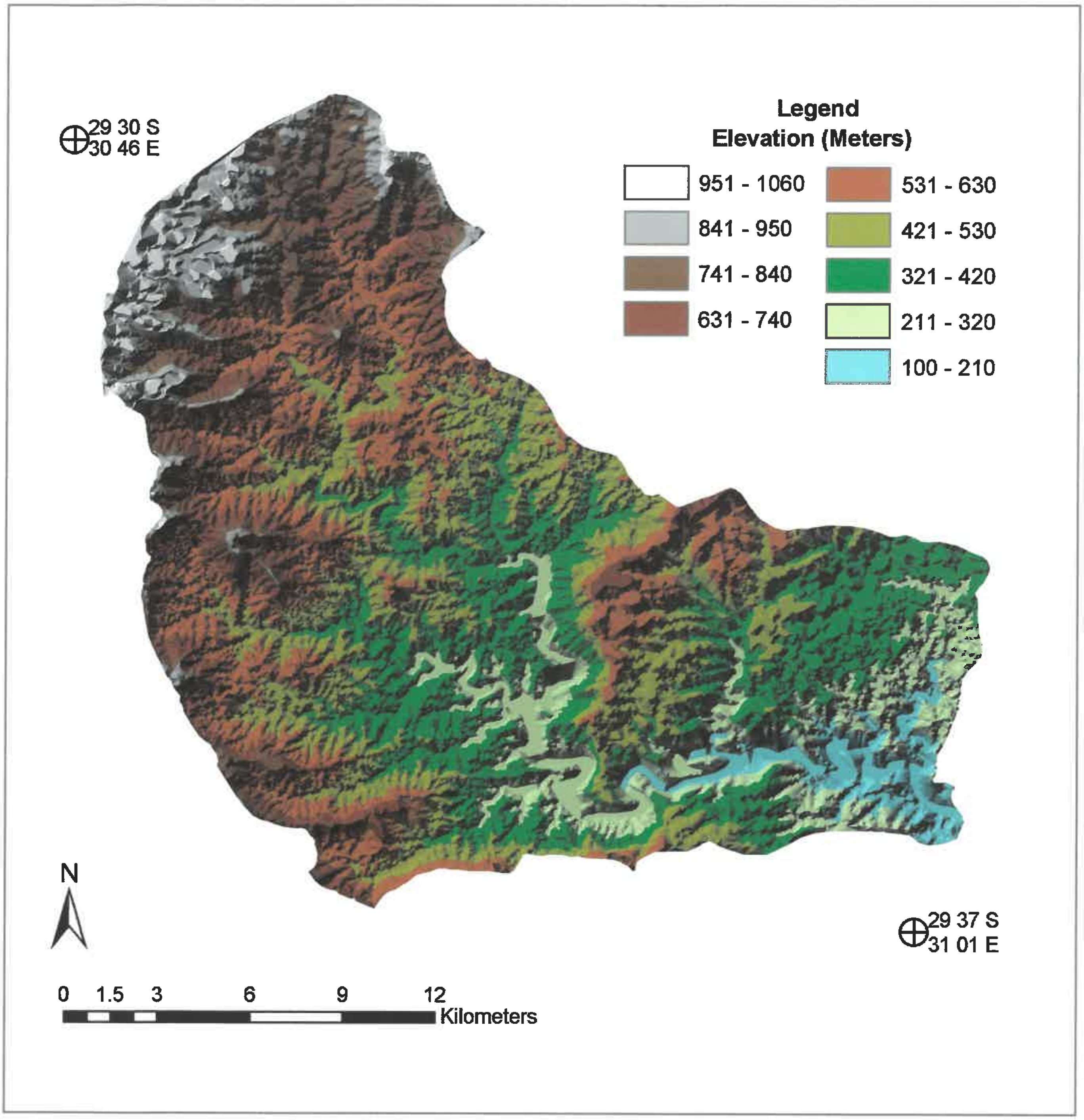


Figure 3.2: Relief map of Hazelemere catchment.
(Source: Derived from 10m interval Contours of South Africa)

3.2 CLIMATE

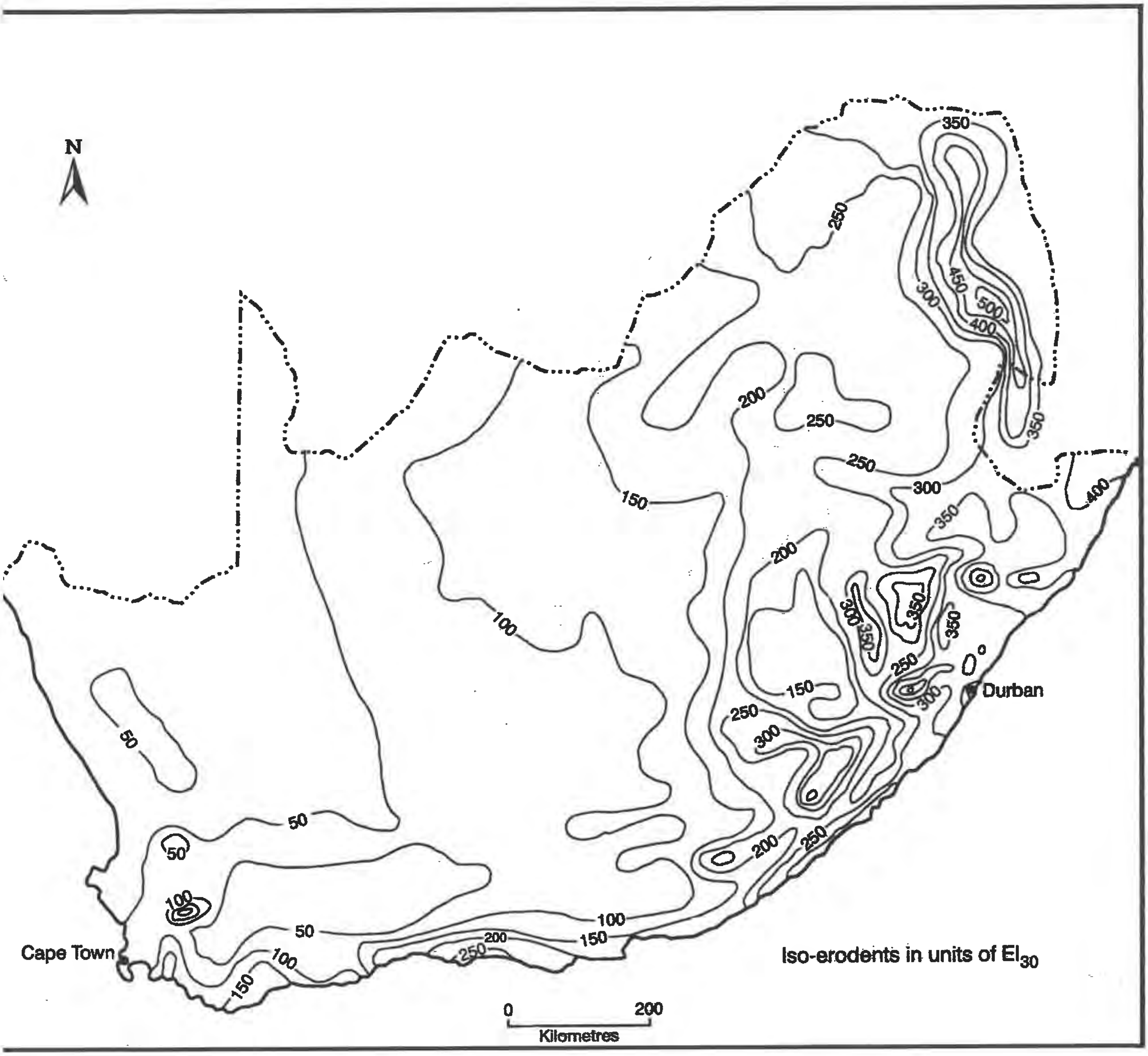
The catchment is situated within the Subtropical Climatic Zone of southern Africa (Schulze, 1982). Characteristics of such zones include: warm to hot temperatures with high humidity levels. Mean daily maximum temperatures range from 11.0°C in winter to 27.2°C in summer (Table 3.1). Daily temperatures also change depending on the proximity to the coast. Generally, coastal temperatures are warmer than those inland because of the warm maritime air. Although the mean daily temperature is 24.6°C, the highest and lowest recorded temperatures are 40.2°C and 0.0°C respectively (Table 3.1).

The mean annual rainfall varies from 967 mm above Hazelmere Dam to 982 mm at the coast, most of which falls during the wet summer months. It occurs in the form of instability showers and convective storms (Russow and Garland, 2000). At present the daily climatic statistics and conditions are limited as the five weather stations which were operational within the Hazelmere catchment have ceased operating since 1992 (Currie, 1997). At current there are no weather stations in operation within the Hazelmere catchment. The nearest Class one weather station in the district of the Hazelmere catchment is located at Mount Edgecombe, some 12 kilometres south west of Hazelmere Dam (Figure 3.1). Prior to 1992 there were 14 weather stations located in and around the Hazelmere catchment; this makes it impossible to infer the relationship between precipitation and discharge and the present rainfall distribution of the Hazelmere catchment cannot be mapped accurately. Rainfall erosivity cannot be determined nor the recurrence intervals of the extreme events calculated from existing real time data. Recurrence intervals of extreme events and actual rainfall erosivity can only be obtained through inference from past events or by mathematical modelling. Currie (1997), however, compared mean annual precipitation data from the weather stations in the Hazelmere catchment prior to their closure with the same data from the Mount Edgecombe Weather Station and found that the mean values were comparable. These data are, therefore, presented here in Table 3.1 and used in the present study, notwithstanding their limitations.

Table 3.1: Rainfall, Temperature and Evaporation conditions in the vicinity of the Mount Edgecombe weather station (modified from Currie, 1997).

	Rainfall (mm)		**Temperature (°C)**				**Evaporation (mm)**
Month	Mean Monthly Total	Maximum in 24 hr	Mean daily		Extremes		Class A Pan
			Max	Min	Highest	Lowest	
January	123.7	98.0	27.2	20.1	38.3	0.0	26.6
February	104.0	97.5	27.2	20.2	40.0	0.0	5.4
March	100.8	93.0	26.9	19.3	34.4	12.8	19.4
April	56.2	72.0	25.3	16.7	35.8	0.0	No Data
May	53.8	216.0	23.9	13.8	38.6	0.0	25.4
June	27.4	95.5	22.4	11.3	35.0	5.0	7.8
July	23.5	60.0	22.2	11.0	3.2	4.4	15.6
August	48.2	96.0	22.5	12.3	36.4	4.9	No Data
September	59.6	72.0	23.0	14.6	38.1	5.4	22.6
October	90.6	71.5	23.7	16.0	40.2	8.1	5.3
November	112.7	80.2	24.8	17.6	37.6	10.1	33.3
December	100.2	99.9	26.4	19.2	37.5	10.8	No Data

A comprehensive discussion of the rainfall erosivity characteristics within Hazelmere catchment is hindered by the shortage of the long term autographic rainfall records significant for calculating the index. However, Smithen (1981) and Beckedahl (1998) have provided an iso-erodent map for the greater southern Africa in general (Figure 3.3). Estimates of erosivity for a given area are then taken through interpolation between contours (Moodley, 1997). As an approximation the EI_{30} index for the maximum erosivity for Hazelmere catchment is 350J. mm. m^{-2}. h^{-1}.



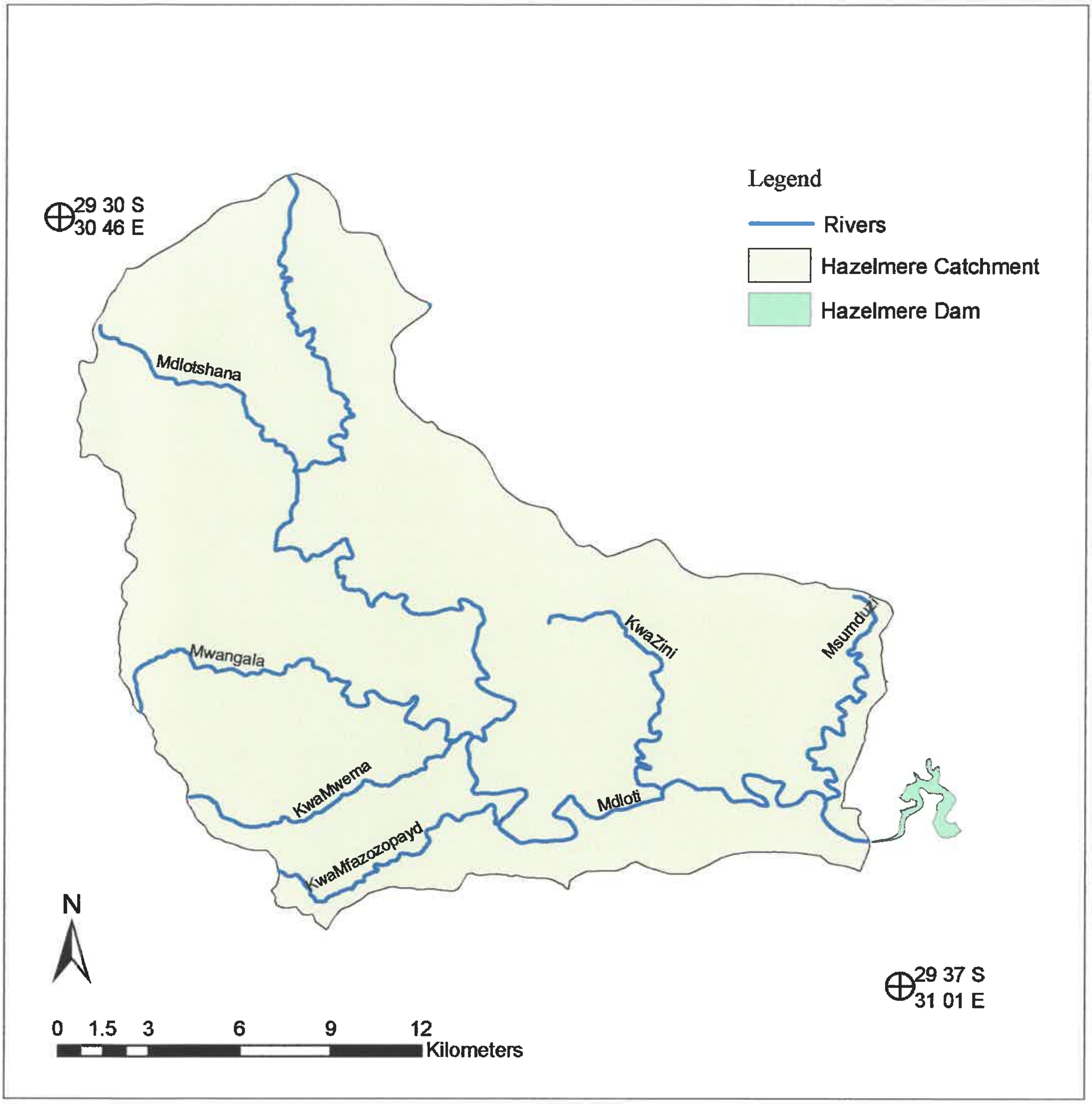
'igure 3.3: Iso-erodent map of southern Africa showing the distribution of EI_{30} values
Beckedahl, 1998after Smithen, 1981)

3.3 DRAINAGE

The headwater of the Mdloti River originates at an approximated altitude of 860 metres above mean sea level and it reaches the Indian Ocean 50 km to the east, draining a catchment area of 375 km^2. The tributaries of the upper Mdloti River include the Mdlotshana, KwaMwema, Mwangala, Kwazini, Msunduzi and Kwamfazophayo rivers while the Black eMhlasini River converges with the Mdloti River in the lower reaches of the river below the Hazelmere Dam (Department of Water Affairs and Forestry (DWAF), 1994) (Figure 3.4).

The drainage pattern of the Mdloti River is dendritic with a drainage density calculated at 0.343 m/km^2 (Currie, 1997). The mean discharge varies between 0.34 cubic meters per second (cumecs) in the dry season to 25 cumecs in the wet season (Grobbler, 1987). The gradient of the Mdloti River increases significantly as the river flows from the typical rolling countryside of the KwaZulu-Natal midlands through an incised gorge of Natal Group Sandstone into a valley comprising the Namaqua Natal Mobile Belt granite gneiss.

The average annual discharge into Hazelmere Dam is 70.54 million m^3, but inflow into the dam varies with rainfall, and annual runoff co-efficients between 1988 and 1991 were found to be between 17 – 35 percent of measured rainfall (Umgeni Water, 1993). The Hazelmere Dam is located approximately 5 km upstream of the town of Verulam and was constructed in 1977 to cater for the development of the town of Verulam and the surrounding areas, as a result of the proposed La Mercy airport development. Adverse economic factors have stopped the progress of the airport and thereby slowed development in the Verulam area (Walmseley and Butty, 1980). At current full supply level, the Hazelmere Dam stores 17 million m^3 of water and is the major bulk water supply for the town of Verulam, its associated industrial area Canelands and the KwaZulu-Natal coast as far as Stanger (Umgeni Water, 1993).



gure 3.4: Drainage map of the Hazelmere catchment

3.4 GEOLOGY

The geology of KwaZulu-Natal consists primarily of lithologies belonging to the Karoo Supergroup, with the moderate exposure of the Natal Group Sandstones and basement granites and gneiss of Namaqua Natal Mobile Belt. The geological structure is dominated by the presence of the Natal Monocline which according to King (1982) was identified by the German geomophologist, Penck, in 1908. The Natal Monocline is thought to have its original Form from the Mesozoic break-up of the Gondwana Pangea. Erosion and the incision by the rivers has caused the development of the rugged terrain common in KwaZulu-Natal. The pre-Karoo sandstones in KwaZulu-Natal which rise on the basement granites, were formerly classified as part of the Table Mountain Series of the Cape System, but are now classified independently as the Natal Group. These rocks dominate the coastal and the sub-coastal regions of KwaZulu-Natal. This group thins in a westerly or inland direction, and is overlain by the increasing thickness of rocks of the Karoo Supergroup in this direction (Figure 3.5) (Brink, 1981; South African Committee for Stratigraphy (SACS), 1980).

The Mdloti River has its source in the Noodsberg near Kingscliff and it drains an area underlain by granite and gneiss of the Basement Complex until it reaches the contact with rocks of the Natal Group, approximately 20 km upstream of the Hazelmere Dam site. Due to the seaward dip of the strata in this region, the river also flows over rocks of the overlying Dwyka Formation, but a major North East to South West fault with upthrow on its eastern side brings the river back on to the rocks of the Natal Group. The most contact between the Natal Group Sandstone and the Dwyka Formation is located approximately 60 m above river level at the dam-site. The upward displacement of the resistant rocks downstream of the major fault, the erosion of less resistant rocks downstream of the major fault and the erosion of less resistant Dwyka tillite further upstream have led to a general flattening of the river gradient and the formation of the efficient dam basin. The west of the catchment lithogy consist of the granite, gneiss and schists of the Basement Complex. The central sections comprise largely of Natal Group Sandstones. To the east of the catchment there are diamictites of the Dwyka Formation, outcrops of the Ecca Group Shales, and at the coast very small deposits of quaternary dune and beach sands of the Berea and Bluff Formations are found. The geological stratigraphy of the Hazelmere catchment is illustrated in Table 3.2.

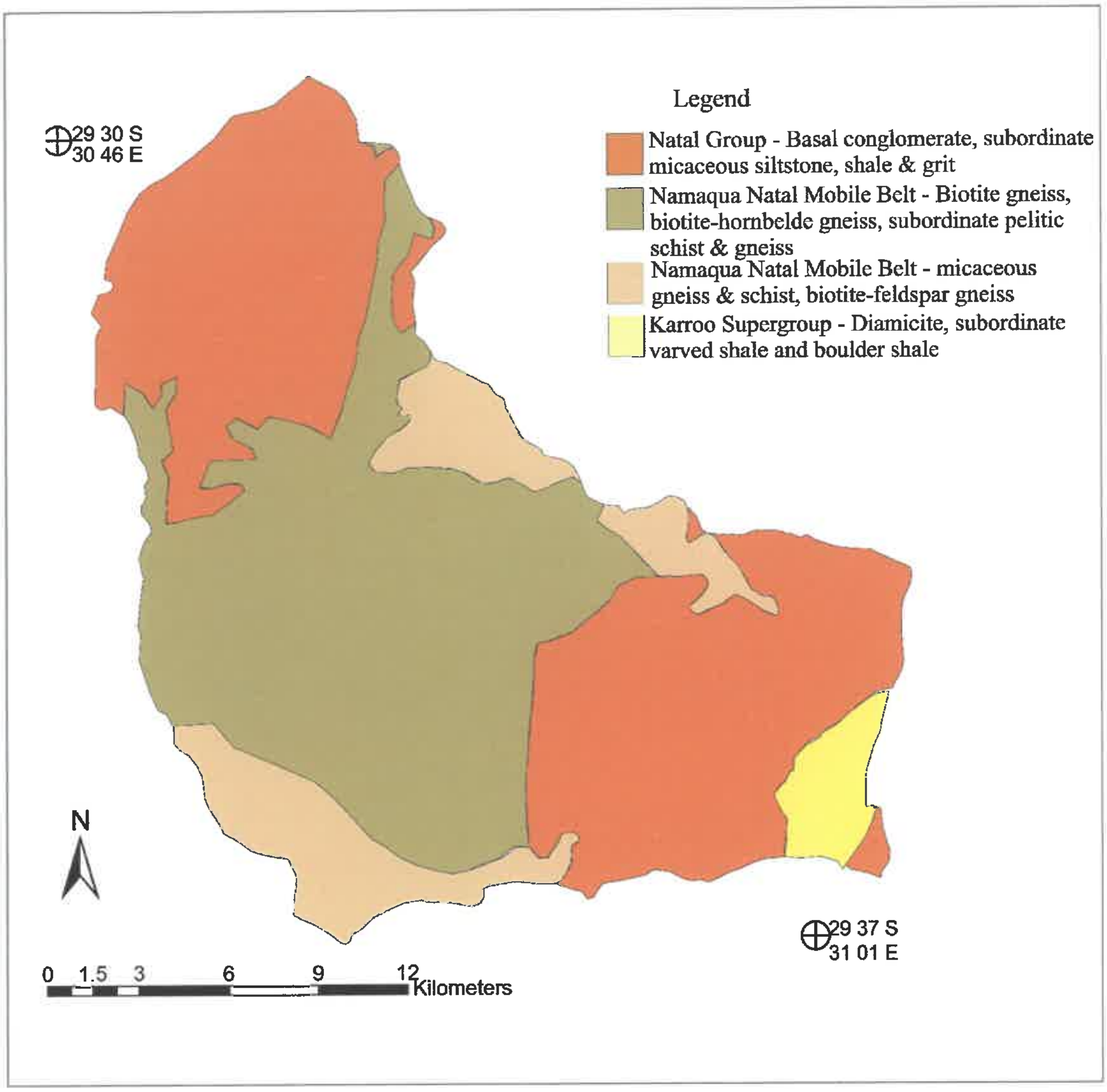


Figure 3.5: Geology map of the Hazelmere catchment. (Source: KwaZulu-Natal Hydrogeological Map, 1999)

Table 3.2: General stratigraphy of the Hazelmere catchment (modified after Truswell, 1977; Kent, 1980; Tankard *et al.* , 1982; Beckedahl, 1998).

Supergroup	**Group**	**Subgroup/ Formation**	**Mean Max Thickness (metres)**	**Lithology**	**Period and approximate ages (Ma)**
		Berea	60	Red sand, subordinate white yellow brown and purple sand, basal conglomerates.	Quaternary
Karoo	Ecca	Vryheid	500	Medium to coarse-grained sandstones with thin grit beds; subordinate grey shale and siltstone.	Permian 280
		Pietermaritzburg	400	Dark-grey shale; siltstone;subordinate sandstone.	Permian 280
		Dwyka	>100 (variable)	Diamictite; subordinate varved shale and boulder shale	Permo-carboniferous 350
	Natal	Hibberdeen, Inanda, Mlazi, Eshowe	900	Red-brown coarse-grained arkosic to subarkosic sandstone,quartzarenite micaceous sandstone; small pebble conglomerate; subordinate siltstone and mudstone.	Ordovician-silurian 500
Namaqua Natal Mobile Belt				Biotite gneiss, biotite-hornblende subordinate pelitic schist and gneiss	Namibian 1500

The Natal Group Sandstones are believed to be time equivalents to an undefined portion of the Cape Supergroup stratigraphy (Beckedahl, 1998) and are the lowest and the oldest rock strata that cover the Natal Mobile Belt basement rocks. Composed almost entirely of sandstones with subordinate quartzite bands, some pebble beds and lenses of shale or mudstone irregularly distributed within the sequence (King and Maud, 1964), the Natal Group lies unconformably on the Achaean granite-gneiss of the Namaqua Natal Mobile Belt.

The red sands of the Berea Formation represent the most recent lithology in the catchment. Kent (1980) states that these red sands, which are largely restricted to the coastal plain of KwaZulu-Natal have been reworked into thin discontinuous beds of pink, brown and white sands. This Formation generally occurs very close to the coast but does move further inland as one moves further northwards. The oldest portions of the Formation are usually situated further inland and can be identified by their dark-red colour and high clay content thought to be associated with extensive weathering of feldspathic coastal sands of 125ka (Tankard *et al.,* 1982; Brink, 1985). Berea Formation sediments in the Hazelmere catchment area lie bordering the coastline and extend inland towards the towns of Verulam, Tongaat and La Mercy.

The Karoo Supergroup arguably, the most famous of South African rock systems, covers the larger portion of southern Africa (Beckedahl, 1998). The Karoo Supergroup is characterized by changing tectonic framework and records the migration of Gondwana from polar to tropical latitudes. Karoo lithologies span a period of nearly 200 Ma (Currie, 1997). The transition from the Natal Group to the Karoo Supergroup is evident through a succession of diamictites varvites, through to interbedded shales and sandstones (Beckedahl, 1998). The whole sequence of the Karoo Supergroup is preserved in Kwazulu-Natal, but only those lithologies of the Dwyka Formation and Ecca Group are found in the Hazelmere catchment.

In Kwazulu-Natal, the Ecca Group is divided into various Formation, namely the Pietermaritzburg Formation which consist of shale and this Formation is found in lower reaches of the Hazelmere catchment upstream of the dam; the Vryheid Formation which includes sandstones, shale and surbordinate beds of coal; and the soft blue shales of the Volkrust Formation. The Vryheid Formation is present in the Hazelmere catchment but covers only a small portion of the catchment at Canelands near the town of Verulam.

3.5 SOILS

Soil characteristics within the Hazelmere catchment, described by King (1982) and Francis (1988) are lithosols related to the underlying lithology. Basement soils are nutrient-rich and light to moderate brown, although they may be grey and sandy on sloping areas (Soil Classification Working Group (SCWG), 1991). Soils on the coastal region of the Hazelemere catchment are regosols of the Fernwood Form derived from coastal dunes of the Berea Formation. This Fernwood Form is characterised by an Orthic A horizon overlying an E horizon which has undergone the *in situ* net removal of colloidal matter through the leaching of iron oxides, clays and organic matter. Parallel to the Fernwood Form, further inland, are soils of the Escourt and Glencoe Form (Soil Classification Working Group, 1991).

The Escourt Form is characterized by an Orthic A horizon overlying the E horizon which in turn overlies a prismacutanic B horizon. The Escourt Form is also associated with mass soil wasting such as soil piping and gullying and these are frequently found in the sugarcane regions of the Hazelemere catchment (Soil Classification Working Group, 1991). The Glencoe Formation differs from the Escourt Form in that the orthic A horizon overlies a yellow brown apedal B horizon which in turn overlies a hard plinthic B horizon. Soils derived from the Dwyka Diamictite (Tillite) are moderately fertile, but have poor physical properties. The soils derived from the Natal Group Sandstone are typically those of the Cartref Form and are characterised by an orthic A horizon overlying an E horizon which overlies a lithocutanic B horizon. Soils developed on the sandstones of the Natal Group are generally shallow, due to the prevailing topographic conditions which contribute to erosion. These soils are characteristically young which strongly reflect the dominance of parent material as a soil forming factor (Soil Classification Working Group, 1991).

Within Hazelmere catchment the Glenrosa Series is derived from geology of the granite gneiss basement complex of the Namaqua Natal Mobile Belt. The Glenrosa Form constitutes an orthic A horizon overlying a lithocutanic B horizon. In humid regions granite decomposes into residual soils of great depth (Soil Classification Working Group, 1991). Mica particles remain unaltered except in the upper zones of the soil profile, where they have decomposed, while quartz grains remain unaltered as sand grains. Feldsprars are kaolinised by the chemical reaction of water charged with carbon dioxide. Particles of colloidal kaolinite are fine-grained and are conducive to leaching and removal in suspension, leaving behind a residual of micaceous silty sand that collapses easily (Brink, 1979). Such mass wasting features are common on steep slopes and marginal lands in the upper reaches of the Hazelmere catchment and contribute greatly to suspended solid and turbidity values measured in the Mdloti River and Hazelmere Dam (Currie, 1997).

3.6 LAND USE

Rural subsistence farming and natural veld for grazing dominate land use in the catchment, although commercial cultivation (predominantly sugar cane) and timber production are common near the coast and at the inland extremes of the catchment respectively. The land use for the whole catchment can be divided into four categories: subsistence farming, commercial farming, industry and urbanisation. Commercial farming and industry includes forestry and sand mining from the Mdloti River. Below the dam 75 percent of the catchment land area is under sugarcane; this figure drops to 22 percent above the dam (Currie, 1997; Read, 2002) (Figure 3.6).

3.6.1 Subsistence Farming

Subsistence farming is the predominant land use in the Hazelemere catchment, as it covers 52 percent of the catchment (Currie, 1997). It is mainly concentrated in the upper reaches of the catchment and decreases towards the lower reaches of the catchment where there are isolated areas of subsistence farming near Verulam. Slopes in the subsistence farming area are generally steep. Population densities in the subsistence farming areas are high and this contributes to the high erosion rates in these areas, mainly due to the creation of unarmoured roads and footpaths for access to communities and for water collection, washing and cattle watering. Large section of the subsistence farming is in the former KwaZulu homeland areas, people living in these areas are impoverished and rely on land for survival. Land preparation and mechanical soil erosion control measures include bench terraces, contour bunds and strip cropping (Currie, 1997; Russow and Garland, 2000).

3.6.2 Commercial Farming

Commercial farming constitutes 35 percent of the catchment and is the second largest land use after subsistence farming. Sugar cane is the main crop cultivated in the catchment, on the gentle slopes with isolated pockets of commercial timber in areas too steep for sugarcane cultivation. Small scale cash crops of tomatoes, potatoes, green peppers, peas, beans, strawberries, pawpaw and bananas are also found in the vicinity of Verulam (Currie, 1997).

3.6.3 Industry, Mining and Urbanisation

Industry covers a very small component of land use in the Hazelemere catchment, and it is concentrated in the areas in and around Verulam and along the coast at Umhlanga. There are sand winnowing operations (sand mining) that take place along the Mdloti River. These operations have altered the river channel through widening and deepening and river vegetation disturbance as well as increasing suspended solids and turbidity values downstream (Russow and Garland, 2000). Urban land use constitutes 12.9 percent in the Hazelmere catchment which can be further divided into formal urban which is 6.7 percent, transitional urban 3.9 percent and dense informal urban 1.4 percent (Currie, 1997).

3.6.4 Road Construction

The Hazelmere catchment is transversed by gravel roads. Comparison of the 1970 and 1989 1:50 000 topographic maps shows that there has been an increase of roads within the catchment (Russow and

Garland, 2000). Drainage from the roads is contributing to the erosion and sediment rates within the catchment. The extensive study undertaken by Russow and Garland (2000) on road system of the catchment shows that roads have contribution on soil erosion. The erosional features include large erosion-excavated box-like gullies, which are metres deep, large and small rills and also sub-surface piping. As also discovered by Russow and Garland (2000), the sediments from these features has accumulated at the base of the slope and some is washed into the river channel.

Water from the roads in Hazelmere catchment is removed through a series of road drainage pipes into a canal running parallel with the road. Sediment removed from the gully system over time is transported downslope and ultimately into the Mdloti river. The study conducted by Russow and Garland (2000) show that there is an estimated 32000m^3 of sediment released into the drainage system by the gully system resulting from roads. This shows some erosion and sediment sources associated with road construction.

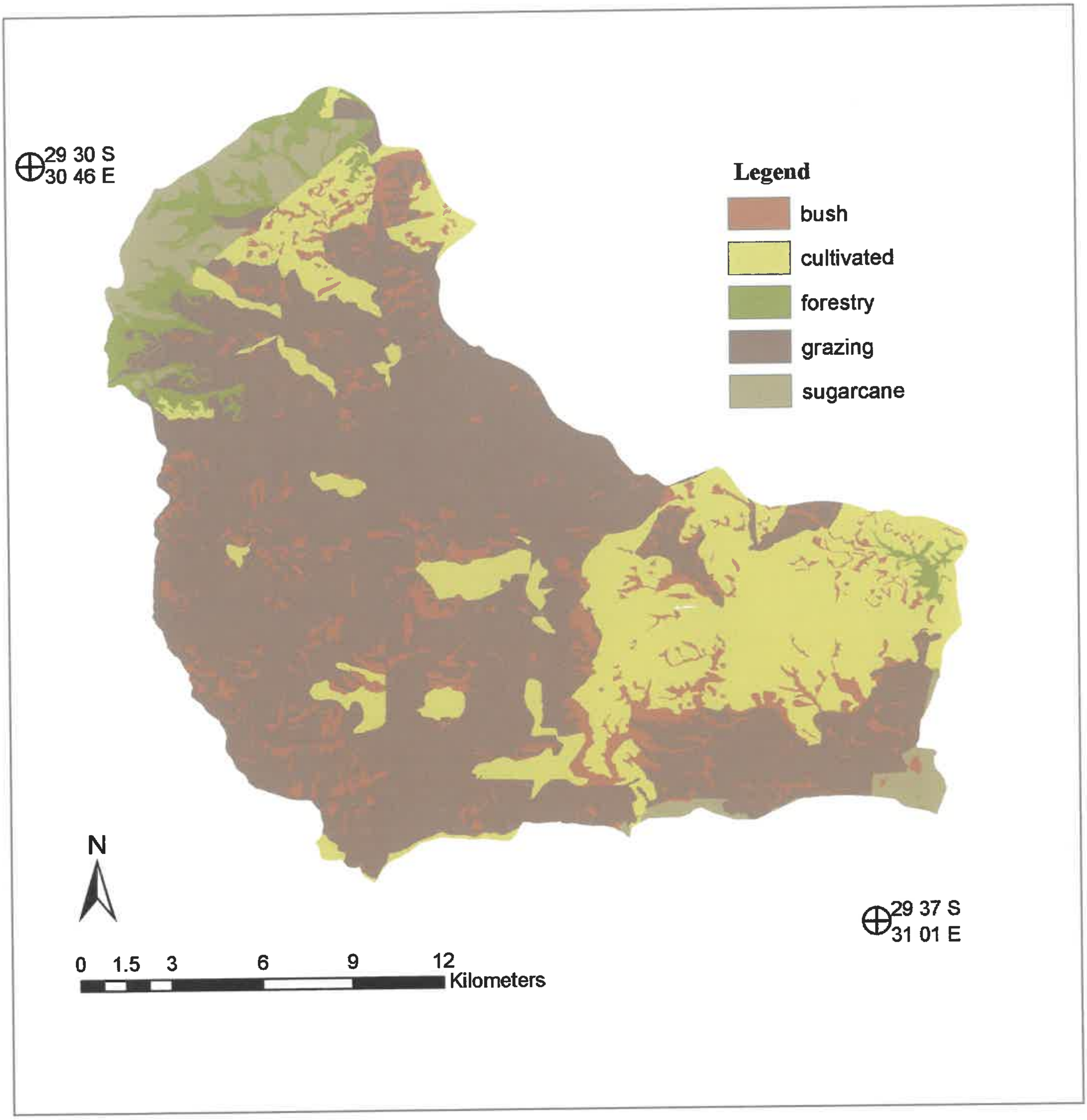


Figure 3.6: Land Use map of the Hazelmere catchment (Read, 2001)

3.7 NATURAL VEGETATION

The natural vegetation of Hazelmere catchment is dominated by *Acacia sieberina* savanna, with the Dry Valley Lowland scrub and woodland mosaic dominating river valleys. The coastal region is dominated by coastal forest and palm veld, with the central region dominated by a small patch of secondary *Aristida junciformis* grassland (Camp, 1999). The catchment of the Hazelmere Dam has a high biodiversity with respect to natural vegetation (Currie, 1997; Low and Rebelo, 1996). According to the Bio-resource groups of KwaZulu-Natal the Hazelmere catchment has been classified into moist coastal forest, dry coastal forest, dry coast hitherland Ngongoni veld, coast hitherland thornveld and valley bushveld (Camp, 1999) (Figure 3.7).

Near the coast there is moist coastal forest and further inland there is dry coastal forest. Vegetation of the coastal forest is a narrow belt on the leeward side of high dunes and is important for dune stabilisation (Low and Rebelo, 1996). The valley bushveld vegetation consists of a very dense thicket of woody shrubs and trees that occur in the river valleys. This vegetation facilitates bank and channel stability along rivers. It also serves as a source of fuel and building material to the people.

The vegetation of the Ngongoni veld occurs from just above sea level to approximately 300 metres above mean sea level, its terrain is flat to undulating, but rises quite steeply when moving inland, and is deeply incised by the rivers (Low and Rebelo, 1996). The vegetation of the coastal hitherland region covers an irregular area of the exposed upland hilltops and the ridges of rolling country on the lower escarpment slopes of the Drankensberg.

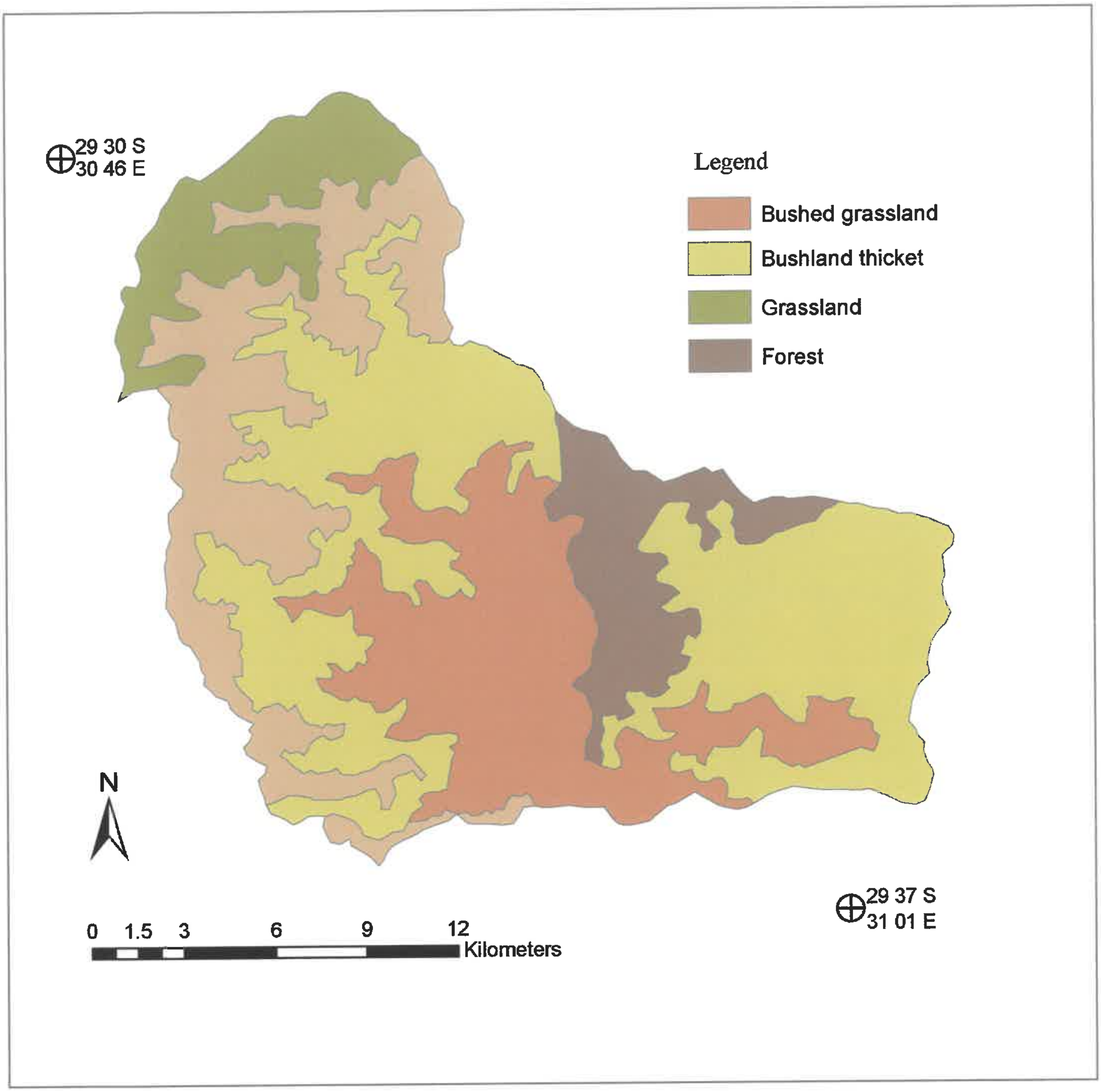


Figure 3.7: Vegetation map showing the vegetation relevant to the Hazelmere catchment (Camp, 1999)

3.8 ECOTOPES, LAND UNIT CLASSIFICATION AND LAND TYPES

Ecotopes are the smallest divisible unit within the Bioresource Group (BRG) classification system developed by the KwaZulu-Natal Department of Agriculture at Cedara (Camp, 1999). This land unit classification system was established based on the land systems type mapping concepts described in Cooke and Doornkamp (1990) and Morgan (1995). The ecotope system classifies land according to the types of plant species present and their preferences in terms of relief, soil, water and nutrient needs in order to determine the narrow range of farming activities each land unit can support, as well as the potential yield and production techniques necessary for each activity (Camp, 1999). This system is, therefore, used to define land use capabilities for particular sites, according to the nature of its attributes when farm planning (Camp, 1999). The Hazelmere catchment has been divided into seven ecotopes (Figure 3.8), described in Table 3.3 below (Liam, 2001 pers. comm.).

From Table 3.3 and the other information provided in the above chapter, it is evident that the high precipitation, moderate to steep rolling hills and the former grassland/bushland or forest vegetation areas provide optimum conditions for perennial crops such as sugarcane and timber plantations as well as for use as pastoral or grazing land. The growing of seasonal crops is best suited to the gentler slopes.

The relationship between land type units and BioResource Units is that BioResource units are looking at the land use potential using the data available from land types. A land type denotes an area that can be shown at a 1: 250 000 scale that displays a marked degree of uniformity with respect to terrain form, soil pattern and climate. One land type differs from another in terms of one or more of terrain form, soil pattern and climate. Different occurrences of the same land type may be separated from one another by one other land types. The land type map is then compiled by superimposing the climate map on the pedosystem map. The land type inventory is also compiled using data collected from the terrain, soil and climate survey phases, prepared by the Department of Agriculture and Water Supply. Within the catchment of Mdloti there are 16 land type units, (Figure 3.9).

Table 3.3: A summary of ecotope groupings found in the Hazelmere catchment (Camp, 1999).

Ecotope	**PPT**	**Elev**	**Slope angle**	**Natural vegetation**	**BRG**	**Land use dominance**
EMakuluzeni - Wa6	800 – 850 mm/a	126 – 548m amsl	Steep >12%	Moist Coastal Forest; Thorn and Palm veld	1.3	48% perennial pastures, sugarcane and timber. Gentle slopes for cropping
Kwanyuswa – Xb10	850 – 900 mm/a	346 – 850m amsl	Steep	Moist Coast Hinterland Ngongoni Veld	3.5a	61% perennial pastures, sugarcane and timber
North Coast – Ya14	900 - 1100 mm/a	3 – 661m amsl	Steep to moderate > 5%	Moist Coastal Forest; Thorn and Palm Veld	1.3	54% crop farming and steeper slopes for sugarcane and timber
Ozwatini – Yb13	900 – 1100 mm/a	283 – 1042m amsl	Steep	Moist Coast Hinterland Ngongoni Veld	3.5a	70% sugarcane and timber use.
Inanda – Yb14	900 - 1100 mm/a.	466 – 586m amsl	Moderate to steep	Moist Coast Hinterland Ngongoni Veld	3.5c	53% sugarcane and timber cultivation. Gentler slopes for cultivation
Bruyn's Hill – Yc21	900 - 1100 mm/a	748 – 1071m amsl	Gentle to moderate	Moist Midlands Mistbelt Grassland	5.2	74% of the area suitable for growing crops
Ndwedwe – Zb3	>1100 mm/a	409 – 661m amsl	Steep	Moist Coast Hinterland Ngongoni Veld	3.5a	63% sugarcane and timber crops

Key:
PPT = Precipitation
BRG = BioResource Group
Elev = Elevation

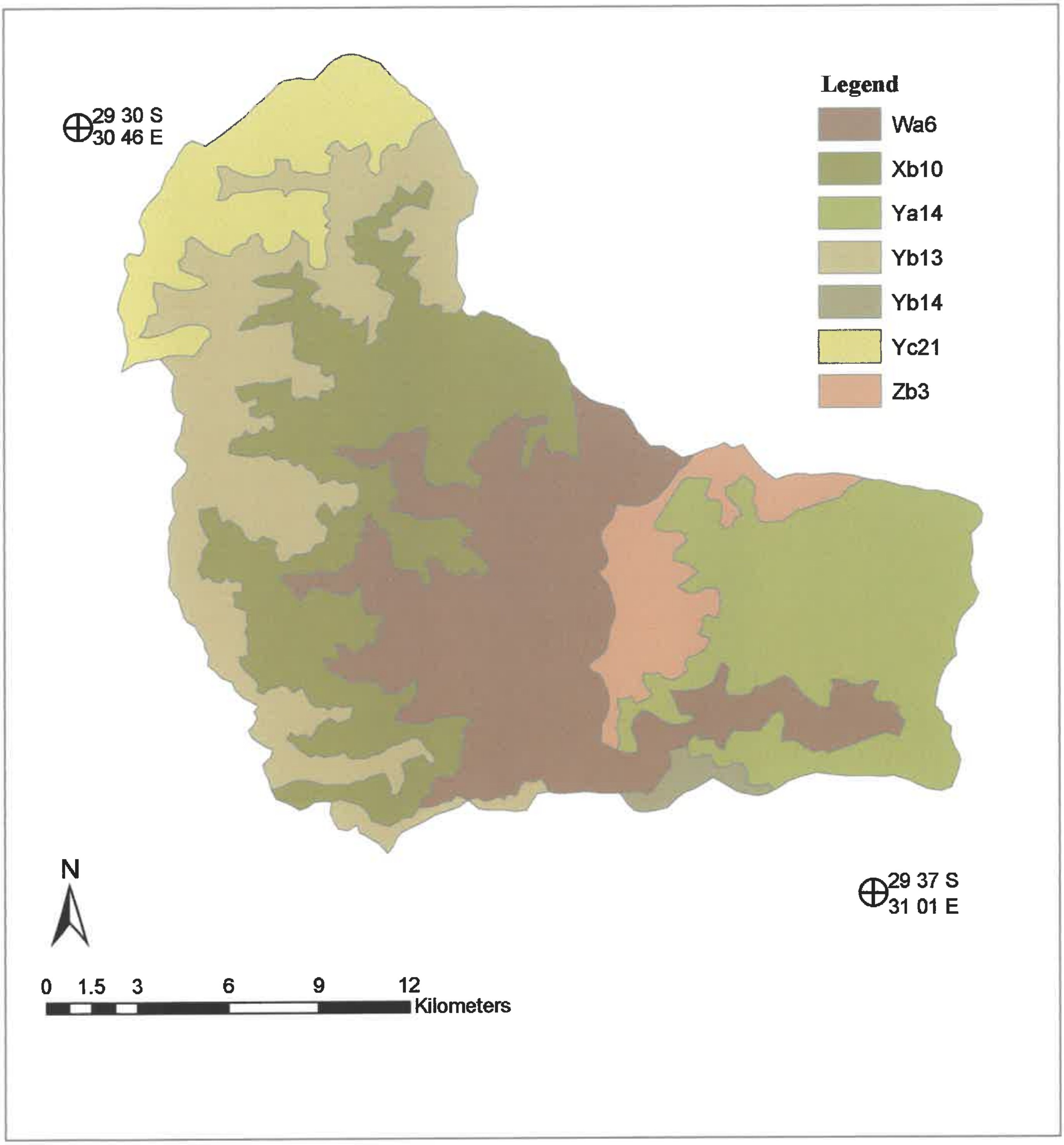


Figure 3.8 : Ecotope areas for the Hazelmere catchment (Camp, 1999)

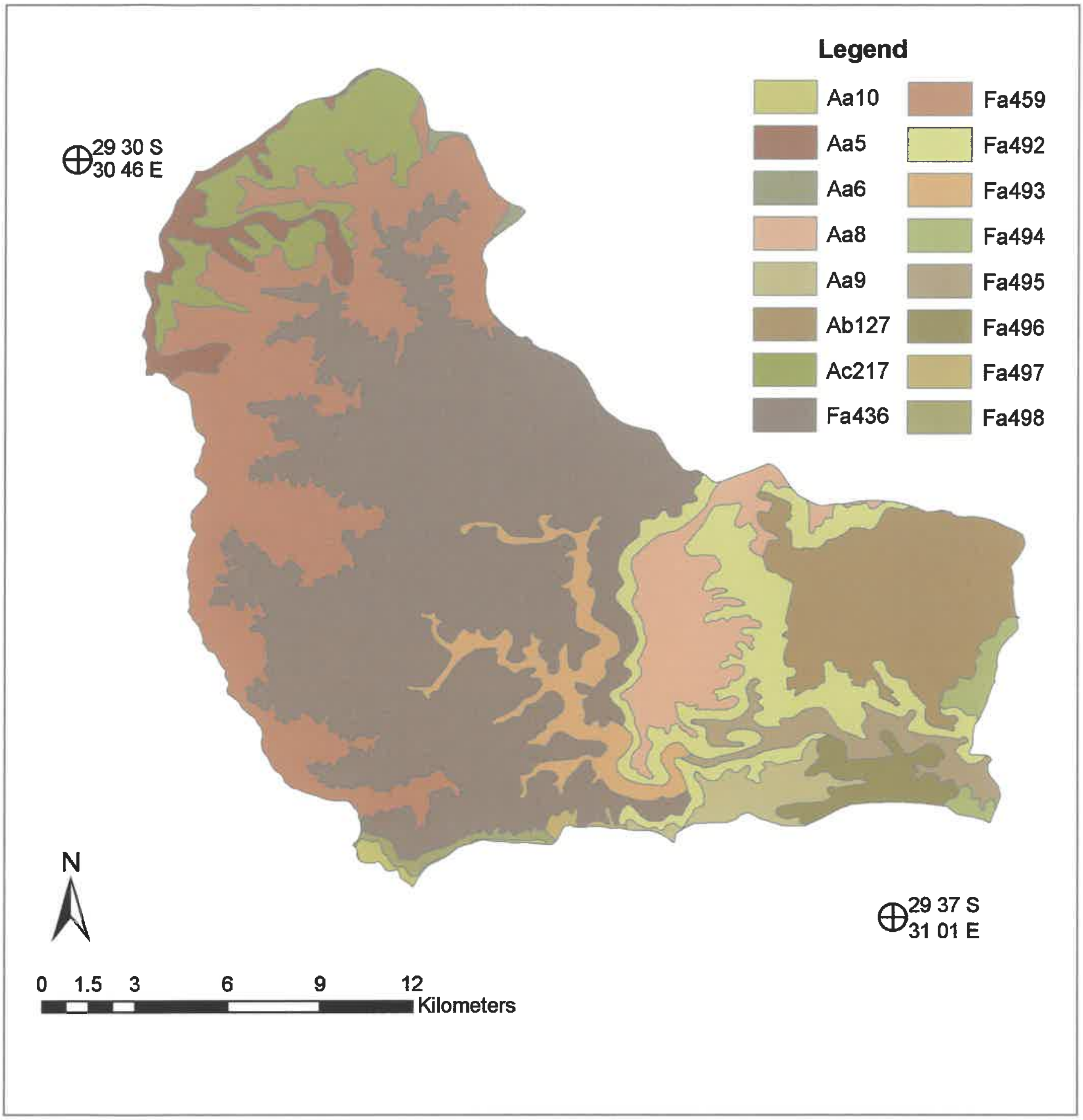


Figure 3.9: Land Type map of the Hazelmere catchment
(Source: Institute for Soil, Climate and Water)

3.9 ANTHROPOGENIC FACTORS

The Hazelmere catchment, lies within four magisterial districts (based on the 1996 census). These are:

i) The Ndwedwe district comprising, 90 percent of the catchment area;
ii) the Mapumulo district, 2 percent;
iii) the New Hanover district, 5 percent; and
iv) the Inanda district, 3 percent.

The total population of the catchment is difficult to measure accurately as the magisterial districts do not coincide with the boundary of the catchment (Currie, 1997; Russow and Garland, 2000). The population for the Ndwedwe district in 1996 was approximately 144 170, which was a decline from the 1991 census estimating to be 318 100 people in the same district (Currie, 1997; Russow and Garland, 2000; Mommen, 2001 Pers. Comm.). The 1996 figures show an average population density of 162 people per square kilometre. The value for the same area in 1985 was approximately 138 600 people (Currie, 1997) which is 156 people per square kilometre.

The people inhabiting the catchment are primarily from the Zulu tribal group, as the majority of this area was part of the former KwaZulu homeland area. The land owned by the tribal council has been divided into small parcels and distributed to the tribal community. It was observed that the homes have been traditionally built using natural resources; typically mud walls supported by branches of wattle and with thatch roofs, although many have since adopted the 'western' galvanised iron roofing. These dwellings are found in clusters, generally surrounded by cultivated fields from which extends a communal grazing area.

Infrastructure decreases with distance from the road networks and urban centres, yet schools, religious centres, police stations, shops and clinics are numerous throughout the catchment, although poorly equipped. A large hospital, servicing the area, is situated near Verulam. Although basic services are increasing steadily, electricity, water and telephones have not yet reached all dwellings.

Public telephones, water pumps and postal access are scattered throughout the catchment and streetlights line the main access routes of the major centres of Verulam and Ndwedwe. Lack of education and employment forces the people to live off the land cultivating staple foods, such as mealies, potatoes, cabbages, and beans. Cattle are kept as a symbol of wealth, often causing serious overgrazing problems in these traditional areas.

The population statistics on education from the 1996 census show that 24 percent of the people inhabiting the catchment area have no education while only 15 percent have grade 12 or higher (Statistics South Africa (StatsSA), 2001). Virtually half of the population is unemployed and of those that do have employment, 56 percent earn less than R 1000 per month (StatsSA, 2001). The majority of the men have become migrant workers since the lifting of influx control laws, leaving women, children and the elderly to tend the farms. This accounts for the slightly larger female to male ratio (1.2:1) in the catchment area (StatsSA, 2001). The small section in the north of the catchment that forms part of the New Hanover magisterial district (approximately 5 percent), and outside the former 'homeland', has well-established, commercial sugarcane and timber farms.

Important aspects relating to the environmental setting of the Hazelmere catchment have been reviewed in this chapter. In addition, the land use and anthropogenic factors have been discussed. This information serves as a vital background for the contextualization of the study on soil erosion within Hazelmere catchment. Before the results of the investigation are presented and discussed it is, however, necessary to first review the methods by which the information for the study was obtained. This forms the content of the next chapter.

CHAPTER 4

METHODOLOGY

The research aim is to characterize the soils of the Hazelmere catchment and identify those which are susceptible to soil erosion and hence act as major sediment sources within the Hazelmere catchment. This chapter describes the methods that have been used to assess soil erosion in spatial context within the Hazelmere catchment.

4.1 AERIAL PHOTOGHAPH INTERPRETATION

The erosion survey undertaken for this research consisted of mapping soil erosion occurring in the Hazelemere catchment. A Southern African Regional Commission for the Conservation and Utilization of Soils (SARCCUS) type map was generated indicating the degree of erosion according to the number and severity of visible erosion forms (SARCCUS, 1989). Although much information was obtained from aerial photographs, this was supplemented by ground thruthing and additional data collected in the field. The severity of erosion was rated using the SARCCUS (1981) classification method.

Aerial photographs are used extensively in the landscape approaches to terrain analysis and classification (Bergsma, 1974) in the following manner:

i) As the sources of information;

ii) as means to prepare prior to fieldwork;

iii) as means of planning transverses and stratified sampling whereby observation of the aerial photographs allows the selection of favourable traverse routes and sampling area prior to fieldwork; and

iv) as a means of interpolating information between transverse routes whereby observation of the aerial photographs allows the areas in between transverse lines to be easily mapped on the basis of recognition of characteristic landforms and photo tones.

Aerial photographs and associated with these, orthophoto maps, are a means of assessing erosion over a large geographical area rapidly and in a very economical way, and enabled the coverage of relatively inaccessible areas. Aerial photograph interpretation does not however provide the rates of soil loss but rather an indication of the areal extent of erosion forms.

According to Bergsma (1974) and Garland (1982), in order to extract information from aerial photographs several interpretation elements should be used at the same time. For the study of soil erosion the aerial photograph interpretation elements and some of their attributes are provided in Table 4.1.

Table 4.1: Elements and attributes used in air photo interpretation of the Hazelmere catchment.

ELEMENT	ATTRIBUTES
Greytone	Grade
Relief	Inclination
Land use	Density of surface cover
Vegetation	Density of surface cover

The presence of soil erosion features is reflected in the degrees of greytone in most cases. The other elements only indicate the conditions of erosion hazard, and therefore guide the interpreter to the places in the landscape where these can be expected to occur.

4.1.1 The Classification System

For the purpose of soil erosion mapping a classification system was required to avoid inconsistency in terms of the degree of generalisation. Classification is the process of arranging objects into groups based on their relationship with each other (Di Gregorio, 1996). According to Di Gregorio (1996) the structural criteria for an acceptable classification system include a hierarchical classification structure whereby classes start off broad to allow for the flexibility of subdivision into more detailed sub-classes, if so required to meet the needs of a variety of study objectives. Secondly a *priori* system indicates that the classes are defined prior to data collection, thus standardising classes independent of the area and creating a comprehensive system. Lastly, classes should be mutually exclusive and unambiguous, defined by specific diagnostic criteria which are easily measured and which do not vary with season.

SARCCUS (1981) has outlined a soil erosion classification system for mapping purposes within the Southern African Development Community (SADC). The basic method involves the delimitation and classification of erosional land units on a large scale (e.g. 1:30 000) aerial photographs. The soil erosion classification system identifies the degree and intensity of erosion within a given area of land or agro-ecological unit. The identification is done through aerial photograph interpretation which is supported by field checks. The classification system has been used widely in other studies of soil erosion in the southern African region and it has proved effective (see for example Chaleka *et al.*, 1985; Liggit, 1988; Garland and Broderick, 1992; Whitlow, 1992; Watson, 1996). Table 4.2 lists the classes of soil erosion used by SARCCUS (1981).

Table 4.2: Soil erosion classes used in soil erosion classification of the Hazelmere catchment (SARCCUS, 1981).

CLASS	DESCRIPTION
1:No apparent erosion	No visible signs of sheet, rill, gully, wind or other types of erosion are identifiable on aerial photographs. The standard of crop and veld management is high. Plant cover is adequate to provide effective protection against accelerated erosion.
2:Slight erosion	Erosion noticeable but not obvious. Denudation less than 10 percent. Plant cover is somewhat poor and is not effective in providing adequate protection of the soil. Plant pedestals and small alluvial deposits are often discernible in grazing lands where soil displacement and surface compaction by trampling have taken place.
3:Moderate erosion	Moderate erosion is very obvious on aerial photographs. Denudation is 10 to 25 percent. A considerable area of bare eroded soil is clearly discernible. Erosion hindering tillage operations.
4:Severe erosion	Characterised by large areas of land totally denuded by sheet erosion and or widespread dissection by rill, gully or other types of erosion. Denudation 25 to 50 percent.
5:Very severe erosion	Very severe erosion occurs when over 50 percent of the land is severely degraded by erosion mainly gully erosion and is rendered unsuitable for crops and livestock production, the so-called badland areas are included in this class.

4.2 DATA SOURCES

In this research assessment of erosion was achieved using the 1996 1:30 000 aerial photographs and 1989 1:10 000 orthophotos. A complete coverage of both aerial and orthophotos was available for the study area. The quality of the orthophotos was generally poor and the field tests showed that gullies could be identified in grassland areas but not in woodland or dense grass. On the other hand, the quality of aerial photographs was generally high, this then supplemented the poor quality of orthophotos. An additional advantage of aerial photography was the potential for comparing erosion patterns on photos taken at different dates, in this case 1989 and 1996, to determine rates of degradation. Although the primary concern of the study was to carry out a baseline survey of the present situation, the need to monitor changes in erosion cannot be neglected.

4.2.1 Data Extraction

The whole mapping procedure has been undertaken in five steps, namely: identification, digitising, projection, error assessment and ground truthing.

Identification was done using a Topcon mirror stereoscope fitted with threefold magnification lenses. Variations in tone, texture, shadow and pattern of the photo images were used to identify and delimit these surfaces following the method described by Whitlow (1986), Morgan (1995) and Watson (1996). As outlined by Watson (1996) very light, virtually white toned surfaces were designated actively eroding or eroded surfaces. Light, grey toned surfaces were designated susceptible to erosion and active gullies were traced on the basis of field evidence.

After identification, the document with traced features was positioned on the surface of the digitising tablet and the control points (minimum of four points per orthophoto) were recorded to which known real world coordinates were assigned. A Root Mean Square Error (RMSE) was calculated, indicating the difference between each measurement and its true value. The RMSE remained less than 0.508mm, which on the orthophoto with a scale 1:10 000 converted to an effective error of 5m on the ground. The control points are used to geographically position the features digitised, according to the distance from the known points. Digitising is essentially scale-dependent, the digital representation can never contain greater detail or achieve higher locational accuracy than the original document, furthermore, the degree of generalisation during input phase is under the subjective control of the operator (Martin, 1991). In this research generalisation depended on the degree of detail set by the SARCCUS (1981) classification system.

Projection refers to the representation of a spherical earth onto a flat medium. South Africa's standard projection has been recently changed to the World Geodetic System 1984 (WGS84) because of the advancements in the modern positioning technologies and the globalisation of techniques and data. The datum, derived from the location of its points, is referred to as the Hartebeeshoek 94 datum. However, the projection used in the study varies from this standard system. The former projection system had reference co-ordinates at Buffelsfontein based on the modified Clarke 1880 spheroid, with a Cape datum. The projection used was the Gauss projection or the Transverse Mercator projection. The Transverse Mercator projection, projects a sphere into a cylinder, tangential to the central meridian (Environmental Systems Research Institute (ESRI), 1998; 2001). This projection is conformal in that the scale of a map at any point on the map is the same in any direction. The projections adjacent to each other cover the large east-west extent of the country. The projections are centred on every odd meridian with two-degree zone widths. The LO31 is the projection used for KwaZulu–Natal as the meridian is centred at 31E, which runs through Durban.

Once the digitising was complete and the image projected, editing and cleaning of positional error was undertaken using the ESRI's PC ArcInfo 3.5.1 Geographic Information System (GIS) software. A relevant database was then created to assign erosion feature and class to each unit, thereby defining the digitised features. The coverage was then converted back to a shapefile (Arc View's format for sorting the location, shape, and attribute information of geographic feature) where editing of the associated attribute table to include all information on erosional land units could be undertaken. The next step was to group all similar erosion classes to develop an erosion severity map of the catchment. This task was performed in Arc View using the Spatial Analyst extension. The classes were grouped to allow three severity classes to be developed (figure 5.4). The grouping was arranged to allow for the identification of three severity classes of erosion listed subsequently as A1, A2 and A3. The value of three is associated with low erosion and the value of one with high erosion.

The final step in soil erosion mapping was ground truthing (or undertaking field checks), to ensure that the information on the map conforms to the features that exist on the ground. Visits were undertaken to ground truth the soil erosion features. Ground truthing was undertaken with a GPS marking points and noting the dominant soil erosion type at each point, to crosscheck the soil erosion on the ground with that on the map derived from aerial photographs.

4.2.2 Data Manipulation and Presentation

On completion of mapping, data manipulation is required to provide meaningful information for the project. As sets were in digital form, a simple grid based GIS computerised overlay technique of ArcView software package (version 3.1) was used to manipulate data.

Data on rainfall distribution, geology, slope steepness, and land use was collected, to investigate the erosion potential of Hazelmere catchment. As it has been stated in the previous chapter that there is only one weather station operating within the catchment, the rainfall data was very limited thus the data obtained from South African Atlas of Agrohydrology and Climatology was used to assess soil erosion. The one minute by one minute rainfall grid was cross tabulated with erosion map to obtain the spatial statistical variation of Hazelmere catchment. Slope steepness was developed from ten-metre interval contour data provided by Umgeni Water for the catchment area.

Data on land use was prepared by Read (2002). This data gives land use categories taken from 1996 aerial photographs, these were the recent land use categories of the whole study area.

Factors of erosion are important in determining the severity of erosion. Strong linkages exist between factors (Liggit, 1988). As noted by Liggit (1988) the advantages of assessing erosion potential are that:

i) It can be used to identify high risk areas before the land has been severely degraded by erosion; and
ii) erosion potential can be determined using easily obtainable information, unlike erosion assessment which requires specialized data collection.

Erosion potential is the measure of the susceptibility of an area to erosion. With erosion potential assessment, it can be deduced that the identification of areas at high risk from erosion will enable future land use to be modified.

A modified simple system for rating erosion risk was devised after Elwell and Stocking (1973) and Morgan (1995). The factors of erosion were also categorized into different classes (Table 4.3). These values are then used to categorize areas of low, moderate and high erosion risk. Each factor is rated from high to low in respect of slope, land use, and geology (Table 4.3).

Table 4.3: Scoring system for the soil erosion factors.

FACTOR	RANGE	CATEGORY/ CLASS
Slope	21% – 100%	High
	11% – 20%	Medium
	0% – 10%	Low
Land use	Grazing and Cultivation	High
	Bush	Medium
	Sugarcane and Forestry	Low
Geology	Natal Group and Namaqua Natal Mobile	High
	Dwyka Formation	Medium
	Pietermaritzburg. Formation	Low

Soil erosion factors as outlined above can reflect the risk of soil erosion. The process of overlay was carried out for erosion factors and erosion severity map. The exercise thus involves the computation of four separate factors, which are then combined to give an erosion risk map.

4.3 TRIANGULAR IRREGULAR NETWORK AND DIGITAL ELEVATION MODEL

A Triangular Irregular Network (TIN) and Digital Elevation Model (DEM) have been used to assess the relationship between slope and erosion. TIN is the surface representation derived by creating a surface or network from point data by joining the points (with height values) to form a set of non-overlaping triangles. A height value is recorded for each triangle node. The heights between each node can thereby be interpolated. Contours at 10m intervals were obtained in shapefile format from Umgeni Water for the catchment area. With the ArcView's software extension (3D analyst) loaded, a TIN could be interpolated from the contour data. The TIN is then converted to a grid to form a Digital Elevation Model in order for spatial analysis to be undertaken on the data. The DEM is the data model used to represent a topographic surface based on a grid with a height value for each cell. The DEM is generated in ArcView from the TIN by converting to a grid using the z-value for referencing each cell. TINs and DEMs are regarded as significant visual aids in carrying out management functions, by creating a better appreciation of scale while facilitating the concepts of plane and space relationship. The DEM was then used to create images of percentage slope and aspect which are important for the analysis of soil erosion.

4.4 FIELD WORK PROCEDURE

The purpose of conducting field work was to collect soil samples, which would determine the physical and chemical properties of the soil. Fifty two soil samples were collected throughout the catchment area using the stratified sampling technique, presented in Table 4.4 and Figure 4.1. A stratified sample was obtained by selecting the sampling sites from different land types and then selecting a sample from different land uses within a land type. Within a land use, sample sites were then selected on the basis of accessibility. The percentage area of each land type was calculated and the relevant proportion of samples was distributed accordingly. This study was concurrently undertaken with a masters thesis which focused on land use effects on sedimentation (Read, 2002). To ensure that the soil sample sites were representative, soil samples were collected on different land uses within each land type. The division of sampling sites according to different land uses was done to determine the effect of regional land use on soil erosion (Read, 2002).

Restrictions on the placement of sample sites were due to the inaccessibility of certain areas of the catchment. Within the catchment of Hazelmere there are 16 land type units Figure 4.1; out of these only eleven were used. The other five were left out because of the small area that they cover, but field checks were conducted to see if there were any evident sources of sediments.

At the fifty two selected sites, soil samples were taken with a standard 75- mm bore auger. Samples were extracted from the surface and the bottom of the soil profile, or from a depth of one meter, whichever was reached first. Land use type was recorded at the sample site. The structure of the soil was also recorded. The samples were sent to the soil laboratory at the Cedara Agricultural College where analysis of the physical and chemical properties was undertaken. The analysis of the soil included tests for organic carbon percentage, pH, Electronic Conductivity (EC), Cation Exchange Capacity (CEC), Exchangeable Sodium Potential (ESP) and textural (particle size) analysis.

Table 4.4: Percentage area of land type units, (shown in Figure 4.1) in the Hazelmere catchment and the Number of Study Sites Selected for each unit (Note that areas with less than one percent were not sampled).

LAND TYPE UNIT	LAND TYPE NUMBER	NUMBER OF STUDY SITES	PERCENTAGE AREA COVERED
Aa10	1	0	0.3
Aa5	2	2	2.5
Aa6	3	0	0.2
Aa8	4	3	5.2
Aa9	5	1	1.7
Ab127	6	5	9.2
Ab217	7	3	5.5
Fa436	8	18	38.0
Fa459	9	9	18.7
Fa492	10	4	8.1
Fa493	11	4	3.8
Fa494	12	0	0.8
Fa495	13	2	2.2
Fa496	14	1	1.8
Fa497	15	0	0.2
Fa498	16	0	0.5

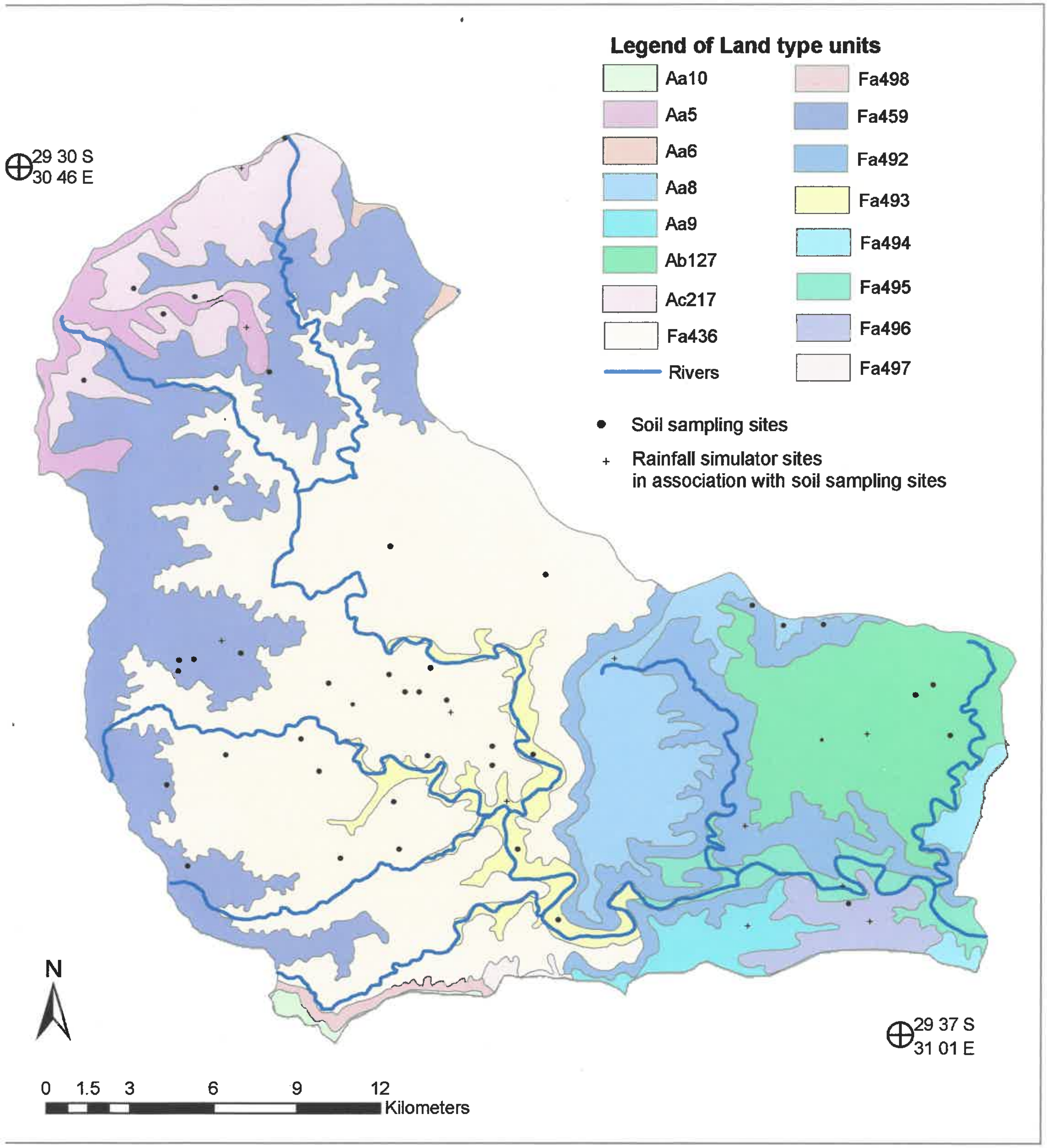


Figure 4.1: Map showing location of sample collection sites,
Rainfall simulator sites, the land type units and an overlay of land use for the Hazelmere catchment.

4.4.1 Use of the Eijkelkamp Rainfall Simulator

A rainfall simulator is a research tool designed to apply water in the form similar to natural rainstorms, a useful tool for many types of soil erosion studies (Meyer, 1994). However, rainstorm characteristics must be simulated properly, runoff data analyzed carefully and results interpreted with caution to obtain reliable information for the conditions under which the simulated rainstorms are applied. The advantages with rainfall simulator research are that it is more rapid, more efficient, easily controlled, and more adaptable than the natural rainfall research (Lal, 1994).

The Eijkelkamp type rainfall simulator (Figure 4.2) has been used to determine the erodibility of the Hazelmere catchment soils. With the rainfall simulator one can measure the runoff and soil loss generated by a standardized rainshower on a plot with a standard slope and surface area. Rainfall simulator tests were conducted on 11 land types where the data for runoff, soil loss and sediment concentration was known. Within each land type six repetitions were conducted on different gradients (gently and steep), three repetitions for each slope were then averaged to give one value. The summary of the procedure followed is outlined below.

A plot with a slope of 20 percent is prepared with the aid of a spade. During the shaping of the slope, smearing may occur. To open up the natural soil pores below the smeared surface, a thin layer of soil material is removed with a point of a knife or spatula. The loose material produced by this operation is carefully removed with a soft brush. The slope length should be at least 0.4m, to accommodate both the test plot and the gutter. At the bottom of the slope a small trench is made, in which a sample receiver for the collection of runoff and soil loss is placed. The support is placed on the plot. Adjoining to the test plot an auxiliary plot is made, which is used for filling the sprinkler with water. Then the aeration pipe is closed with a cock and the sprinkler is placed upside down on the support, to fill it with water. To check if the sprinkler has a required discharge, a watch and a measuring tape is necessary. During simulation the sprinkling head is moved sideways in all directions, to make sure that the drops are equally and randomly distributed over the test plot. After three minutes the simulation is stopped, sediment left behind in the gutter is added to the contents of the sample receiver with the aid of wiper.

As stated by Kamphorst (1987), measuring soil loss and runoff from simulated rainfall is the most promising method to obtain a quantitative rating of the erodibility of different soils. However, as stated by Meyer (1994), simulated rainfall is not a magic method for satisfying all erosion and hydrologic research needs. There are also limitations to the types of research that can be conducted with rainfall simulators, studies that need a wide variety of rainfall intensities or impact energies may not be possible with certain rainfall simulators.

Figure 4.2: The Eijkelkamp type rainfall simulator

Furthermore, this method has the advantage that the recorded runoff and soil loss reflect the integrated effect of all the processes occurring during sheet erosion. These processes include:

i) Splash;
ii) swelling;
iii) slaking;
iv) crusting and sealing;

v) infiltration and runoff;
vi) particle detachment; and
vii) sediment transport.

The detailed procedure and the method followed in using the rainfall simulator is as described and discussed by Kamphorst (1987).

4.5 LABORATORY ANALYSIS

The susceptibility of a particular geomorphic environment to soil erosion, in particular accelerated soil erosion, is partly a function of the erodibility of the material, contained within that environment (Moodley, 1997; Whaley, 1981; Morgan, 1980; Zachar, 1982). When the soil is obstructed in any way (for example, raindrop impact) the soil mass may break up into aggregates. The percentage disaggregation for soil is characterized by:

i) The particle size distribution of the soil;
ii) cation Exchange Capacity (CEC);
iii) exchangeable Sodium Percentage (ESP);
iv) sodium Adsorption Ratio (SAR);
v) organic Carbon (OC); and
vi) soil Acidity (pH).

Each of these characteristics will be reviewed briefly.

4.5.1 Particle Size Analysis

This analysis determines (by weight) the distribution of mineral particles < 2 mm according to size classes. Once the limits of the various particle size classes have been defined it is a matter of determining the statistical distribution of the particles in a sample for these classes (Baize, 1993). Particle size analysis is a laboratory operation which involves complete dissociation of the soil material into its individual particles and the total destruction of aggregates and broken aggregate (Baize, 1993). Texture is also used for the overall assessment of particle size composition in the field. Soil texture is inherently the product of pedogenesis, which is influenced by factors of soil formation, that have been discussed in chapter one and two. Particle size analysis was undertaken to establish the relationship between soil erosion and particle size distribution. The Pipette method for Clay, Silt and Sand was used during this study.

The important property with regard to the erodibility is particle size distribution or texture. Particle size provides an indication of the distribution of the relative amount of sand, silt, and clay and also allows for the classification of soil according to its particle size composition. Particle size composition (as has been discussed in detail in chapter two) is not the only variable strongly correlated with other analytical data, but according to Baize (1993) it directly and very closely determines how a horizon behaves and functions, it is further argued that it is impossible to characterize soil without knowing its textural composition. For particle size analysis the clay fraction is by far the most important because it:

i) Is associated with humified organic matter;
ii) provides essential cohesion in aggregates;
iii) fixes cations on its exchange sites;
iv) retains water; and
v) under certain conditions, migrates.

The problems associated with clays are:

i) It has poor drainage if there is excess water; and
ii) it is easily puddled by animals or machinery when wet.

The mean, median, skewness and sorting coefficients describing the soil condition for soil samples is calculated using the procedure discussed in Briggs (1977). The mean particle size is calculated by averaging the 75th, 50th, and 25th percentiles as follows:

$$\text{Mean} = \frac{\Phi\,75 + \Phi\,50 + \Phi\,25}{3}$$

The median particle size is the size fraction (phi units) corresponding to the 50^{th} percentile of the cumulative frequency graph.

The sorting index is a measure of dispersion or scatter and is an expression of the standard deviation of the particle size distribution. Sorting is thus related to the ability of the transporting process to segregate its load according to size. The equation of sorting is as follows:

$$\text{Sorting} = \frac{\Phi\,84 - \Phi\,16}{2}$$

Skewness may be regarded as an indication of the non-normality of the distribution, for example a positive skewness implies that a greater amount of fine sediment is present than would be expected in a normal distribution and the opposite is true. The formula for calculating skewness is as follows:

$$\text{Skewness} = \frac{\Phi\,84 - \Phi\,50}{\Phi\,84 - \Phi\,16} - \frac{\Phi\,50 - \Phi\,10}{\Phi\,90 - \Phi\,10}$$

4.5.2 Organic Carbon

Organic content of the soil is that material in a soil which is directly derived from plants and animals, and supports most important micro-fauna and micro-flora in the soil. Through its breakdown and interaction with other soil constituents it becomes responsible for most of the physical and chemical properties of the soil, it then becomes a contributing factor to the dispersivity and aggregate stability of soil. Moodley (1997) supports this statement as he states that there is a positive correlation between organic content percentage and aggregate stability of the soil. It is further argued (Moodley, 1997), that organic matter is an important factor controlling soil fertility due to its ability to release nitrogen, phosphorous and sulphur upon oxidation.

Organic carbon is the term used for carbon in the soil. It is expressed as percentage. The organic matter content of the soil was determined using the standard Walkley-Black method by Cedara College of Agriculture Soil Science Department.

4.5.3 Chemical Analysis

An understanding of soil chemical properties is central to the understanding of soil erodibility. The Cation Exchange Capacity (CEC) is the capacity of the soil to hold and exchange cations. It is the major controlling agent of structural stability of the soil besides regulating the nutrient availability for plant growth (Moodley, 1997). For example a high CEC is an indication of high plant nutrient storage. In addition CEC assessment gives an indication of the levels of the exchangeable cations such as Calcium (Ca), Potassium (K), Sodium (Na), Hydrogen (H), and Magnesium (Mg). Sodium determines the salinity of the soil, in leached soils sodium is almost zero, but if soils are sodic it may be up to 50% of the CEC (Rowell, 1994). Hazelton and Murphy (1992), argue that sandy soils and acid soils that have been strongly leached often have very low levels of exchangeable cations.

Chemical analysis of the soil was carried out by Cedara College of Agriculture Soil Science Department. The laboratory analysis was conducted to determine the Cation Exchange Capacity (CEC), Electrical Conductivity (EC), pH, Sodium Adsorption Ratio (SAR), Exchangeable Sodium Potential (ESP).

i) The CEC of the soil is the total electrostatic charge on a mineral, particularly a clay mineral, which is balanced by exchangeable cations of Al, Ca, Mg, K, Na, and H on the crystal surface;

ii) $$ESP = \frac{Na^+}{CEC} * 100$$

iii) $$SAR = \frac{Na^+}{\sqrt{Mg^{++} + Ca^{++} / 2}}$$

Stocking (1976) and Beckedahl (1998), stress that the higher the values of Exchangeable Sodium Potential (ESP) and Sodium Absorption Ratio (SAR), the greater the availability of sodium to cause dispersion and hence the more susceptible the soil is to erosion. The values of SAR and ESP are used as the index of sodicity. Sodicity is the level of exchangeable sodium cations in the soil, it relates to likely dispersion on wetting and shrink / swell properties (Rowel, 1994). Some of the problems associated with sodic soils are:

i) Very severe surface crusting;
ii) very low infiltration and hydraulic conductivity;
iii) very hard, dense subsoils;
iv) high susceptibility to severe gully erosion; and
v) high susceptibility to tunnel erosion.

Many researchers for example Stocking (1976), Selby (1993) and Beckedahl (1998) have shown that sodium exerts a negative influence on aggregate stability by its effect on the clay dispersion process. Dispersion is a process which separates clay particles by breaking the bonds between them (Selby, 1993). Beckedahl (1998) argues that this relationship has resulted in the assumption that the converse must also hold, that soils with low ESP and SAR values have low susceptibility to erosion. Beckedahl (1998) further argues that, when dispersion of the clay fraction occurs within the soil, the rate of that dispersion depends on the ionic content of the soil. According to Jones (1981) and Rowel (1994), soil is usually classified as dispersive when ESP exceeds 15% of the total exchange capacity. Beckedahl (1998) has however shown that this is not necessarily the case, thus corroborating the findings of Bryan and Yair (1982).

This chapter has outlined methods used in data collection as well as the techniques employed in data preparations, processing and analysis both in the laboratory and during field surveys. Appropriate literature that guided the study methodologies has also been presented. Results based on findings of the above mentioned methodologies for the Hazelmere catchment are outlined in the following Chapter.

CHAPTER 5

RESULTS AND DISCUSION

5.1 SOIL CHEMICAL CHARACTERISTICS

As previously indicated, 52 sample sites were obtained throughout the catchment (Table 4.4 and Figure 4.1).

Appendix A and B show the results of chemical analysis from the samples collected in the Hazelmere catchment area. The potassium (K) values of the soils are relatively low and therefore render the soils susceptible to wash processes and become susceptible to surface erosion especially when the vegetation has been removed. This is further supported by Khandlela (2001), who found that all soil samples collected in the Indwedwe area (village within the Hazelmere catchment) have low values of potassium.

Sodicity is determined using ESP and SAR which are described above and in chapter four. When soil chemistry of the Hazelmere catchment is examined as shown in Appendix B the following becomes evident: with the exception of few samples, all soil samples are potentially dispersive when viewed against the criterion for Exchangeable Sodium Potential of greater than six meq/100g used in the literature (Beckedahl, 1998). The ESP values range from 4.8 to 82.7, which is very high for ESP, and this means that these soils are highly dispersive and highly susceptible to severe gully erosion.

Results show that, in general soils have high values of Exchangeable Sodium Potential (ESP) and Sodium Absorption Ratio (SAR). As already indicated, the work of Heede (1971) and Beckedahl (1998) suggest that those soils are prone to erosion. The chemical properties of soil reveal that soils in the Hazelmere catchment are sodic and dispersive. By contrast, when analyzing the Heede's (1971) measure of SAR greater than 15, none of the samples at Hazelmere catchment meet the criterion. The criterion for SAR clearly is of little consequence within Hazelmere catchment as there is severe gully erosion. This is in relation to what Beckedahl (1998) found, in his study of subsurface erosion in Kutsolo and Inxu Drift region in Eastern Cape, South Africa. The criterion for SAR was not met but this had no significant consequence as gully sidewall pipes clearly exist.

Salinity relates to the presence of water-soluble salts, mainly of sodium, calcium and magnesium, these can severely affect plant growth, land use and increase soil erosion. Salinity levels are usually determined by measuring the electrical conductivity (EC) of the soil. When soil chemistry was examined for Hazelmere catchment as shown in Appendix A and B, the following becomes evident: there are high values of soluble salts, taking for example land type Fa459, the first three samples from this land type have extremely high values of soluble salts, as well as the high values of calcium. These samples fall under clay texture class and have the EC of 5.3 to 5.9mS/m, which is described as saline. These values make this soil highly erodible as the vegetation is affected by the salinity of the soil. All soils in Appendix A and B are potentially saline when viewed against the criterion of a saline rating outlined by Hazlton and Murphy (1992), that saline soils are defined as those having EC value greater than 4 mS/m.

The pH is a measure of the acidity or alkalinity of soil. It characterizes the chemical environment of the soil and is used to guide suitability of soils for various land uses. The pH can also be used as an indicator for chemical processes which occur in the soil. Throughout the Hazelmere catchment the soil pH ranges from moderately acid to strongly acid thus it affects fertility and leaching of the soil (Appendix B).

5.1.1 Organic Content of the Hazelmere Soils

The soils within the catchment have low organic carbon percentages. Soils with high organic carbon are taken from the buried A horizon. For the soil from the A horizon, organic content of these soils were very low, with percentages less than 1 and some even less than 0.5. When the soil sample collected from the roadside gully wall in land type Fa495 is considered, this shows a low organic carbon content of less than 0.5%. When comparing this sample with the sample taken from the A horizon of the same Land Type (Fa459), the other sample has organic content of 3.0% which is much higher than the sample taken from the gully wall. This then shows that once the vegetation is removed or where soil has been affected by erosion, the organic content of that soil decreases and thus aggregate stability is affected. This further affects the infiltration rate of the soil because if there is less organic content the rate of infiltration is low and thus leading to wash processes dominating.

There is a corresponding relationship between particle size distribution and organic carbon, (Appendix B and C) as is evident in the samples with high percentages of sand, most of these samples have low organic content for example samples the first six samples, these samples are dominated by sand and have low organic carbon percentages.

As supported by Stocking (1995), sand dominated soils have low aggregate stability, for the soils at Hazelmere catchment this is further exacerbated by the low contents of organic carbon. On clay soils there are also low values of organic matter (see Appendix D), as stated by Moodley, (1997) that many investigators have recorded a positive correlation between organic carbon percentage and aggregate stability, this was not the case with the soils at Hazelmere catchment. The organic content of the soils is very low, as a result of this the permeability of the soil could be low, thus resulting in low infiltration rates resulting in strong wash processes. This coupled with the high dispersivity of the soils due to the sodic nature of the soils as suggested by the chemical results of the soil, leads to the inference that it is likely that these soils are prone to erosion.

5.2 RESULTS OF PARTICLE SIZE ANALYSIS

The role of sand and silt has to be taken into consideration when a sample contains less than 35% clay. According to Baize (1993), the size of these components directly determines the dimensional characteristics of the pore system which is directly related to the behavior of water in soils. The soils in the Hazelmere catchment are dominated by sand, as shown in Figure 5.1, but have an average of 25% clay and 12% silt.

For the soils collected in the field the clay percentages range from a low of 4% to the highest of 65%. The silt percentages range from 4% to 21%. The sand percentages range from 25% to 91% (see Appendix C). The dominant texture classes are sandy clay and sand. The high sand fractions can be attributed to the weathered sandstone and the topography of the area. This point is supported by Brink (1981) who states that the soils developed on the sandstones of Natal Group are generally lithosols derived by the weathering of the sandstone, and are thus shallow and sandy. Given the prevailing topographic conditions which are very conducive to erosion, soils are characteristically young and strongly reflect the dominance of parent material as a soil forming factor.

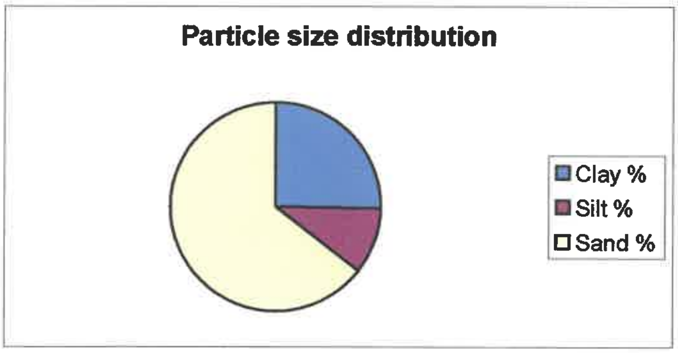


Figure 5.1: The overall (average of all samples) particle size distribution of Hazelmere catchment soils.

However, some soils also showed to percentages of clay, (for example samples from Fa459 and Aa8). As mentioned above, clay provides cohesion in aggregates, but with respect to the soils of Hazelmere catchment this statement is disputed due to the fact that several soils of this area are highly dispersive, due to the sodic nature of the soils already discussed (see for example samples from Aa8 Appendix B).

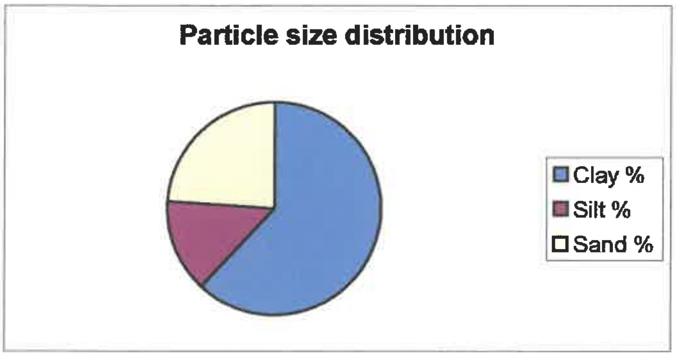


Figure 5.2: Particle size distribution of sample with high fractions of clay such as sample from Aa8.

The other studies carried out by Zachar (1982), Toy (1977), and Morgan (1995), show that soils with high sand content are susceptible to erosion. Sandy soils are prone to erosion due to mobility of sand and poor aggregate stability, whereas the clay rich soils are erodible due to dispersion.

The grain size distribution of the soil is represented as a cumulative percentage in Tables 5.1 and 5.2. The particle size classes are discussed in terms of the phi scale, defined as: $-\log_2 d$, where d is the diameter of the particle in millimeters. It has to be noted that because the negative logarithm is used, the coarsest particles have the lowest phi values. The data presented in Table 5.1 and 5.2 are the averages of soil samples taken from different land use types within each land type (as described in methodology).

The median values which are employed as the approximation of sediment size of the descriptive analysis taken from the cumulative frequency curve range between –1.4 and 1.5 (phi values), (Table 5.1 and 5.2) that implies that the soils at Hazelmere catchment are sand dominated which also implies that they could be easily transportable by wash processes. The mean which also calculates the average grain size, has the ranges between –1.33 and 1.7 (phi values) which is very close to the median.

The sorting indices describing the soils at Hazelmere catchment (obtained as outlined in chapter four) range from 0.65 to 2.3, (Table 5.1 and 5.2) implying that these soils are poorly sorted in their natural state. Sorting is related to the ability of the transporting agent to segregate its load according to size. According to Briggs (1977), very fine or very coarse deposits tend to have a high standard deviation which means that they are poorly sorted.

The data on skewness index show that it is positively skewed, the positive skewness represents a fine tail to the distribution. Thus, the positively skewed size distribution is one in which greater amounts of fine material occur than would be expected in a normal distribution (Briggs, 1977). The data on skewness range from –0.45 to 1.60 which falls between positively skewed and very positively skewed (Table 5.1 and 5.2).

Table 5.1: Cumulative phi percentages of Hazelmere catchment soil.

-1 Φ (%)	0 Φ (%)	1 Φ (%)	2 Φ (%)	3 Φ (%)	4 Φ (%)	<5 Φ (%)
8.64	29.44	61.28	76.93	84.55	92.82	98.75
66.55	80.08	87.29	90.07	90.39	90.54	90.54
0.98	14	49.81	80.7	91	96.59	99.35
13.1	35.84	56.33	74.74	85.15	94.55	98.81
1.43	7.07	24.83	69.8	85.94	94.73	99.1
8.15	44.89	90.11	95.59	95.82	95.93	95.95
11.13	34.81	58.58	78.44	90.87	96.96	98.82
51	66.59	78.19	89.63	95.74	95.84	96.19
18.04	42.79	66.78	84.62	91.98	98.61	100
11.84	29.84	51.13	83.12	93.84	98.46	98.97
17.46	32.1	59.59	86.55	93.69	97.23	98.57
4.16	15.36	39.85	70.89	85.26	88.6	91.92
18.63	39.6	66.81	90.56	96.31	100	100
32.87	57.04	81.73	94.55	95.74	100	100
15.36	43.64	67.92	85.15	91.49	93.27	94.41
18.04	30.37	46.39	76.69	88.83	89.46	92.8
32.44	58.21	75.88	86.72	91.76	97.58	99.55
8.89	20.98	50.16	76.54	86.36	90.29	93.89
37.27	58.87	75.13	86.51	91.51	94.32	97.07
33.21	49.28	66.1	79.85	88.32	99	100
16.91	24.65	39.17	86.34	93.08	96.4	99.21
41.2	59.93	77.97	90.71	95.05	100	100
18.77	43.49	67.35	85.07	91.94	99.26	100
0.68	15.09	46.69	79.32	91.47	95.01	96.68
59.81	75.3	86.7	94.33	96.73	100	100
32.62	51.57	71.62	86.99	92.93	100	100
44.77	62.43	80.83	92.05	95.86	96.7	97.06
51.2	68.94	83.46	92.36	95.81	98.53	99.18
75.56	87.14	93.57	96.9	98.13	100	100

Table 5.2: Descriptive indices calculated from the cumulative frequency distribution results.

Mean Φ	Median Φ	Sorting Φ	Skewness Φ	Description of Sorting	Description of skewness
0.6	0.8	2.15	0.22	Very poorly sorted	Positively skewed
-1.2	-1	0.8	1	Poorly sorted	Very positively skewed
0.9	0.9	0.95	0.36	Moderately sorted	Very positively skewed
0.4	0.6	1.8	0.125	Poorly sorted	Positively skewed
1.7	1.5	1.8	0.52	Poorly sorted	Very positively skewed
0.06	0.2	0.7	-0.228	Moderately sorted	Negatively skewed
0.7	0.6	1.6	1.6	Poorly sorted	Very positively skewed
-0.9	-1	1.9	0.8	Poorly sorted	Very positively skewed
0.36	0.3	1.55	0.15	Poorly sorted	Positively skewed
0.93	1.3	1.4	-0.34	Poorly sorted	Negatively skewed
0.63	0.7	1.55	-0.14	Poorly sorted	Negatively skewed
1.4	1.4	1.4	0.13	Poorly sorted	Positively skewed
0.33	0.4	2.3	0	Very poorly sorted	Symmetrical
-0.3	-0.3	1.35	-0.18	Poorly sorted	Negatively skewed
0.4	0.4	1.5	0.1	Poorly sorted	Positively skewed
0.9	1.1	2	-0.04	Poorly sorted	Negatively skewed
-0.26	-0.4	1.7	0.35	Poorly sorted	Very positively skewed
0.73	1	1.55	0.197	Poorly sorted	Positively skewed
-0.13	-0.5	1.65	0.44	Poorly sorted	Very positively skewed
0.21	0.1	2.025	0.292	Very poorly sorted	Positively skewed
0.7	1.3	1.65	-0.451	Poorly sorted	Negatively skewed
-0.38	-0.6	1.5	0.348	Poorly sorted	Very positively skewed
0.42	0.4	1.53	0.182	Poorly sorted	Positively skewed
1.08	1.1	1.15	0.145	Poorly sorted	Positively skewed
-1.1	-1.4	1.4	0.63	Poorly sorted	Very positively skewed
0.03	0	1.6	0.17	Poorly sorted	Positively skewed
-0.58	-0.7	1.35	0.38	Poorly sorted	Positively skewed
-0.616	-1	1	0.95	Poorly sorted	Very positively skewed
-1.33	-1.4	0.65	0.56	Moderately well Sorted	Very positively skewed

Correlation analysis was used to establish whether there is association between particle size and organic content of the soil. A correlation coefficient is a statistic which describes the degree of association between two sets of values, the coefficient is subject to a test for significance like any other technique in inferential statistics (Hammond and McCullagh, 1978; Bryman and Cramer, 1990; 1999). Table 5.3 presents the Pearson correlation coefficients between particle size and organic content. Clay and silt have positive coefficients of 0.27 and 0.09 respectively, whereas sand has a negative coefficient of 0.25. All three coefficients were not significant even at the 0.05 level.

Table 5.3: Correlation coefficients between organic content and particle size distribution.

Particle Size	Pearson Correlation	Critical value
Clay	0.265	0.164
Silt	0.93	0.633
Sand	-0.250	0.192

5.3 SOIL ERODIBILITY

The ability of soil to resist erosion depends upon the physical and chemical properties which determine it detachability and transportability (Elwell and Stocking, 1982) as reviewed in chapter two. Soil erodibility is thus the susceptibility of a soil to detachment and transportation of soil particles by an erosive agent. Theoretical values for soil erodibility (represented by the K-value of Wischmeier *et al.,* (1971)), were calculated using the nomograph, as it was not possible to determine the K- values empirically in the absence of sufficient standardized runoff plots within the Hazelmere catchment. The K-value represents an approximate index of the susceptibility of a soil to wash erosion, as it provides a measure of commonality and thereby facilitates a comparison of the different soils (Beckedahl, 1998).

As already suggested by the textural analysis, the soils in the Hazelmere catchment generally have a high susceptibility to erosion. The values for erodibility (K) (determined as outlined in chapter four) are moderately high, ranging from 0.06 to 0.65 (Appendix D). Using land type Fa495 (Appendix D), this has the highest value at 0.65 and reflects the sandy texture and low organic carbon content of <0.5%. Using a similar reasoning, the low value of erodibility in land type Fa459 (Appendix D), may be explained by its high clay content. Bearing in mind the earlier discussion concerning the dispersivity of the

Hazelmere catchment clays, this value of erodibility is likely to be a misrepresentation, reflecting one of the shortcomings of using the nomograph to determine K-values.

The K-value of the soils at Hazelmere catchment has an average of 0.39. This suggests that these soils are highly susceptible to conventional forms of wash erosion as well as the dispersion already alluded to. The relationship between soil erodibility and particle size distribution is further discussed in the section on statistical analysis (section 5.5).

5.4 RAINFALL SIMULATION RESULTS

A rainfall simulator (the Eijkelkamp rainfall simulator) is well suited for field studies that compare different soils under standardized precipitation (Kamphorst, 1987). It must however be emphasized that the resulting data give relative values rather than providing absolute rates of erosion. In order to obtain realistic estimates of annual erosion rates, results from long-term studies under natural rainfall are required.

Table 5.4 presents the results obtained for different soils in the Hazelmere catchment following the standard procedure described in Chapter 4. Rainfall simulator tests were conducted on 11 land types as discussed in the previous chapter.

Within each land type, six repetitions were conducted on different gradients (gentle and steep), three repetitions for each slope and the averages of these readings are presented in Table 5.4. The data for runoff, soil loss and sediment concentration, which are averages of six repetitions (done following the standard procedure.) show that the soil loss recorded on these soils ranges between 0.4 (land type Aa8) and 47.2 g per m^2 for land type Fa495, and that the runoff and sediment concentration vary widely between different soils. These results support the notion that some land types are significantly more erosion prone than others. It is also important to note that the highest soil loss occurred on a soil with 53% clay.

Table 5.4: Average runoff, soil loss and sediment concentration measured with the standard procedure on different soils in Hazelmere catchment.

Land Type	Soil	Clay (%)	Organic Matter (%)	Run-off (ml)	Soil Loss (g/m^2)*	Sediment Conc. (g/l)*
Fa436	Sandy Loam	8	<0.5	100	14.2	142
Aa5	Loamy Sand	12	<0.5	270	1.8	6.6
Aa8	Sandy Loam	14	<0.5	110	0.4	3.6
Fa459	Sandy Clay Loamy	29	<0.5	280	41.2	147
Ab127	Sandy	5	<0.5	330	6.6	20
Ab217	Sandy Clay	45	3.9	190	5.3	27.8
Fa493	Sandy Clay	39	5.9	250	1.6	6.4
Aa9	Sandy Loam	16	2.3	315	5	15.8
Fa495	Clay	53	>6	710	47.2	66.4
Fa492	Sandy Clay	43	<0.5	550	27	49
Aa9	Sandy Clay Loamy	35	3.9	490	8.4	17.1

* g/m^2 and g/l were used rather than the more standard t/ha due to the problems discussed extensively in the literature (e.g. Beckedahl, 1998) of upscaling from small field plots to the landscape scale.

The most serious water erosion problems in the Hazelmere catchment are found in areas with high percentages of sand and clay. The samples from land type Fa436 and Fa459 (Appendix D) have high percentages of clay and would conventionally not be regarded as sensitive to erosion (mean K value of 0.17). These land types however, have high soil loss values, further emphasizing the role of dispersivity in the erodibility of the Hazelmere soils. The rainfall simulator results have given useful information in a much more convenient manner than relying on natural rainfall for soil loss estimation in the field.

A weak positive correlation (r = 0.207) exists between simulated soil loss and erodibility (k-factor). This correlation is significant at the 0.5% level of significance. Although the correlation is not strong, there is a relationship between soil loss and erodibility as would be expected if the K-factor does mirror soil sensitivity. The scatter diagram below (Figure 5.3) shows that there is a weak positive relationship. Severity of erosion cannot be judged by the rate of soil loss per se, but should rather include comparative rates of soil loss and soil formation. Other factors such as erosivity and land use should therefore also be taken into consideration.

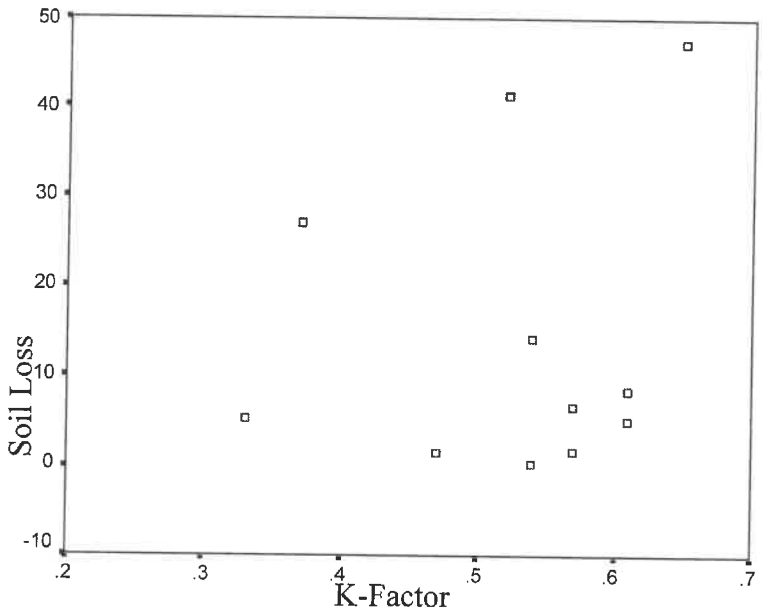


Figure 5.3: Scatter plot showing the weak positive relationship between k-factor and soil loss

5.5 DISPERSION AND SUSCEPTIBILITY OF SOIL TO EROSION AND THE RELATIONSHIP BETWEEN PARTICLE SIZE DISTRIBUTION AND ERODIBILITY

For the purposes of discussion, two Land Types (Fa436 and Fa459), which cover 38 and 18 percent of the total area of Hazelmere catchment respectively, have been considered specifically. This has been done from the perspective that these Land Types cover large areas within the catchment and these are the Land Types mostly affected by subsistence agricultural practice.

From the perspective of the soil chemistry indicated in Appendix A, soils from these land types are acidic. High values of ESP and the EC indicate that these soils are susceptible to dispersion, when viewed against the criterion of 6meq/100 for ESP and are considered saline. It should be noted that the level of salinity can greatly influence the likelihood of dispersion occurring within the soil. When particle size distribution is examined as shown in Appendix C, it becomes evident that, with the exception of few samples all soils are sand dominated. This then renders these soils erodible as sand dominated soils are associated with susceptibility to wash processes. The moderately high values for erodibility (K) are as expected due to high percentages of sand. Using the same reasoning the clay dominated sample (e.g. sample from Fa459) has a low erodibility. As already stated, this suggests that soils within these Land Types are not only dispersive but are also susceptible to other forms of erosion as well.

The role of particle size distribution in relation to the erodibility and the susceptibility of soil to wash erosion has been discussed in the previous sections. The Pearson's correlation coefficient test has been undertaken to verify the relationship between these two factors. The results for this analysis are presented in Table 5.5.

The Pearson's correlation coefficients between clay and K-factor and silt and K-factor are both negative. Clay is significant at the 0.05% level of significance, whereas the silt coefficient is not significant, even at the 0.05% level. By contrast, the correlation coefficient between sand and K-factor is positive and significant at the 0.01% level of significance. The inference that can be drawn from these statistical results is that there is an association between particle size and K-factor, that is if there are high percentages of clay and silt there will be low erodibility whereas if the particle size is dominated by sand there will be high erodibility. This is to be expected, given how the K-factor is derived using the nomograph which relies heavily on texture.

Table 5.5: Correlation coefficients between particle size and K-Factor.

Particle Size	**Pearson Correlation**	**Critical Significance value**	**Significance Level**
Clay	-0.460	0.12	0.05
Silt	-0.358	0.57	Not significant
Sand	0.474	0.09	0.01

5.6 GROUND TRUTHING

Ground truthing is field surveys undertaken to check that the information on the map conforms to that actually on the ground. Points along access routes were taken with a note of the relevant land use and soil erosion feature at that point. These points were matched to the same point on the map and the land use recorded (Appendix E). At each specific site it is this general pattern of the surroundings that was recorded and not the actual practice at that exact point. The features and the land use recorded corresponded with the information on the maps.

5.7 EROSION FACTOR ASSESSMENT

For erosion assessment, erosion areas have been grouped according to their erosion categories (Figure 5.4) as follows:

i. A1 – High.
i. A2 – Moderate.
ii. A3 – Moderate to Low.

It should be remembered that these classes are not absolute, but rather gradational and hence the distinction is 'grey'. These categories were then used with each of the following factors for the assessment of individual erosion factors.

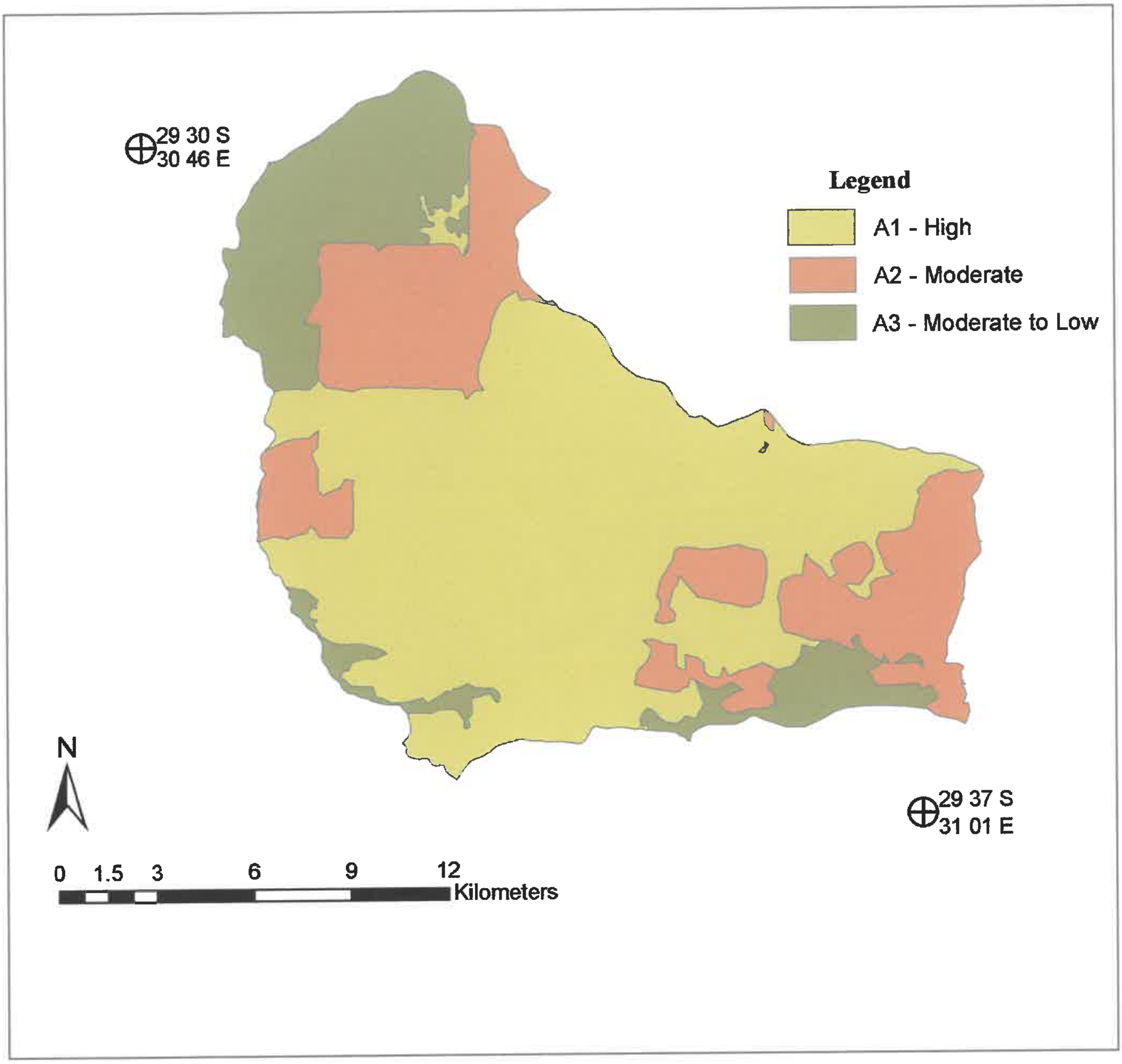


Figure 5.4: Actual erosion severity map of the Hazelmere catchment, based on the SARRCUS (1981) classification of soil erosion.

5.7.1 Rainfall

Rainfall data obtained from South African Atlas of Agrohydrology and Climatology was cross tabulated with Actual Erosion severity by calculating Zonal Statistics in GIS. The spatial statistics (Table 5.4) show that rainfall characteristics are essentially similar across all zones. The mean annual rainfall has no significant difference across all erosion zones. This shows that there is no significant spatial correlation between erosion severity and rainfall. For example (Figure 5.5), it is noticed that high and low rainfall occur in all erosion zones. It is observed that the minimum annual rainfall appears in all erosion zones.

Table 5.6: Showing cross tabulation of Rainfall and erosion severity

EROSION CATEGORY	MINIMUM ANNUAL RAINFALL (mm)	MAXIMUM ANNUAL RAINFALL (mm)	ANNUAL RAINFALL RANGE (mm)	MEAN ANNUAL RAINFALL (mm)	MEDIAN FOR ANNUAL RAINFALL (mm)
A1	720	1198	478	955	942
A2	720	1234	514	1022	991
A3	720	1199	479	986	985

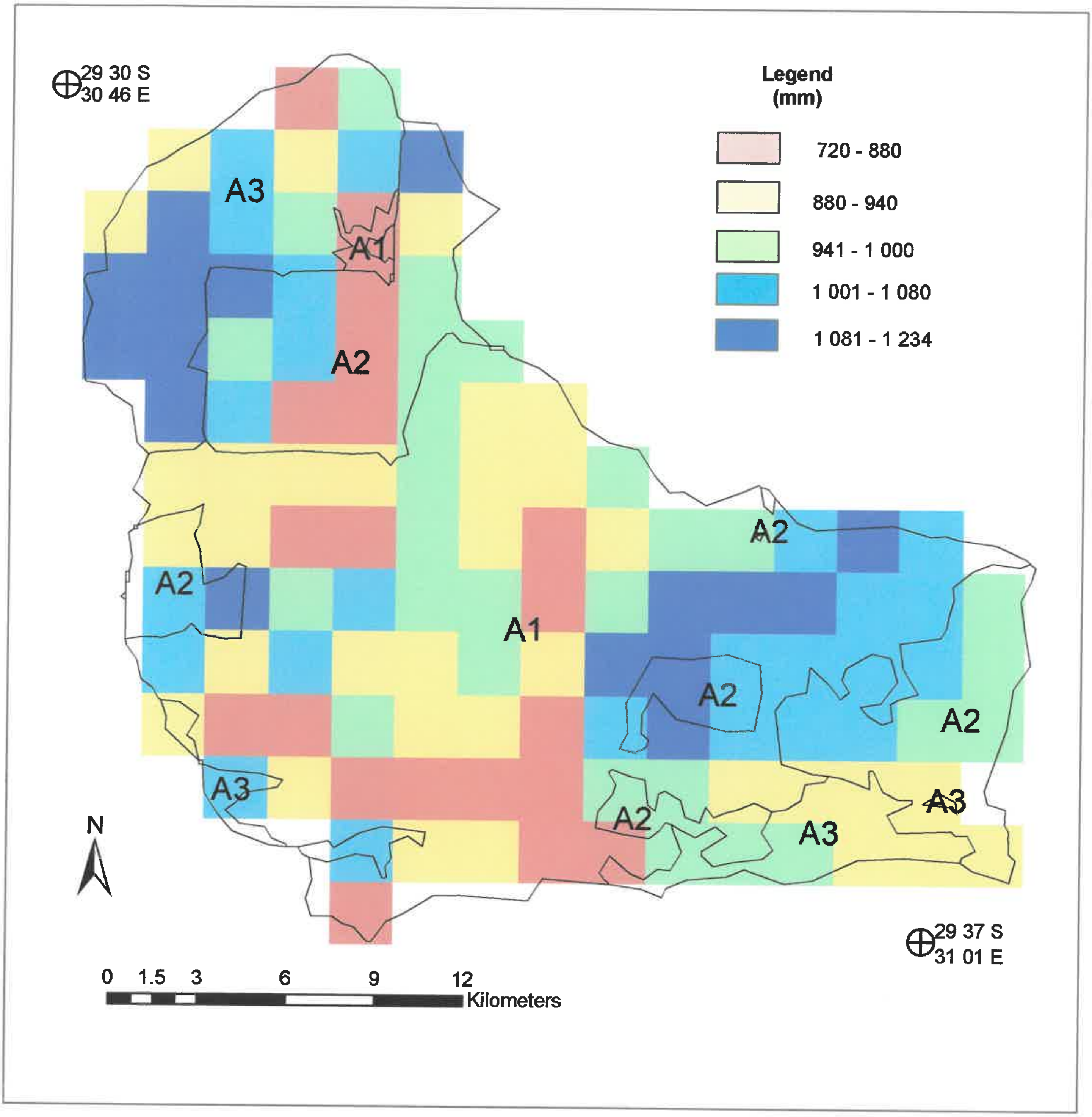


Figure 5.5: Erosion severity relative to rainfal distribution as derived from the South African Atlas of Agrohydrology and Climatology.

5.7.2 Geology

Since geology provides a guide to a soil's parent material, it potentially has a strong influence on erodibility and the level of erosion principally through affecting particle size. Geology is, however, not the only determinant of texture. Areas where severe erosion was recorded on the photographs and in the field are dominated by lithologies of the Namaqua Natal Mobile Belt and Natal Group. The overlay results between geology and erosion are outlined in Table5.7 below. The former weathers to produce clay and sand as some of its soil character, while the latter weathers to produce sand and it becomes more pronounced with weathering (King, 1982) (see Figure 5.6).

Table 5.7: Erosion severity with lithological units for the Hazelmere catchment.

Type	**Area (Km^2)**	**Percentage of catchment**
Natal group on area A1	69.91	19.8
Natal group on area A2	40.86	11.5
Natal group on area A3	40.1	11.5
Total erosion on Natal Group	**150.87**	**42.8**
Namaqua Natal Mobile on area A1	133.82	37.8
Namaqua Natal Mobile on area A2	43.12	12.2
Namaqua Natal Mobile on area A3	21.47	0.6
Total erosion on Namaqua Natal Mobile	**198.41**	**56.6**
Dwyka Formation on area A1	0	0
Dwyka Formation on area A2	2.86	0.8
Dwyka Formation on area A3	0.68	0.19
Total erosion on Dwyka Formation	**3.54**	**0.99**
Pietermaritzburg formation on area A1	0	0
Pietermaritzburg formation on area A2	0.28	0.7
Pietermaritzburg formation on area A3	0	0
Total erosion on Pietermaritzburg Formation	**0.28**	**0.7**

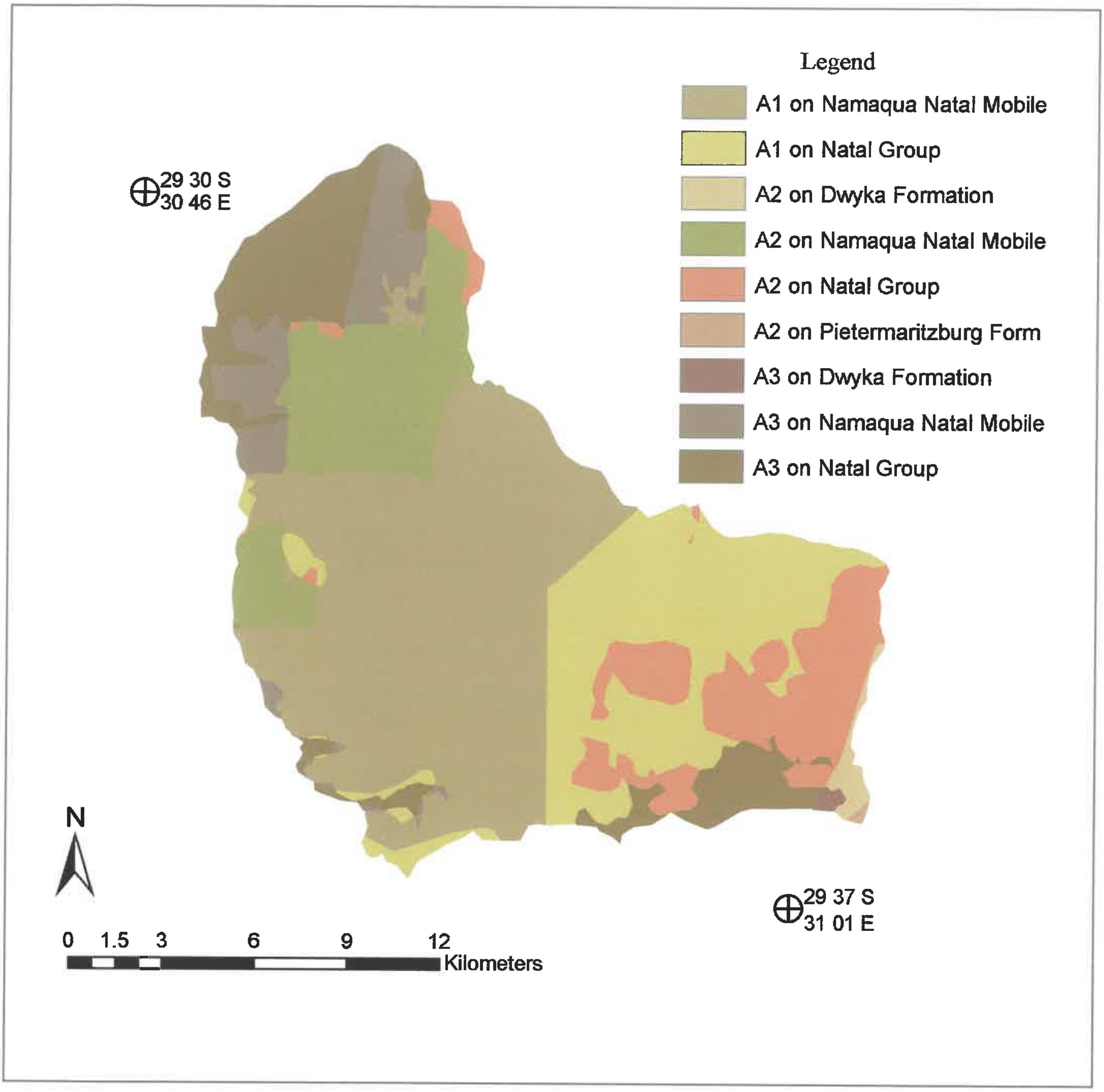


Figure 5.6: Spatial correspondence between erosion severity and lithological units for the Hazelmere catchment

5.7.3 SLOPE

In most cases it was found that erosion was related to slope steepness. This is also supported by the Universal Soil Loss Equation and the Revised Universal Soil Loss Equation where increasing slope was found to increase erosion (Renard, *et al.,* 1991). Although the rates of erosion for the different slopes were found to vary depending on the type of land use, the land use map, slope map shows that erosion is the greatest where subsistence farming is practiced. The other factor influencing the slope effect is geological type. Land under the Natal Group has steeper slopes than the other geological types and gives rise to sandy soils (King *et al.,* 1982) (see Table 5.8 and Figure 5.7).

Table 5.8: Erosion severity and slope class for the Hazelmere catchment.

Slope Class (based on percentage)	**Area (Km^2)**	**Percentage of catchment**
41 – 100 on area A1	6.47	1.82
41 – 100 on area A2	3.81	1.07
41 – 100 on area A3	5.53	1.56
Total erosion on 41 - 100	**15.81**	**4.45**
21 – 40 on area A1	56.06	15.80
21 – 40 on area A2	23.21	6.55
21 – 40 on area A3	16.33	4.60
Total erosion on 21- 40	**95.6**	**26.95**
11 to 20 on area A1	90.86	25.68
11 to 20 on area A2	38.24	10.80
11 to 20 on area A3	23.42	6.60
Total erosion on 11 - 21	**152.52**	**43.08**
0 – 10 on area A1	50.24	14.20
0 – 10 on area A2	22.18	6.26
0 – 10 on area A3	17.4	4.80
Total erosion on 0 - 10	**89.82**	**25.26**

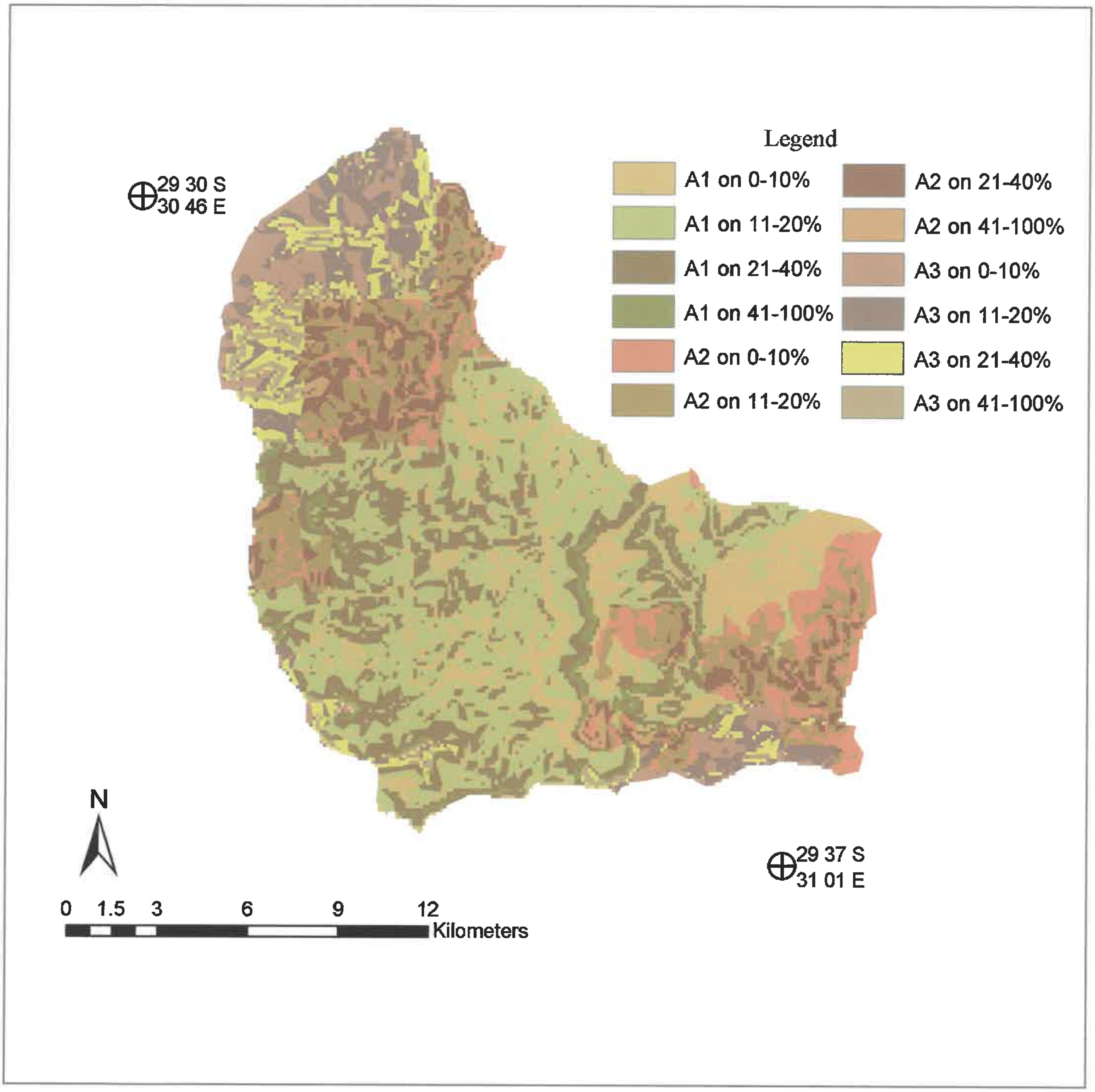


Figure 5.7: Spatial correspondence between erosion severity and slope class for the Hazelmere catchment

5.7.4 LAND USE

Land use is a contributing factor in accelerating erosion. Some important differences in the physical features influence that contribution. In areas where subsistence farming dominates the underlying rock is Namaqua Natal Mobile Belt and Natal Group. As the Natal Group gives rise to sandy soils, this makes soil to be prone to erosion. Nevertheless, these results must be treated with caution since other factors may have had an influence. Since land use is one of the factors which is influenced by man, further research is needed so that management may become a tool in combating soil erosion. Large differences in erosion levels were found between subsistence farmlands and commercial farmlands, (Table 5.9) indicating important influence of humans on soil erosion (see Figure 5.8).

Table 5.9: Erosion severity with Land use for the Hazelmere catchment.

Type	Area (Km^2)	Percentage of catchment
Grazing on area A1	136.85	38.75
Grazing on area A2	45.3	12.82
Grazing on area A3	23.48	6.64
Total erosion on grazing	**205.63**	**58.21**
Bush on area A1	20.2	5.72
Bush on area A2	9.82	2.78
Bush on area A3	3.77	1.06
Total erosion on Bush	**33.79**	**9.56**
Forestry on area A1	0.1	0.02
Forestry on area A2	1.72	0.48
Forestry on area A3	12.69	3.59
Total erosion on forestry	**14.51**	**4.09**
Cultivated on area A1	46.87	13.27
Cultivated on area A2	28.58	8.09
Cultivated on area A3	9.32	2.63
Total erosion on cultivated	**84.77**	**23.99**
Sugarcane on area A1	0	0.62
Sugarcane on area A2	2.21	3.71
Sugarcane on area A3	13.13	0
Total erosion on sugar cane	**15.34**	**4.33**

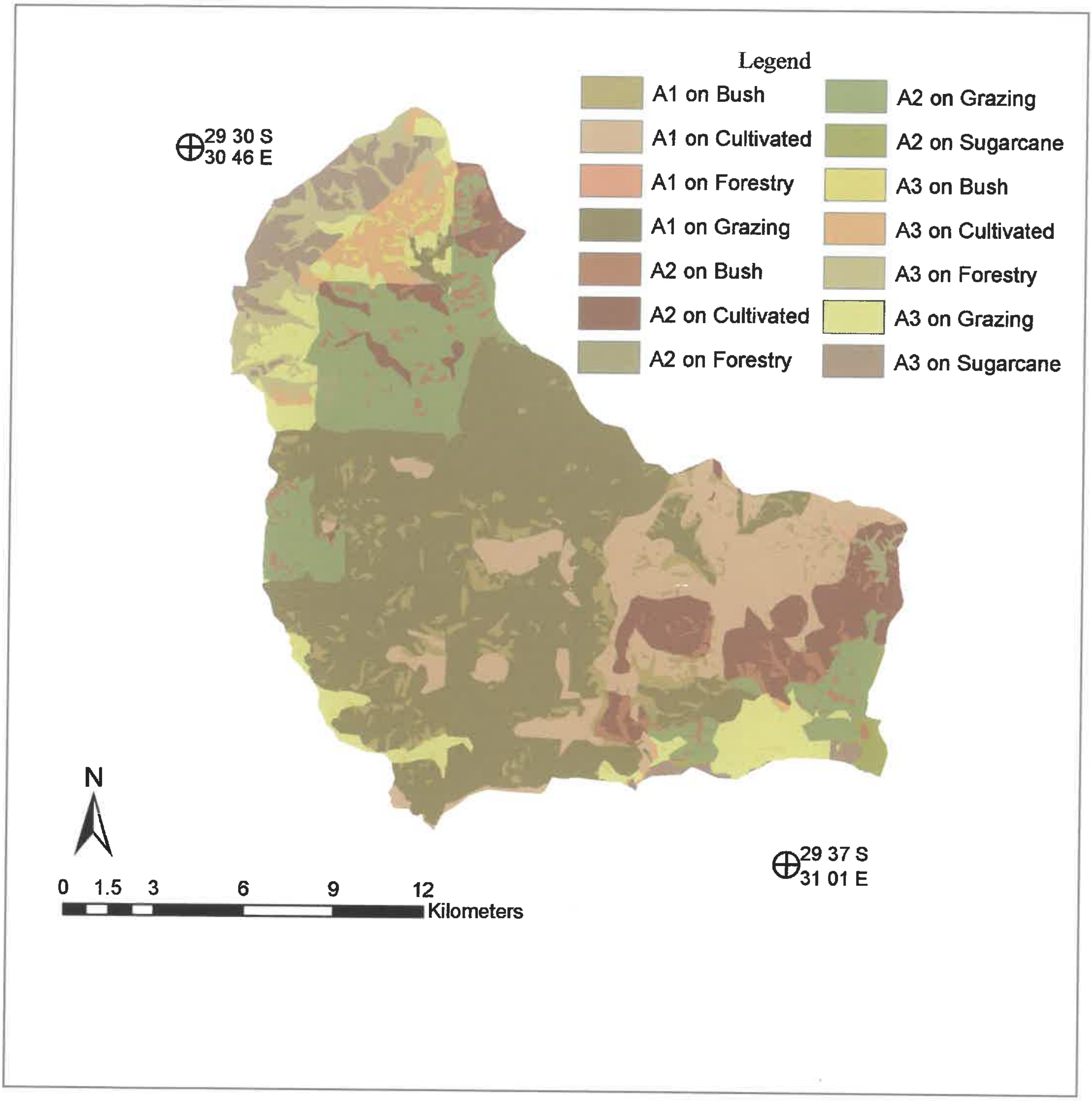


Figure 5.8: Spatial correspondence between erosion severity and Land use for the Hazelmere catchment

5.8 ANALYSIS OF THE SPATIAL DISTRIBUTION OF SOIL EROSION

The soil erosion risk relates more to the current risk of erosion under present vegetation and land use conditions. The soil erosion risk results are derived by adjusting the actual erosion to allow for the influence of the soil erosion factors. As a consequence, the areas of land at risk (especially very high risk) tend to be high.

As mentioned in chapter 4 and in the introduction to this chapter, assessment of soil erosion was carried out on a three-point scale ranging from 1 (High) to 3 (Low). As such, the model clearly represents a considerable simplification of the USLE, but it is felt that, at the scale and with the data available, such simplification is justifiable. It is further argued that, the results nevertheless, provide sufficient discrimination to meet general policy needs. In particular, they allow the definition of areas of high erosion, where active measures to control soil erosion may be needed, and of areas of low erosion where agricultural practices probably present no threat. By comparing actual erosion with the individual factors influencing erosion, it is then possible to combine these factors using GIS technology to arrive at a map of erosion risk.

Soil erosion risk is calculated by aggregating the mapped soil erosion, geology, rainfall distribution, land use and slope steepness. This is taken to indicate the inherent susceptibility of the land to erosion. It thus provides a worst possible case. In policy terms, this is likely to be of particular significance since it highlights areas which may be adversely affected by policy-induced land use changes (e.g. grazing or agricultural intensification).

An erosion risk map for the whole catchment, where land use, slope, geology, and rainfall distribution are combined, is shown in Figure 5.9. This map is designed to show the varying degrees of erosion risk. It is interesting to observe that the erosion pattern is similar from across the epochs studied, with the concentration of rill and sheet erosion to certain areas, these processes are mainly concentrated on the footslope pediments, which are areas with thin soil cover and many hardpan surfaces (Russow and Garland, 2000).

When comparing the aerial photos from the different years and field observations from 2000 and 2001 (Russow and Garland, 2000), also with other field results and observations from 1997 (Currie, 1997), the erosion pattern is similar, indicating a system of sediment source areas. Using the SARCCUS (1981) classification the footslope pediment is characterized by moderate to severe rill and sheet erosion, while the areas with plantations of sugar cane experience at most slight to moderate rill and sheet erosion.

Closer examination of the occurrence of eroded land indicated that there is a close association between erosion classes and land use, particularly farming systems. Virtually all the land in erosion classes very low and low (with very limited erosion) occur within the commercial farmlands, whereas erosion classes high and very high (severe to very severe erosion) occur within areas of subsistence farmlands. The highest hazard is within the area covered by Land Type Fa436 where a combination of the high rainfall distribution (800 – 850mm), slope (20 – 40 %) and land use (grazing) makes it vulnerable to erosion. Certainly, this area has the highest erosion within the catchment, this is further supported by the chemical and physical properties results of soil discussed in previous sections. The distribution of the erosion risk broadly follows that outlined previously. In quantitative terms, the largest area of high risk land occurs in Land Type Fa436 (covering 38% of the catchment), mainly in the south and west. These areas clearly represent zones whose traditional land use systems need to be changed if soil erosion is not to be made worse. They serve to emphasize the importance of vegetation cover for soil erosion control, and the dangers inherent in changes in land use practice.

Soil erosion within the Hazelmere catchment varies spatially and temporally. In general, soil erosion increases with annual rainfall, slope, and land uses with open cover (for example cultivation and grazing).

By overlaying the erosion risk map with that of erosion susceptibility based on the rainfall simulator, the GIS based spatial correlation using the statistical method of cross-tabulation (which is better known as Chi-Square test) could be obtained. The chi-square analysis can be used to test if there is an association between the two variables. The hypothesis that was tested is that there is no correlation between erosion risk and the soil loss obtained from simulated rainfall. For this cross-tabulation the chi-square statistic was 22226 with 18 degrees of freedom and the significance level of 0.01. Looking at a chi-squared distribution table, the p-value was 28.869. The chi-square value is sufficiently large for us to reject the hypothesis and to conclude that there is a relationship between soil loss and soil erosion risk. In other words, the null hypothesis of independence between the two variables is rejected. The cross-tabulation of land use and soil erosion risk map, generates a chi-square value of 17578 with eight degrees of freedom which is significant at the 0.01 level. The p-value obtained was 15.507, implying that we could have confidence in a relationship between the two variables. The comparison of soil erosion risk map within the Hazelmere catchment, with simulated erosion based on rainfall simulator, indicates that on average 59% of eroded soil is derived from the high risk area. Most of this sediment is probably deposited at the base of hillslopes or in depressions, but will eventually reach the stream channel, and ultimately contributes to the turbidity problems of the Hazelmere Dam.

The cross-tabulation of mapped soil erosion and soil erosion risk, generated a chi-square value of 88666.6 with twelve degrees of freedom which is significant at the 0.01 level. The p-value obtained was 21.02, which rejects the null hypothesis that there is no relationship between mapped erosion and erosion risk obtained from soil erosion factors. The cross-tabulation of mapped erosion and soil loss was conducted to test the null hypothesis that, there is no relationship between soil loss and mapped soil erosion, this hypothesis was rejected at 95% confidence level with a p-value of 18.49. Land use and soil loss was cross-tabulated to see if there is any relationship between the two variables, with the chi-square value of 122778 and 36 degrees of freedom the null hypothesis was also rejected at 0.05 level of significance, this again implies that there is a relationship between the two variables. The results suggest that determination of risk is a good indicator of actual erosion and can thus be used in a predictive capacity.

As is evident there is a clear relationship that emerges for the distribution of soil erosion, whether it be the actual mapped or the soil erosion risk obtained by combining the factors of erosion with land use and soil loss. This relationship emerges again with the relationship between mapped soil erosion and soil erosion risk. The available data indicate that there is a 95% probability that the spatial position of the actual soil erosion is determined by the distribution of simulated soil loss and distribution of land use. The above results are primarily indicative of the already stated relationship in the distribution of soil erosion. The spatial distribution of soil erosion and land use reported in this present work correspond broadly with the data reported by Del Mar Lopez *et al.* (1998) for the Guidiana watershed in Puerto Rico. The argument in favour of relationship existing between soil loss and land use is given confidence by the positive relationship between erosion risk and land use, where high risk areas exist in land use areas with high soil loss.

The median rate of soil erosion in polygons of different land uses decreases in the following pattern: grazing > cultivated > bush >sugar cane > forestry. However, median erosion rates between areas forestry and sugar cane were not significantly different. With the exception of the relatively high erosion rates in areas of grazing, this pattern is similar to those found in other catchment studies (Stocking, 1972; Stocking and Elwell, 1973; Chaleka *et al.*, 1985; Lal, 1990; Lutchmiah, 1999) and in plot measurements of erosion made in Puerto Rico (Smith and Abruña, 1955). The relatively high erosion rates estimated for areas with grazing and cultivation sites are related to the topographic conditions where this is practiced occur. Moreover, although greater vegetative cover in the forest protects the soil from the direct impact of precipitation, the steep, long slopes result in greater soil erosion compared to areas with active subsistence agriculture on more gentle slopes.

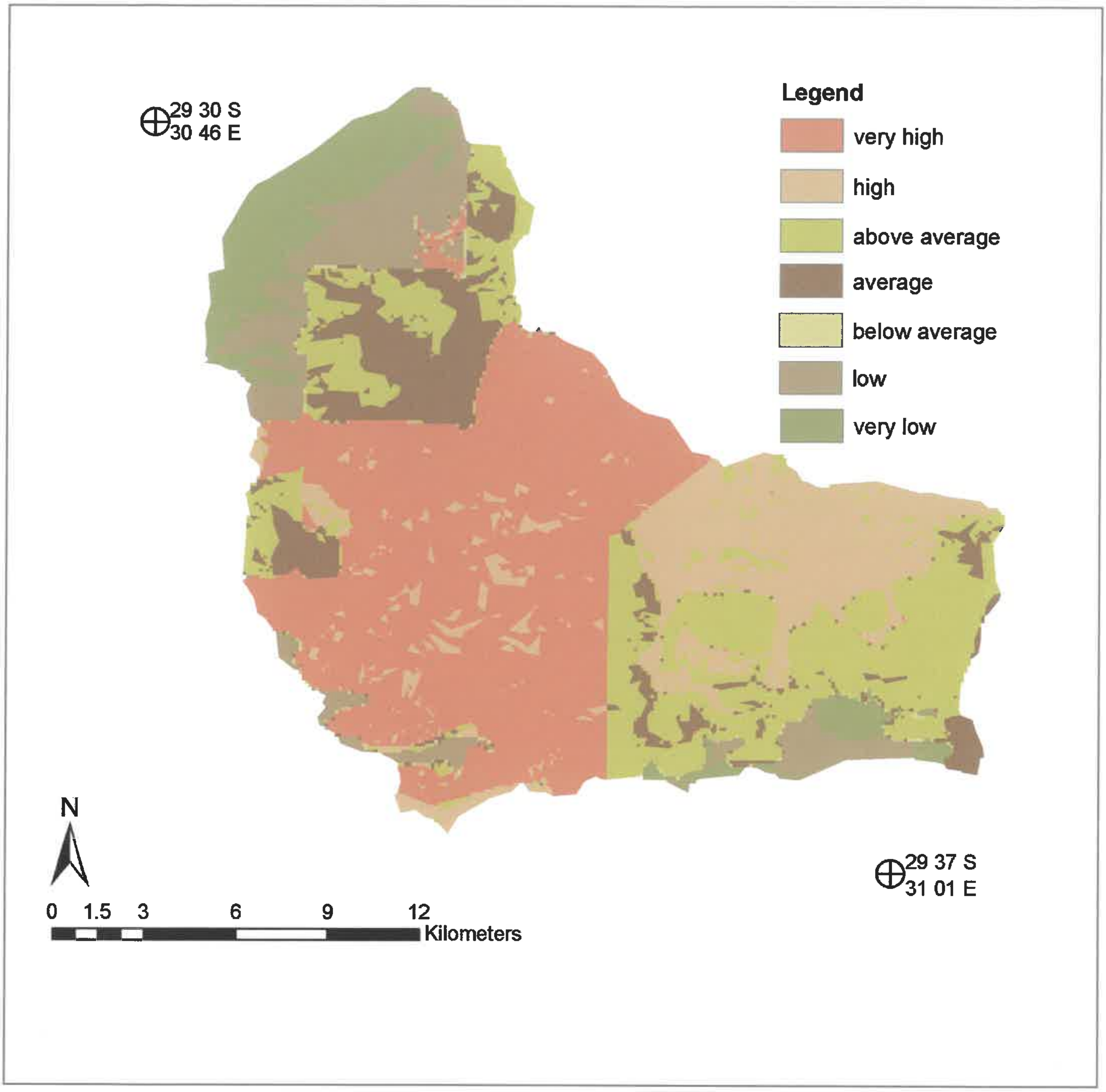


Figure 5.9: Spatial distribution of soil erosion risk for the Hazelmere catchment

From the results and discussion presented thus far, it is evident that sources of soil erosion in Hazelmere catchment are related to specific variables. The results of the soil analysis reveal that all soils are at least to some extent prone to erosion. This has been shown by the particle size distribution and the chemical properties of the soil. The mapping results revealed that erosion is also related to the factors of erosion as shown by results. Results of chi-square testing using cross-tabulation revealed that there is a relationship between the actual soil loss and land use; a similar trend being evident between soil erosion risk and land use. There is also a relationship between mapped soil erosion and the soil erosion risk. The following chapter investigates this relationship further and gives the conclusions drawn from the results obtained.

CHAPTER 6

CONCLUSION

The aim of this research was to identify soil characteristics, determine erodibility of the soil and to obtain spatial distribution of soil erosion using Geographic Information System. Five objectives set out in the introduction were necessary to achieve the aim of the research. This chapter aims at drawing conclusions from the results that were obtained with a view to determining the extent to which the problem of soil erosion can be attributed to specific soil characteristics and definite regions within the catchment.

The first part of this chapter reviews the role of soil character and its relationship with erodibility and draws conclusions on this aspect of the work. The second part focuses on the erodibility of the soil. The third part of the chapter is concerned with soil erosion mapping and erosion risk assessment in regard to selected soil erosion factors. The forth and the fifth part of the chapter looks at some measures that are to be taken for effective soil erosion control and highlights some recommendations towards improved soil erosion control. The last part looks at some avenues of further research, considered to be beyond the scope of the study.

6.1 SOIL CHARACTER

The results presented for the particle size analysis suggest that soils of the Hazelmere catchment are very prone to erosion, and are generally rendered highly erodible. It has further been shown repeatedly in the literature that there is a relationship between the particle size distribution and erodibility (Boardman *et al.,* 1990; Cooke and Doornkamp, 1990; Beckedahl, 1998). The statistical correspondence that has been shown to exist between erodibility and particle size distribution has facilitated the quantitative explanation on the erodibility of soil in Hazelmere catchment.

The analysis of 52 soil samples has shown that soils at Hazelmere catchment are not only susceptible to erosion as a result of their physical character, but are also very dispersive due to their chemistry and this renders them to be particularly highly erodible and prone to erosion. The chemical and physical properties of the soil cause it to be prone to erosion both individually and in concert with one another.

6.2 SOIL ERODIBILITY

Results of the nomograph showed that soils at Hazelmere catchment are susceptible to conventional forms of erosion. Although in some cases clay soils had low erodibility (K-values) this is likely to be a misrepresentation and can be disputed on grounds that soils at Hazelmere catchment are highly dispersive. As mentioned in the previous chapter, that the similar findings were observed by Beckedahl (1998). Erodibility results from the rainfall simulator also suggest that soils at Hazelmere catchment are highly erodible. This corresponds with the work done by Sumner (1995) in his study of footpath erosion in Drakensberg area in South Africa. The most serious water erosion problems in the Hazelmere catchment are found in areas with high percentages of clay and sand. Due to the sodic nature of Hazelmere catchment soils, these soils are very dispersive. Furthermore, these soils are sandy, sandy soils are easily detached by water and easily eroded (Holy, 1980; Hudson, 1981; Selby, 1993; Meyer, 1994). Results from the rainfall simulator show that land types Fa436, Fa459 and Fa495, are the land types with serious water erosion problem. The soil loss recorded on the Hazelmere catchment soil ranges between 0.4 and 47.2 g per m^2, and that the runoff and sediment concentration vary greatly between different soils. Sumner's (1995) results for soil loss correspond to some degree with the results for this study where rainfall intensity was most correlated to soil loss. Field evidence also support this finding as there is extensive water erosion occurring within these land types.

6.3 SOIL EROSION FACTOR ASSESSMENT

Given the several problems recognized in the raw data, it is evident that similar caution must be stated regarding the assessments of soil erosion risk derived therefrom. Inevitably, aggregation of uncertain data produces uncertain results. To a large extent, however, this uncertainty has been allowed for by the recognition of only 7 classes of soil erosion risk. The results therefore are intended to show no more than the general patterns, and at this level of analysis would be broadly reliable and correct. Nevertheless, it is important that anyone using the results appreciates their limitations and do not attempt to go beyond them, for example by interpolating between classes.

It should also be noted that the aggregation methods used in this analysis were knowingly simple. The justification for this has been presented, given the data available and the constraints of time and resources, other more sophisticated procedures could not be used. The approach, however, clearly makes no allowance for the complex and dynamic interactions between the various determinants of soil erosion risk. Assumptions have also had to be made regarding the relationships of these phenomena to the individual variables (e.g. land use, geology, slope). Each of these assumptions, though defensible in general terms, can be challenged at the detailed level. The model is admitted to be a preliminary one, and the results are explicitly a first approximation. They provide only a qualitative assessment of soil erosion risk; more detailed quantitative assessments must await the availability of better data. These provisos must be borne in mind when the data are used.

Soil erosion does not necessarily develop as a direct consequence of soil chemistry nor of soil physical properties only, but may also be associated with other factors (Beckedahl, 1998). Using the factors slope, land use, geological type and rainfall, an erosion risk or hazard map of the Hazelmere catchment has been produced (Figure 5.9). Results of assessment analysis showed that there is high risk of erosion within land type Fa436 where a combination of the high rainfall, slope, and subsistence farming dominance make it vulnerable to erosion. Also it became clear that within any erosion potential class, the actual rate of erosion can be expected to be largely influenced by land use although the other factors were also contributing. Thus, where erosion risk is the greatest, those areas should be carefully managed to ensure that actual erosion is minimized. Similar influence was discovered by Bocco *et al.* (1990) in the study of gully modeling using GIS and geomorphic knowledge at Mexico, where land use and slope had a major influence in gully formation.

The map of erosion risk for Hazelmere catchment shows that areas of high erosion risk occur north of the Hazelmere Dam where there is intensive grazing and cultivation. This occurs largely as a result of subsistence farming dominated by grazing and cultivation. This finding is supported by the spatial relationship between land use and soil erosion. Where commercial farming occurs to the east and southwest the erosion risk is moderate to low due to better land management.

6.4 SOIL EROSION CONTROL

One of the main applications lies in community structures on soil erosion control. As has been noted, soil erosion represents an important and costly problem in Hazelmere catchment, in the short term it results in damage to crops, loss of fertilizers and reduced yields. In the longer term, it causes degradation of soil fertility and siltation of Hazelmere Dam. It may thus lead to extensive damage to the land resources with wide-ranging implications for farming and rural societies. One of the main concerns of the community must therefore be the prevention and control of soil erosion. The question remains however, what types of policies should be introduced, and where should they be directed?

Results from this project clearly help to tackle these questions. Figure 5.9 for example, shows the distribution of land with a high potential erosion risk. This comprises those areas where the natural conditions favour soil erosion in other words, soil erosion in these areas is likely to occur whenever management practices do not provide active protection to the soil.

The primary need in these areas is thus for positive soil erosion control more detailed studies should therefore be undertaken on, for example, measures such as contour cultivation and zero tillage. In extreme cases, there may also be a need for more fundamental changes in farming practices.

To facilitate the introduction of these measures, government and community structures are required to provide support (e.g. finance, advice) to land users. At the same time, there is a need for preventive policies which discourage rapid or insensitive development and land use change. This is exemplified by the information in Figure 5.9, indicating those areas where the current vegetation cover is instrumental in protecting the soil from erosion; and thus where vegetation removal is likely to exacerbate the erosion problem. Clearly, it is important in these areas to ensure that development, agricultural practices or other activities do not lead to the damage or removal of this vegetation cover. Instead, policies are required which help to protect the vegetation and thus minimize soil erosion.

Soil erosion is not only a threat to agricultural land; equally it may threaten natural habitats. Conservation of natural vegetation not only protects wildlife, it may also help to prevent soil erosion. For these reasons, the soil physical characteristics and soil erosion risk assessment is of considerable importance.

6.5 RECOMMENDATIONS

Land use should be planned taking into account the cumulative erosion factor which are identified in this study. The geological type, rainfall distribution and slope should be considered together for the clear understanding of erosion risk. To prevent high risk erosion areas occurring as a result of land use these factors should be clearly understood and the appropriate soil conservation measures be employed to minimize the risk. Much of erosion is occurring in areas where grazing and cultivation is dominating. It is suggested that stringent anti-erosion measures should be considered in areas where subsistence farming is being practiced. Areas with slopes suitable for grazing and cultivation have high recorded erosion, this shows that land use is the main controlling factor of erosion and it is the controllable factor.

Areas that receive 900 mm and above of annual rainfall should be regarded as high risk areas for subsistence farming. If these areas are overgrazed the risk of erosion becomes very high. These areas then require management to ensure that the land is not overgrazed or not incorrectly cultivated.

Soils derived from the Natal Group and Namaqua Natal Mobile are susceptible to erosion. In the rural setting like Hazelmere catchment, high density settlement and grazing on these soils is not advisable. Soils from Dwyka formation and Pietemaritzburg formation have moderate to low risk of erosion and may be used for cultivation and grazing given the fact that soil conservation measures are taken. In the interest of soil conservation land types Fa436 and Fa459 need proper soil management strategies. The rest of this area has high to very high erosion hazard, this is largely due to combined factors, of geology and land use. Land use needs an urgent attention within these land types.

6.6 FURTHER RESEARCH

Much can still be done to extend the data and improve the methodology. This section outlines some of the specific aspects of the assessment methodologies that could usefully be improved, and indicates the needs for further analysis and research.

Although the soils of Hazelmere catchment are naturally susceptible to erosion, this study has highlighted the need of land management in controlling soil erosion. The findings identified the areas which are vulnerable to erosion, this is particularly useful in an area such as Hazelmere catchment where subsistence agricultural practices predominates and it is therefore important to identify those areas of low erosion risk which need to be safeguarded against erosion. It is therefore suggested that erosion risk should be assessed in any area within the Hazelmere catchment where alterations of any form are being planned and that the applicability of the results to other areas should be tested. This study has mainly concentrated on the scientific and technical aspects of soil erosion. However, some of the greatest barriers to adequate soil conservation are likely to be social and economic constraints. Until such problems are addressed, it will be difficult to implement soil conservation measures successfully.

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APPENDIX A: Exchangeable Cations of Hazelmere catchment Soils

Land Type	Potassium (K) mg/L	Calcium (Ca) mg/L	Magnesium (Mg) mg/L	Sodium (Na) mg/L
Fa493	15	21	21	1.2
	28	69	69	4.5
	223	249	107	13.9
	112	534	377	12.21
Aa5	33	64	64	4.2
	35	72	72	2.32
Aa495	45	119	119	12.64
	28	372	171	53.45
Aa9	20	22	22	1.26
Aa8	309	141	141	12.65
	22	130	385	24.31
	28	158	395	20.91
Fa436	21	395	322	24.23
	24	345	346	23.67
	21	283	355	31.81
	38	815	364	20.35
	45	827	362	23.03
	40	860	381	17.19
	69	479	220	10.95
	72	470	228	12.72
	90	464	225	17.16
	52	70	50	4.9
	50	69	49	5.26
	66	83	66	6.64
	79	132	260	17.24
	86	120	248	20.01
	84	123	248	20.44
	34	87	25	2.37
	28	77	33	2.23
	133	207	136	8.32
Fa459	129	2888	749	32.54
	138	2799	760	37.23
	35	262	121	17.24
	27	250	107	14.2
	39	429	350	26.08
	43	437	358	30.96
	130	629	267	21.24
	140	635	277	13.48
Ab127	20	809	273	45.32
	42	754	312	37.44
	46	768	321	59.02
	41	152	58	4.71
	46	440	126	9.12
Fa492	37	142	230	15.54
	53	130	220	21.1
	338	329	149	13.89
	50	150	148	11.19
Fa496	255	674	313	10.77
Ab217	21	129	168	8.42
	30	133	160	9.12
	30	152	197	13.84

APPENDIX B: Soil Chemical Properties and Organic Carbon

Land type	pH KCL	Organic Carbon %	Electronic Conductivity mS/m	ESP	SAR	CEC
Fa493	4.34	<0.5	7.20	4.80	0.70	0.40
	4.68	<0.5	15.70	6.00	0.70	1.10
	4.11	3.60	6.50	21.70	1.00	0.50
	4.61	<0.5	11.90	12.10	0.30	1.00
Aa5	4.00	<0.5	8.50	5.90	0.30	0.40
	4.80	<0.5	9.10	5.50	0.50	1.00
Fa495	4.25	<0.5	6.00	41.50	1.60	0.40
	4.90	3.00	20.90	56.00	0.80	1.40
Aa9	4.20	<0.5	6.50	5.20	0.50	0.40
Aa8	4.70	3.70	42.40	5.20	0.50	3.00
	4.67	1.30	6.00	50.40	0.50	0.10
	4.61	<0.5	5.60	51.00	1.10	0.50
Fa436	4.65	3.90	6.30	43.30	0.50	0.30
	4.71	3.80	6.80	42.90	0.80	0.50
	4.29	2.40	6.70	43.40	0.80	1.00
	4.51	5.90	8.40	18.90	0.70	1.30
	4.27	4.20	8.90	19.60	1.40	0.80
	4.15	5.80	8.80	19.40	0.90	1.50
	4.10	2.30	15.50	13.40	0.30	1.40
	4.29	2.70	16.00	12.90	0.70	0.90
	4.30	2.30	15.90	13.20	0.80	1.00
	4.19	3.90	8.90	7.80	0.30	0.40
	4.28	3.20	9.50	7.40	0.70	0.90
	4.22	1.70	9.20	7.60	0.50	1.00
	5.39	<0.5	6.90	83.10	0.40	0.20
	5.31	1.00	6.40	82.50	0.50	0.50
	5.35	<0.5	6.50	82.70	0.90	0.50
	4.22	1.00	7.50	8.40	1.30	0.50
	4.16	>6.0	7.10	7.60	0.70	0.90
	4.31	4.50	13.40	14.10	1.40	0.80
Fa459	4.74	4.10	5.90	27.80	0.70	0.10
	4.79	<0.5	5.30	27.40	1.10	0.60
	4.78	3.80	5.60	27.60	0.90	0.50
	4.25	4.10	9.90	38.50	0.70	0.40
	4.29	1.40	9.30	37.90	1.10	0.80
	4.29	3.80	11.20	56.40	1.50	0.90
	4.21	<0.5	10.60	55.60	0.50	0.50
	4.59	<0.5	14.80	30.50	0.90	0.70
	4.49	1.20	15.20	29.90	0.50	1.30
Ab127	4.19	<0.5	15.60	20.80	0.30	0.80
	4.10	4.80	15.10	20.10	0.80	1.30
	4.19	1.00	15.20	20.60	0.70	0.90
	4.77	2.60	8.00	7.00	0.70	0.60
	4.47	<0.5	12.10	11.40	1.10	0.70
Fa492	4.09	<0.5	6.00	33.50	1.40	0.30
	4.07	<0.5	5.60	32.90	0.80	0.10
	4.19	1.00	15.20	11.10	0.80	1.00
	4.22	<0.5	12.10	32.20	0.40	1.10
Fa496	4.39	<0.5	11.10	16.30	0.60	0.60
Ab217	5.05	<0.5	11.01	19.60	0.50	0.40
	5.00	<0.5	10.50	19.90	0.70	0.90
	5.01	<0.5	10.89	19.90	1.20	0.50

APPENDIX C: Soil Particle Size Distribution of Hazelmere Catchment Soils

Land type	Clay	Silt	Sand	Texture Class
Fa493	5	4	90	Sand
	6	8	86	Loamy sand
	19	8	72	Sandy loam
	19	10	70	Sand loam
Aa5	13	9	78	Sandy loam
	7	5	88	Loamy sand
Fa495	32	19	48	Sandy clay loam
	11	19	70	Sandy loam
Aa9	6	4	90	Sand
Aa8	19	7	74	Sandy clay loam
	65	13	22	Clay
	59	15	28	Clay
Fa436	39	12	49	Sandy clay loam
	43	14	43	Clay
	47	7	46	Sandy clay
	35	9	56	Sandy clay
	41	13	46	Sandy clay
	38	8	54	Sandy clay
	18	8	74	Sandy loam
	14	15	71	Sandy loam
	16	10	74	Sandy laom
	5	4	91	Sand
	9	2	89	Loamy sand
	7	3	90	Sand
	20	16	64	Sandy clay loam
	25	21	54	Sandy clay loam
	27	17	56	Sandy clay loam
	4	4	91	Sand
	28	16	56	Sandy clay loam
	38	8	54	Sandy clay
Fa459	48	14	38	Clay
	53	19	28	Clay
	57	18	25	Clay
	38	6	56	Sandy clay
	44	10	46	Sandy clay
	21	16	63	Sandy clay loam
	27	10	63	Sandy clay loam
	54	9	37	Clay
	34	7	59	Sandy clay
Ab127	7	4	89	Loamy sand
	5	8	87	Loamy sand
	12	9	79	Sandy loam
	14	7	79	Sandy loam
	30	12	58	Sandy clay loam
Fa492	46	17	36	Clay
	19	7	75	Sandy loam
	34	8	58	Sandy clay loam
	28	12	60	Sandy clay loam
Fa496	29	12	59	Sandy clay loam
Ab217	7	8	87	Loamy sand
	13	11	76	Sandy loam
	12	13	75	Sandy loam

APPENDIX D: Showing Erodibility (K-factor) Values with Particle Size Distribution derived from the Nomograph of Wischmeier and Smith (1965)

Land Type	Clay %	Silt %	Sand %	Organic Carbon %	K-Factor
Fa493	5	4	90	<0.5	0.47
	6	8	86	<0.5	0.42
	19	8	72	3.60	0.22
	19	10	70	<0.5	0.14
Aa5	13	9	78	<0.5	0.65
	7	5	88	<0.5	0.49
Fa495	32	19	48	<0.5	0.65
	11	19	70	3.00	0.25
Aa9	6	4	90	<0.5	0.61
Aa8	19	7	74	3.70	0.55
	65	13	22	1.30	0.53
	59	15	28	<0.5	0.42
Fa436	39	12	49	3.90	0.15
	43	14	43	3.80	0.13
	47	7	46	2.40	0.14
	35	9	56	5.90	0.17
	41	13	46	4.20	0.15
	38	8	54	5.80	0.13
	18	8	74	2.30	0.25
	14	15	71	2.70	0.30
	16	10	74	2.30	0.29
	5	4	91	3.90	0.59
	9	2	89	3.20	0.60
	7	3	90	1.70	0.43
	20	16	64	<0.5	0.35
	25	21	54	1.00	0.42
	27	17	56	<0.5	0.25
	4	4	91	1.00	0.65
	28	16	56	>6.0	0.19
	38	8	54	4.50	0.17
Fa459	48	14	38	4.10	0.06
	53	19	28	<0.5	0.25
	57	18	25	3.80	0.33
	38	6	56	4.10	0.35
	44	10	46	1.40	0.34
	21	16	63	3.80	0.32
	27	10	63	<0.5	0.33
	54	9	37	<0.5	0.56
	34	7	59	1.20	0.48
Ab127	7	4	89	<0.5	0.35
	5	8	87	4.80	0.33
	12	9	79	1.00	0.45
	14	7	79	2.60	0.59
	30	12	58	<0.5	0.63
Fa492	46	17	36	<0.5	0.62
	19	7	75	<0.5	0.58
	34	8	58	1.00	0.40
	28	12	60	<0.5	0.37
Fa496	29	12	59	<0.5	0.38
Ab217	7	8	87	<0.5	0.13
	13	11	76	<0.5	0.17
	12	13	75	<0.5	0.15

APPENDIX E: GPS Points showing Land use and Erosion features

Location	Land use	Feature
29°35′ 31 S 30°52′ 47 E	Grazing	Gully
29°35′ 44 S 30°52′52 E	Cultivated	Rills
29° 35′ 5 S 30° 53′ 6 E	Grazing	Gully
29° 33′ 1 S 30° 53′ 14 E	Sugar cane	Covered
29° 32′ 49 S 30° 52′ 52 E	Grazing	Road cut
29° 32′ 33 S 30° 51′ 50 E	Grazing	Road gully
29° 32′ 14 S 30° 51′ 33 E	Sugar cane	Rills
29° 31′ 45 S 30° 50′ 32 E	Grazing	Gully
29° 31′ 22 S 30° 49′ 40 E	Grazing	Gully
29° 31′ 43 S 30° 49′ 0 E	Grazing	Gully
29° 32′ 26 S 30° 48′ 26 E	Sugar cane	Rills
29° 32′ 17 S 30° 48′ 5 E	Grazing	Gully
29° 32′ 17 S 30° 47′ 22 E	Cultivated	Gully
29° 32′ 36 S 30° 46′ 59 E	Grazing	Severe erosion