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Title: Soil Erosion Assessment in the Republic of Cape Verde, West Africa, Using a Geographic Information System

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Charles Rosenfeld

Soil erosion is a natural physical process. However it can become a detrimental force when factors such as infertile soils, steep topography and poor farming practices are combined. An important initial aspect of resource planning and/or soil conservation involves locating areas where such potentially hazardous combinations occur in the field.

This study proposes the development of a soil erosion hazard map for a watershed in the Cape Verde islands, West Africa. The Cape Verde archipelago is composed of volcanic islands that constitute the western extreme of the Sahel. They provide classic examples of those areas where combinations of certain environmental factors result in cases of severe sheet, rill and gully erosion.

A range of computer software and theoretical modelling was used to develop a soil erosion hazard map for a 110 sq.km. watershed on the main island of Santiago. The programs included a computer cartography programme (AutoCAD), a Digital Elevation Modelling program (SURFER) and a Geographic Information System - GIS (IDRISI).

The research provided a study of the independent variables that impact soil erosion and their interactions. It also illustrated several concepts of automated environmnetal modelling and mapping: for instance data entry; vector-raster, raster-vector conversions; data analysis using a GIS and data output.

The final map indicated that most of the watershed was susceptible to low-moderate risk erosion. And the rest of the land posed a moderate-high or severe risk erosion. More importantly, the map will allow planners to gain an insight into the location of areas that require attention for conservation measures in the watershed.

Soil Erosion Assessment in the Republic of Cape Verde, West Africa, Using a Geographic Information System

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INTRODUCTION

Soil Erosion in Cape Verde

Soil erosion is a persistent problem which threatens the fragile economies of many developing nations, especially those countries where the density of the population is high and the carrying capacity of the land is being stretched to its limits (Bee, 1983). The Cape Verde islands, off the coast of West Africa, is one such nation, affected by soil degradation.

The Cape Verde islands (the archipelago is composed of ten islands) are located in the Atlantic Ocean. The islands are situated about 450 km. from the West African coast. See Figure 1. The islands generally have a mountainous terrain (except the islands of Boa Vista and Sal, which have a more flat terrain), with sandy, rocky soil of volcanic origin. There is sparse vegetation on most of the islands except in the cultivated valleys and the moister highlands (American Embassy, 1987).

The archipelago is considered to be part of the Sahelian region of Africa. Drought is therefore a common occurrence in Cape Verde. After an eighteen year drought,the country experienced a good rainy season in 1986 (American Embassy, 1987). When there is rain, however, it often falls as a tropical downpour and becomes a destructive force causing extensive soil erosion (Lescaze, 1986).

A qualitative assessment of land degradation rates since 1977 for the Sahelian nations was performed in 1982 by the United Nations Environmental Program (UNEP). The findings are summed in Table 1.

Table 1. Rates of Desertification

The results of the study indicate an increase in the rate of land deteriortation in Cape Verde. It is therefore essential to increase the flow of resources for future desertification control activities in this region (Berry, 1984). A move towards such a goal in Cape Verde was realised with the initiation of the Cape Verde

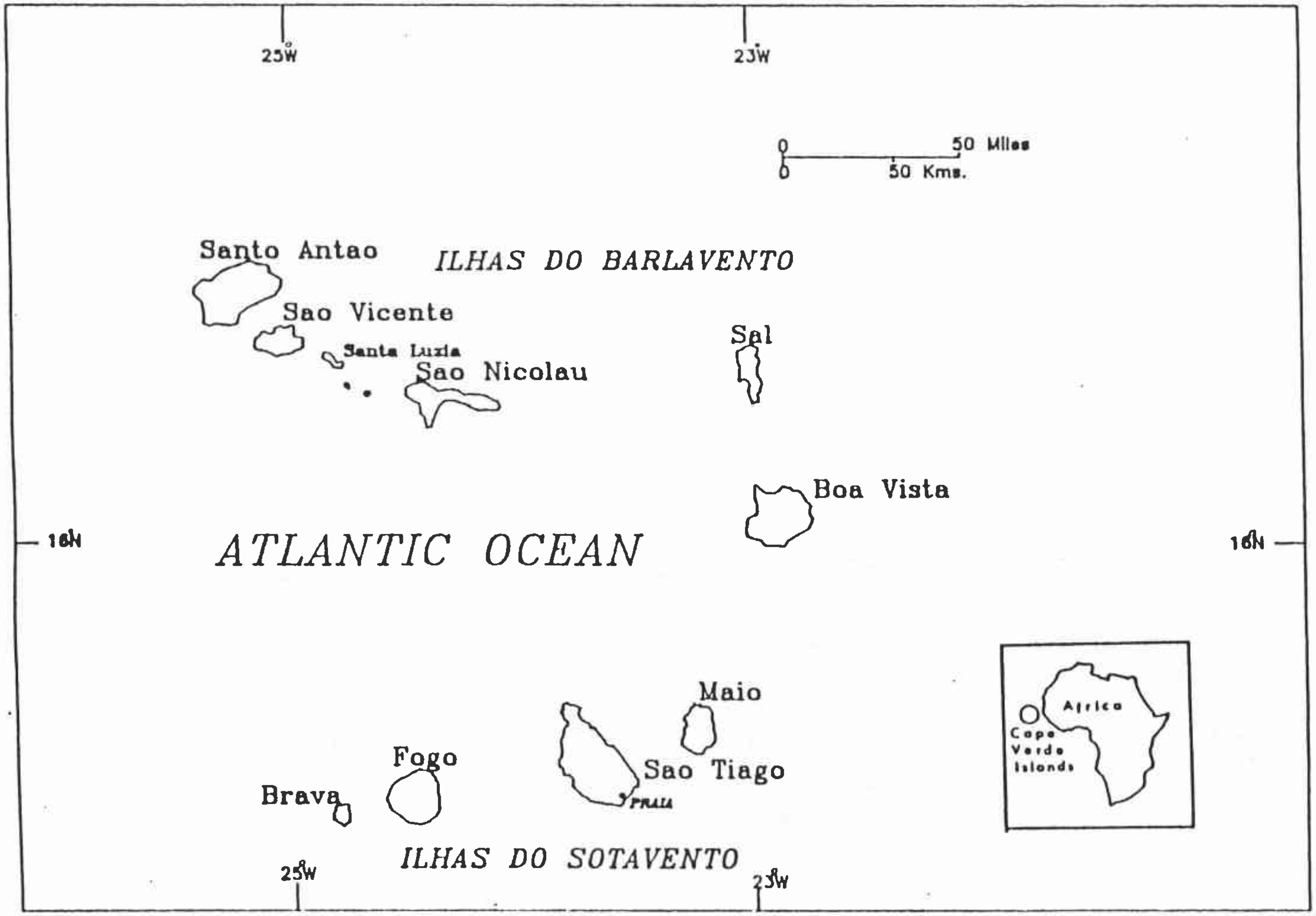

Figure 1. The Cape Verde Archipelago

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A qualitative assessment of land degradation rates since 1977 for the Sahelian nations was performed in 1982 by the United Nations Environmental Program (UNEP). The findings are summed in Table 1.

Table 1. Rates of Desertification

Countries	Sand Dune Encroachment	Deterioration in Rangelands	Forest Depletion	Deterioration of Irrigation Systems	Rainfed Agriculture Problems	General Assessment
Benin	o	*	*	o	*	*
Cape Verde	*	*	o	*	**	*
Chad	**	**	*	**	**	**
Djibouti	*	**	*	*	NA	*/**
Ethiopia	*	**	**	*	*	*/**
The Gambia	*	*	**	**	*	*
Guinea	o	o	*	*	**	*
Guinea-Bissau	o	o	*	*	*	*
Kenya	o	**	*	o	*	*
Mali	*	**	**	*	*	*/**
Mauritania	*	**	**	*	*	**
Niger	*	**	*	**	*	*/**
Nigeria	o	*	**	o	*	*
Senegal	*	**	*	*	**	**
Somalia	*	*	*	**	*	*
Sudan	**	*	*	*	o	*
Uganda	o	**	o	o	*	*
United Rep. Cameroon	o	*	*	o	*	*
Upper Volta	o	*	*	*	**	*

KEY: o =Stable. * =some increase. ** =significant increase

SOURCE: United Nations Environment Programme 1982 and analysis of questionnaire letter that was sent to colleagues.

The results of the study indicate an increase in the rate of land deteriortation in Cape Verde. It is therefore essential to increase the flow of resources for future desertification control activities in this region (Berry, 1984). A move towards such a goal in Cape Verde was realised with the initiation of the Cape Verde Watershed Development Project (WDP). In 1984 the WDP was approved and had as its main objective, "to develop and protect the soil and water resources of the project-designated watersheds" (Egli, 1989). Information resulting from the implementaion of this project included a soil survey, collection of rainfall data, channel reach inventories and air-photographs.

Erosion Studies

The assessment of erosion hazard is a specialised form of land resource evaluation, the objective of which is, to identify areas of land where the maximum sustained productivity from a given land use is threatened by excessive soil loss (Morgan, 1979). It is an important aid to broad-scale resource land use planning.

Erosion is a natural process on the earth's surface. When the soil erosion processes occur at a faster rate than the soil forming processes, then severe erosion leading to removal of fertile topsoil layers over large tracts of land occur. A previous study by Norton (1986) on soil erosion modelling for Santiago Island, distinguished between two types of erosion that occur in Cape Verde: geologic erosion and erosion enhanced by the activities of man (cultural erosion).

The islands are fairly young, and are still subjected to subareal processes, one of them being erosion (geologic). Cultural erosion, on the other hand, is an accelerated process of geologic erosion caused by a shift in the equilibrium between soil erosion and soil formation (Norton, 1986). This latter process is encouraged by poor farming practices and deforestation.

It is difficult to apply already existing erosion potential classification systems to Cape Verde, as the islands have unusual climatic and terrain conditions that are rarely found in other regions of the world. This study aims at developing a specific erosion hazard map for a watershed on the island of Santiago.

Objectives

The two main objectives of this research are:

1. To develop a soil erosion hazard map for the Picos and Seca watershed on the island of Santiago, Cape Verde.
2. To develop and refine an evaluation methodology that integrates the use of a computer assisted mapping/drafting programme (AutoCAD), geographic information system (IDRISI) and a surface analysis system (SURFER), simplifying data entry, data analysis and output.

Each objective had equal weighting in importance in the ensuing research. The study proposes a methodology that is based only on theoretical models and premises. Fieldwork to support and validate the proposed methodology may be used to follow up this study.

STUDY AREA DESCRIPTION

Due to the unusual nature of the environment of the Cape Verde islands, it is necessary to provide a more detailed description of the study area than was outlined in the introductory chapter.

Location

The study site of Picos and Seca watershed on Santiago island was chosen for the Cape Verde Watershed Project, by Sheladia Associates and Oregon State University, as a prototype watershed to be used for evaluation purposes. A resource inventory and assessment was to be performed for this study site, in order to develop a Geographic Information System (G.I.S.) for watershed planning purposes.

Ribeira dos Picos and Ribeira Seca are located in the east-central section of Santiago island, about 10 km. north of Praia (Figure 2 Location of study site on Santiago Island). This is the windward side of the island. The two rivers run almost parallel to each other and have their sources in the central highlands of the island of Santiago. The total area of the study site is approximately 110 sq. km.

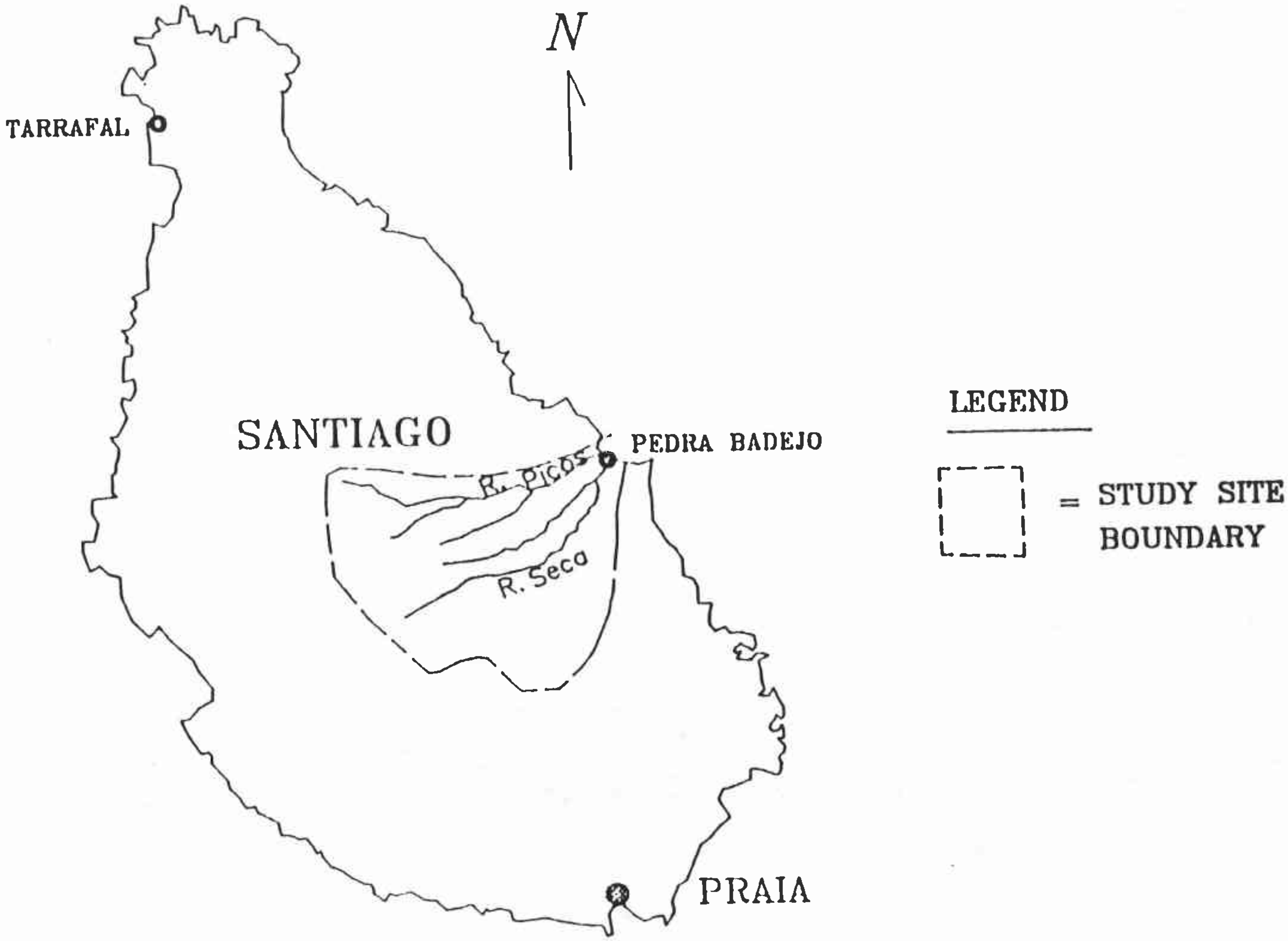


Figure 2. Location of Study Site on Santiago Island

Climate

Mannaerts (1986) described the islands as the western most state of the Sahelian region. An analysis of climatological records shows that meteorological drought is an inherent feature of the Cape Verde Islands (Mannaerts, 1986). The annual average rainfall, of 250 - 300 mm. is low, with extreme interannual variability, characteristic of a semi-arid zone. Precipitation is seasonal with a monsoon rainy season followed by a prolonged dry period (Simonson, 1988). See Figure 3 for representation of annual precipitation in Santiago. High intensity precipitation events are common in this region; often the total monthly precipitation of even the wettest month is often a result of only two or three storms (Egli, 1989). Lenhart (1989) described the two types of extreme rainfall events: thunderstorms and orographic lifting. The rainfall quantity used to differentiate the two events was one of 20 mm. A rainfall event exceeding 20 mm. was considered a thunderstorm. See Figure 4 for frequency of thunderstorms. One conclusion of this study was that there was an 80% chance of a 430-680 mm. rainfall event occurring every 100 years.

Rainfall on Santiago is governed by two macroscale mid-Atlantic air mass movements: the tropical Inter Tropical Convergence Zone (ITCZ) in summer and the north-easterly trade winds in Winter and Spring

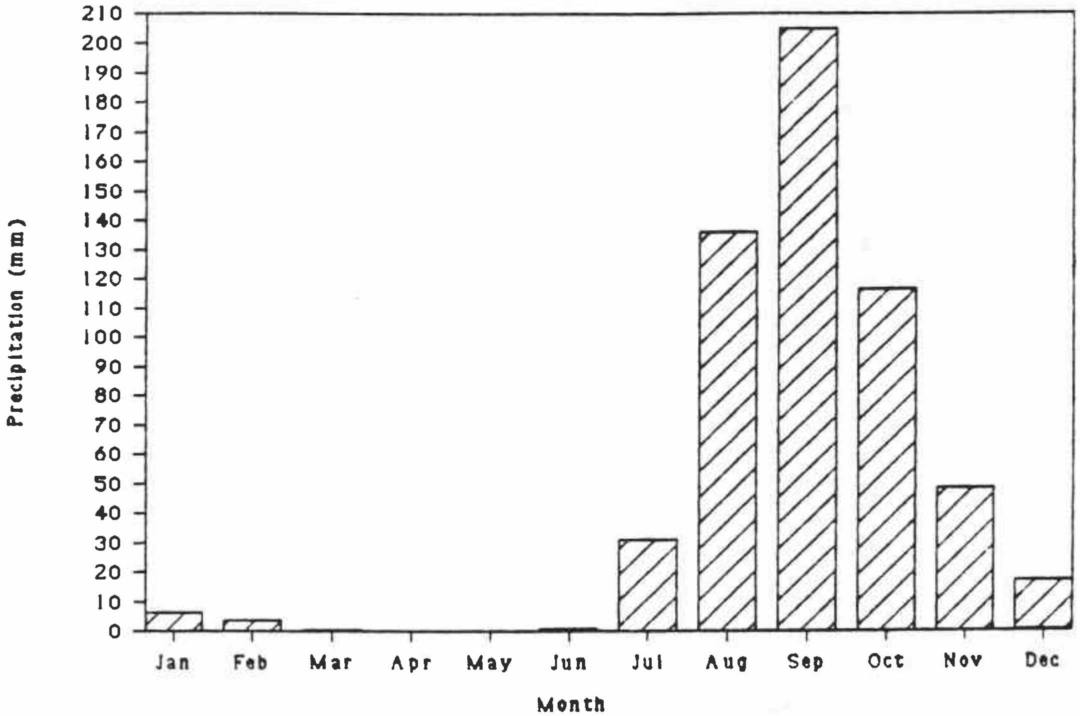


Figure 3. Average Monthly Precipitation for San Jorge (station 12), to Illustrate Distribution of Annual Rainfall (Source: Lenhart, 1989)

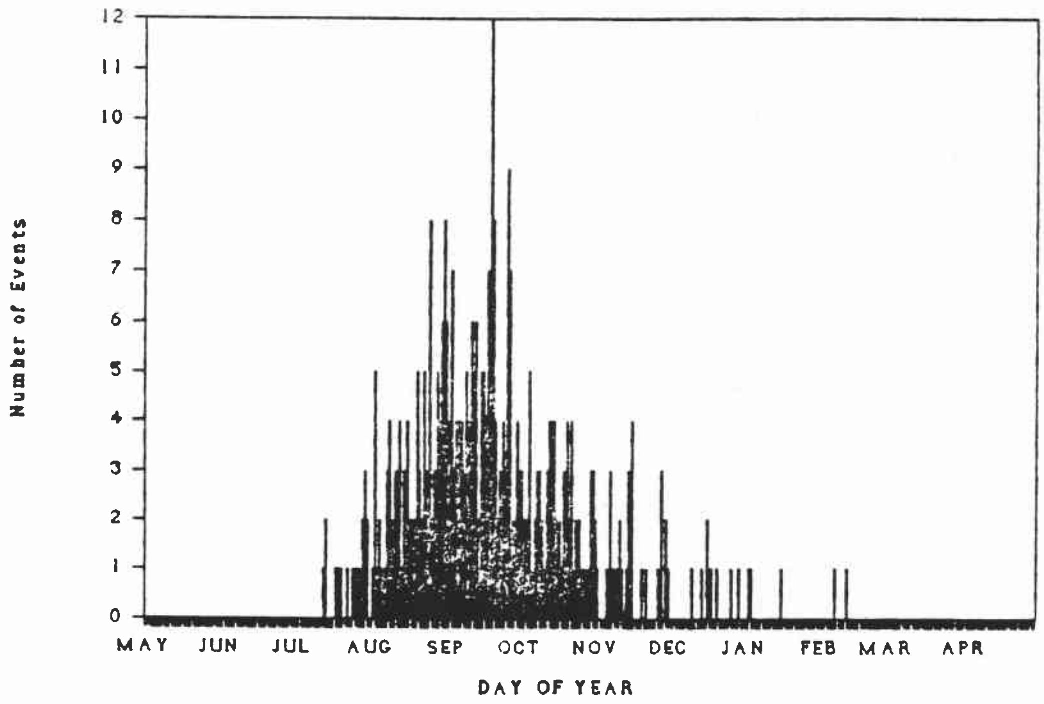


Figure 4. Frequency Distribution of Thunderstorm Events Greater than 20 mm.
(Source: Lenhart, 1989)

(Mannaerts, 1988). The ITCZ is an area of rising air caused by the heating effect of the sun (Gilbert, 1982). The ITCZ is a trough of low pressure, that shifts north and south depending on the sun's overhead position. When the sun moves into the northern hemisphere, from April to September, the ITCZ shifts north, and similarly when the overhead sun is in the southern hemisphere in December to February, the ITCZ moves south (Gilbert, 1982). See Figure 5.

During recent decades, the Sahel region has experienced two major anomalous rainfall conditions: the 1950's wet decade and the 1968-'73 drought period (Nicholson, 1981). Nicholson, in her study suggested that a northward displacement of the ITCZ could account for wetter years, but a "weakened" intensity of the rainy season, independent of the ITCZ position, was the most likely cause of drought in this region of West Africa (Nicholson, 1981). Since the Cape Verde archipelago is located at the northwestern limit of the ITCZ, the smallest change in weather systems in this region portend disaster (Meintel, 1984).

Precipitation occurs on the islands, as a result of convectional and orographic lifting (Riegelmann, 1989). Due to the orographic effects, different bioclimatological zones have appeared: there is a general sequence from an arid coastal zone, to semi-arid

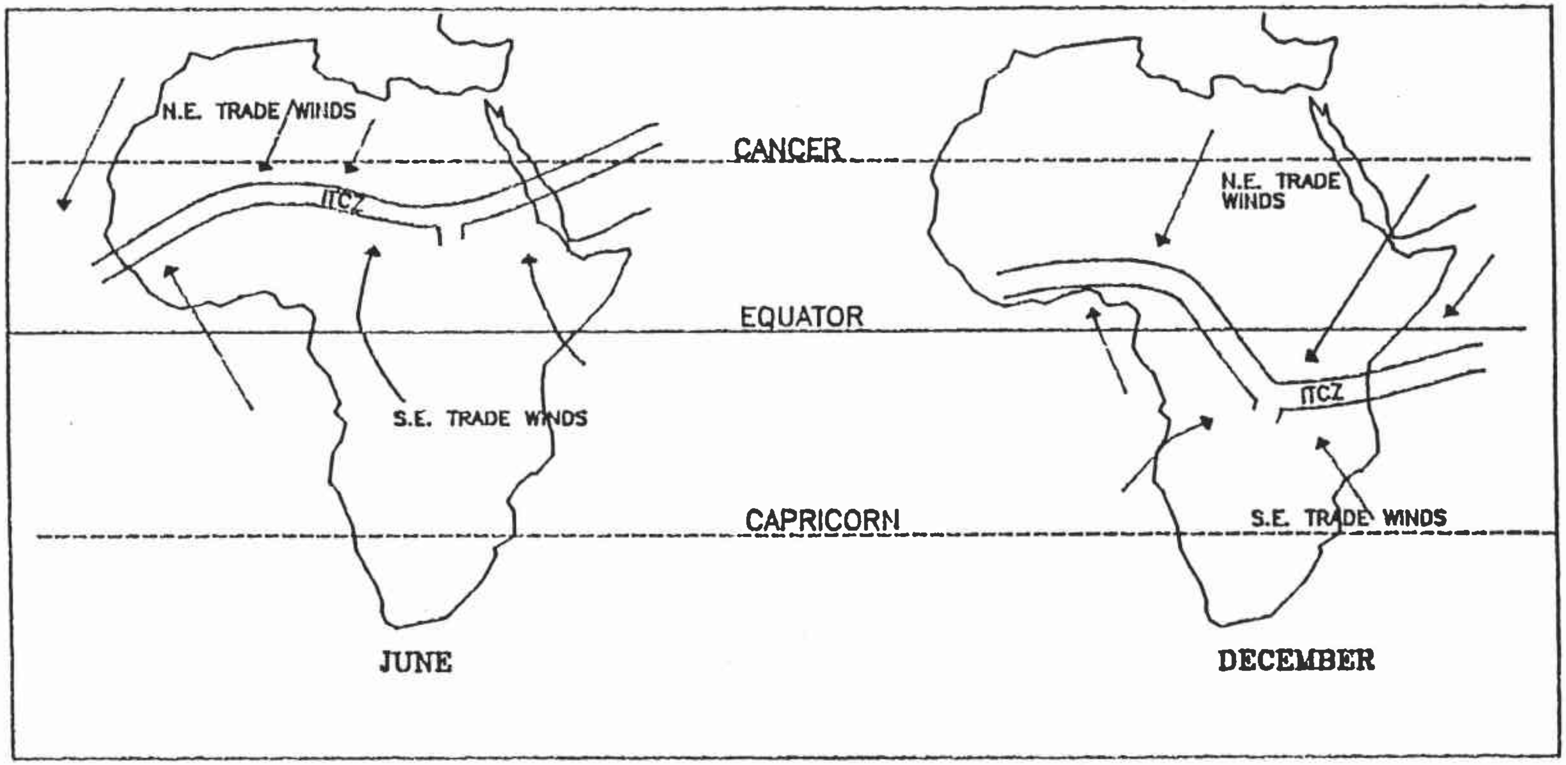


Figure 5. Movement of ITCZ band in Africa
(Source: Gilbert, 1982)

inlands to a sub-humid upper mountain range (Mannaerts, 1986). The microclimatic regimes of the island vary due to distinct differences in elevation. The mountainous islands of Santiago, Brava, Fogo, Sao Nicolau, Santo Antao and Sao Vicente are mosaics of microclimates (Meintel, 1984).

Mean monthly temperatures do not vary widely and range from 19.7° - 26.3° C with a maximum range of 23.2° - 30.4° C and a minimum range of 14.3° - 22.2° C. Despite the even temperature experienced throughout the year, there are seasonal variations. For example, from November to March the "windy" season prevails. Dry tropical winds from the north-east called 'Harmattans' blow from Mauritania and Senegal and cover the land in yellow Sahara dust (Meintel, 1984). Cooler, humid winds from the south-west bring some precipitation during the winter months.

Geology/ Relief

The islands were formed by a series of volcanic eruptions. The oldest rocks exposed on the island of Maio indicate the late Jurassic-early Cretaceous period. The geology of these islands have shed light on paleoenvironments of the eastern central Atlantic and help to document the early history of a deeply dissected

Atlantic island (Robertson, 1984).

The Picos/Seca basin study site is in a highly dissected volcanic terrain (Simonson, 1988). The geology of the underlying rock is basaltic in nature. Semi-consolidated weathered tuff brechias and/or tuffaceous mud flow rocks are also major parent material sources for the soils in this area (Simonson, 1988).

The study site exhibits the rugged terrain characteristics of Santiago Island (Egli, 1989). The generally high relief (the highest point being Pico da Antonia, with an elevation of about 1400 m.) in the two watersheds have given rise to steep, long slopes (Simonson, 1988). This relief is considered to be a result of the alteration and erosion over time of a massif of relatively recent volcanic origin (Egli, 1989). Streams have dissected the land to form deeply incised valleys and high narrow ridges/achadas in between.

Detailed soil mapping was performed by Simonson (1988) and was one of the variables entered into the Geographic Information Systems (GIS). The soils of the study site were formed from volcanic bedrock or colluvium, slope wash, and stream alluvium derived from upslope (Simonson, 1988). Simonson observed that most of the soils in the Picos/Seca basin were Mollisols. The term Mollisol is derived from a Latin word meaning soft: the surface layer is often soft, dark fertile and deep (Gersmehl et al, 1980).

Vegetation

The Portuguese settlers found no edible native plants (except the fruit of the tamarind tree) and the islands proved to be inhospitable to wheat and other cereals of the continent (Meintel, 1984). Due to the varying bioclimatological groups caused by orographic rainfall, vegetation is absent on the dry plateaus or achadas, whereas in the valleys and foot slope areas drought resistant tree and shrub species flourish (Mannaerts, 1986). In the higher mountain ranges, where more precipitation falls, shrub vegetation with some perennial and annual grasses grows.

The natural vegetation of the semi-arid areas in Santiago have been influenced by drought and human activity(Mannaerts, 1986). The original forest resources, which included species such as Acacia spp., Tamarindus indica, and Aloe spp. dwindled as more land was converted to agriculture.

In the hotter lowland areas, the local people grow crops such as papaya, mango, coconut, and citrus along with bananas and sugar cane; in the uplands, maize and varieties of beans, squash and gourds are grown (Meintel, 1984). Even the steep slopes of the watersheds have been cultivated with sisal (an agave native to southern Mexico) (Riegelmann, 1989).

The food-bearing plants most important in the Cape Verdean diet come from Latin America (for example maize, sweet potatoes, manioc); Asia (yams, fava beans, bananas, coconuts) and Africa (coffee, yams, beans and nuts) (Meintel, 1984). Other crops grown include garden vegetable varieties and tobacco.

Land Use

A land use study for Cape Verde was published in 1981, by the French (Egli, 1989). The results of this survey indicated that rainfed agriculture was regularly practiced in the more humid middle and upper parts of the watershed, whereas irrigation appeared to be concentrated in the lower drier sections (Egli, 1989). The following categories of land use were identified for this 1981 study:

1. Arable land - Regularly Rainfed
   - Occasionally Rainfed
   - Irrigated
   - Semi-Irrigated
2. Uncultivable Land
3. Barren Land

In Riegelmann's (1989) more recent work on the Boca Larga sub-basin, land use was divided into two types: irrigated and non-irrigated agricultural land (grazing). A very small percent of the land was subjected to perennial irrigation and the majority of land was observed to be non-irrigated agricultural land (and grazing). Mannaerts (1986) described the upper mountain ranges as having a mixed land use pattern consisting of seasonal rainfed agriculture, cattle grazing and forest plantations. The official land use policy established by the government, for the arid coastal regions, which occupy more than 50% of the total area is afforestation for conservation and production (Mannaerts, 1986).

Agriculture

The cropping systems are based on a traditional agricultural method which often accelerates erosion processes and decreases water retention (Lenhart, 1986). Land ownership is based on an equally traditional, highly complex system, which results in a myriad of small plots. These factors form a barrier to control of cropping systems and/or agricultural practices (Lenhart, 1986).

Egli (1989), in his discussion of agricultural practices in the Picos watershed, described the two main methods of agriculture as rainfed and irrigated cropping. Rainfed agriculture often consists of cropping. Rainfed agriculture often consists of varieties of beans intercropped with maize. No fertilizers are used and the crops are grown primarily for home consumption (Egli, 1989). Irrigated crops are often sugar cane, manioc and sweet potato planted on steep slopes, or grown along river floodplains.

Most non-irrigated lands are subject to annual grazing by livestock (Riegelmann, 1989). Most families own goats, pigs and some poultry. Livestock raising is also integrated with agriculture (Egli, 1989).

LITERATURE REVIEW

A literature search was performed in three major fields: literature pertinent to the overall theme of erosion studies in Cape Verde; literature dealing with the methodology used for the research, and finally, as one of the variables that had to be formulated was a land use/land cover map, a literature survey was conducted on the different methodologies that exist for developing a land use map using air-photographs.

There are few systematic research observations on erosion in Cape Verde that have been documented. Therefore, studies on erosion in areas with similar conditions/situations as that of Cape Verde (that is, semi-arid or arid areas in developing nations) were chosen as case studies in the literature review. The case studies in the following discussion parallel the scenario in Cape Verde and are considered pertinent to this study.

Erosion Studies in Cape Verde

The literature that exists on erosion studies in the Cape Verde Islands often appears indirectly as a sub-section from a major research effort. Little research has been done over the past few years on erosion on these islands. Nevertheless, it remains a constant and well recognised problem.

As an introductory source, a chapter in Meintel's book (1984) entitled, "The Crises: Drought and its Social Consequences," deals briefly with erosion as a factor in the drought crisis. She states, "the effects of both low and erratic rainfall were exacerbated by a number of other factors, both natural and man-made." Meintel further observed that original plant cover was overgrazed by livestock (especialliy goats) and a serious reforestation program had not been implemented. These factors have aggravated the process of erosion.

In a report by Mannaerts (1986) the two major causes of desertification on the islands were cited as: a.)tree and shrub cutting for wood as an energy source; b.)cultivation of short cycle erosive crops (especially maize) on marginal land with topographical constraints, that is, steep slopes. The main objective of the Mannaerts study was to study the environmental and socio-economic impact of forest plantations as an introduced land use type in marginal semi-arid areas of

Cape Verde.

Mannaerts considered the Cape Verde islands to be the most western edge of the Sahelian region. The semi-arid inlands constitute the rural, most important zone of Cape Verde, where signs of severe, widespread sheet, rill and gully erosion were evident, especially in areas of subsistence agriculture. The main land use practices in the semi-arid areas were extensive grazing and rainfed agriculture.

Part of Mannaert's study involved assessment of erosion rates. One of the techniques used involved measuring suspended loads and a qualitative evaluation of the bed load that passed through a hydraulic flume during a rainstorm. The study concluded that under normal rainfall conditions major soil loss occurred. Another technique tested for measuring soil loss was the Universal Soil Loss Equation (USLE). The USLE was first developed in the U.S.A. by Wischmeier and Smith, 1965, to study soil loss rates in the mid-west. The results of this method, showed large discrepancies between the actual measured soil loss and the predicted values (using the USLE). Thus USLE values were considered to be non-applicable to this study, on these islands (Norton, 1986).

Three watersheds of similar size area were used for Mannaert's (1986) work. Each watershed was prepared for different land uses as follows: afforestation (using bench terraces and mini-catchment techniques), natural vegetation cover, and finally rainfed agriculture consisting of maize and bean crops without erosion control practices. These practices were to be monitored over a 2-3 year period. More specifically, the hydrological (and erosion) parameters of the three catchments during the rainy season, and economical valuation of the "crops" of the watersheds, were to be studied. A follow-up report on the evaluation has not yet been published.

Following Mannaerts work, Norton (1986) applied four erosion models to measure soil loss on experimental sites on Santiago island. They were the USLE and models in the form of computer packages, ANSWERS (Areal Non-Point Source Watershed Environmental Response Simulation), GUESS (Griffith University Erosion Sedimentation System) and EGEE (Ephemeral Gully Erosion Estimator). After installation of the experimental sites, the data on soil loss was to be collected and used in the four computer models. Norton used the three watershed basins with different classifications of forest, fallow and cultivation developed by Mannaerts. Norton confirmed Mannaerts observation that although the erodibility characteristics of the basin soils were low, other factors such as excessive slope, high intensity precipitation and management techniques resulted in severe erosion. He also observed that the L factor (the slope length) in the USLE model did not hold true for the types of soils found in Cape Verde or the extremely long steep slopes (Norton, 1986), again negating the application of the USLE. Norton recommended more detailed study of slope gradient and soil loss in the islands.

The intensive soil survey was recently performed by Simonson (1988) for the Picos and Seca watersheds on Santiago island used the U.S. Soil Taxonomy (1,2) as the basis for describing and classifying the soils. This system reflected differences in soil development as indicated by the nature of genetic horizons in the soil profile. Simonson observed that the soils of Picos and Seca basins were mainly formed from volcanic bedrock or colluvium, and stream alluvium. Basalt formed most of the ridges and achadas while weathered tuff brechias were found to be the parent material for most mid and lower slopes below the ridges.

The description of each soil series gave estimates of permeability, infiltration rates, water-holding capacities and relative erodibility (Simonson, 1988).

Simonson reiterated Norton's point, that despite the low erodibility of the soils, high rates of soil loss were occurring and this was due to a combination of negative factors such as cultivation of soils on steep slopes, lack of vegetation on soil surfaces and high intensity precipitation. Finally recommendations concerning soil conservation techniques were made, in this study.

Lenhart (1987) in his rainfall/hydrological report for the Cape Verde Watershed Development Project. He mentioned that the various cropping systems observed were found to be detrimental to the soil. For example, on slopes where the gradient was almost 100%, the land was initially cleared of vegetation by manual labour before a corn crop was planted. When rainfall did occur, loose soil was easily eroded and rilling occurred (Lenhart, 1987). The paper also discussed soil/water conservation structures and their effectiveness on the island of Santiago. A strong recommendation was made to change cropping systems on the fundamental level or else accelerated erosion would continue.

Lenhart followed this latter report by a thesis (1989) in which more detailed work on the rainfall data was accomplished. This research on rainfall modelling for Santiago Island was a quantitative study using the statistical analysis of rainfall values. Lenhart also developed a database program (RIS) that was used for storage and analysis of rainfall data. An understanding of the rainfall regime for an area such as Santiago

Island, is essential for the determination of water supply, basin response, erosion potential, flood and drought frequencies (Lenhart, 1989).

Data from the rainfall station San Jorge (located in the Seca basin) was used throughtout the study, as it was one of the few stations with complete records dating from the 1940's. The three distribution models that are applied to rainfall data were a truncated Log-Normal, Log-Pearson Type III and an emperical distribution for the determination of rainfall depth and a Markov chain was used to determine the occurrence of precipitation (Lenhart, 1989).

Some conclusions of his study that are interesting to note are for example the storm event in 1951, of 534 mm. rainfall, is a 100 year event. Probabilities of dry runs during the months of September and October indicate a 10% probability of a 17 day dry run during the growing season (Lenhart, 1989).

One of the most recent publications regarding the Cape Verde Watershed Development Project was written by Egli (1989). The report discussed the Phased Watershed Development Plan (PWDP) for the Picos watershed. The basic purpose of the PWDP plan (PWDP) was to provide the framework for rational planning and programming of the watershed development work (Egli, 1989). One of the first steps undertaken was a resource base assessment for the Picos watershed. Recommendations included afforestation, establishing permanent vegetal cover on slopes over 45%, and creating new irrigable lands. Resource protection and development measures were grouped into two classes: soil and water conservation measures (to increase infiltration and reduce erosion) and water resources development (to capture, convey and store water for irrigation) (Egli, 1989).

Finally, Riegelmann (1989) used stream reach inventory methodology to measure and evaluate stream channel bed/bank materials. He also provided information about the capacity of streams to react and adjust to potential changes in flow and increased sediment production. This study used a prototype watershed basin within the larger basin of Ribeira Picos and Ribeira Seca, in the east-central part of Santiago island. The environmental and human factors that are integral to the process of erosion are interactive parts with the watershed microenvironment (Riegelmann, 1989). Causative factors affecting erosion, that were identified, included rain, wind, fire, construction, grazing or cultivation.

The study was conducted in several phases: a photographic inventory of the changing landscape was documented and field data was collected for the study site of Ribeira da Boca Larga. Aerial photographs were also a vital data source for information such as erosion control structures, location, land use, transportation network, water resources, mass wasting, irrigated land and crop types (Riegelmann, 1989).

Processing of data in this project centered around computer analysis, that is the creation of a Digital Elevation Model (DEM) and development of a GIS. Several observations were made concerning the erosion dynamics of Ribeira da Boca Larga watershed: for example during the first convectional rainfall of the season, high velocity flows occurred over bare slopes entering the stream channels (Riegelman, 1989). Thus, much of the Boca Larga channel bed consisted of coarse sand and gravel, which formed an infertile base for the crops that had been planted in the river bed.

The application of A Geographic Information System (GIS) in Studying Erosion

A wide diversity of definitions exists for the term Geographic Information System (GIS). One general definition by Parker (1988) stated that a GIS is, "best defined as an information technology which stores, analyses, and displays both spatial and non-spatial data." There are numerous publications concerning the application of a GIS in studying any type of resource management issue. The major GIS application in natural resource management is planning (Parker, 1988). The resource manager often has to display and analyse the interpreted information or data in a spatial context (Lillesand and Kiefer, 1987). Thus a GIS is of great value when several variables have to be interrelated.

To illustrate the use of a GIS in a resource management context, Lillesand and Kiefer (1987) dealt with the situation of a hydrologist studying erosion and sedimentation in a watershed. At a minimum, the process would require the study of topographic slope, soil erodibility and surface runoff characteristics (Lillesand and Kiefer, 1987). In order to derive certain information, source maps would be used - slope can be determined from contours on a topographic map; soil erodibility from the soil map and runoff potential from a land cover/use map. This information is interrelated to locate areas where combinations of site characteristics indicate high soil erosion potential (Lillesand and Kiefer, 1987).

An article by Walsh (1987) on the use of a GIS for natural resource management, stated that planners can correlate land cover and topographic data with a variety of environmental parameters relating to indicators such as surface runoff or terrain configuration. Walsh discusses one particular GIS, the Oklahoma Geographic Information Retrieval System

(OGIRS), and the application of such a system.

Walsh describes the different stages in developing a GIS: data entry, where spatial information froma map has to be transformed into an array of X, Y and Z coordinates that describe the data (Walsh, 1987). The transformation occurs via a graphic digitizer. The OGIRS stores data in thematic libraries, while data display is performed using electrostatic printer/plotter maps and color images. Finally, data manipulation involved a standard set of mathematical functions, five value selection modes and three mapping functions (Walsh, 1987).

An example of an application was the estimation of runoff. As runoff is a function of soil, vegetation, and antecedent moisture, these land data files could be entered separately, and then analysed to develop runoff maps.

An article by Meijere and Van de Putte (1987) also used a watershed study as an example of a case where GIS was used for a planning or managerial purposes. The study dealt especially with the organisation required to incorporate a GIS with a data base for natural resource management. In Indonesia, five objectives of watershed management were formulated, one of them being erosion control: that is maintenance of productive and ecological characteristics of the land (Meijere and Van de Putte, 1987). In this study, erosion modelling was based on an adjusted USLE, and formed only one part of the model base.

Millington et.al. (1982) described some of the parameters that need to be studied in order to develop a soil loss and erosion hazard map in a developing country. They noted that the parameter inputs for the USLE were not generally available in developing countries. However, inputs representing rainfall, topography, soil, land use and vegetation are basic requirements in such a study. These parameters were presented as unit grid systems and then overlaid to obtain values for soil loss.

Turner et.al. (1988) described a PC-based GIS developed by the International Institute for Aerospace Survey and Earth Sciences (ITC), the Netherlands, for integrated assesment of environmental hazards in developing countries. ILWIS (Integrated Land and Water Management Information Systems) combines vector and raster georeferencing and is currently operating in Indonesia, Colombia, Nigeria and India. The Indonesian watershed studies could be considered typical of many applications for a GIS: agriculture is expanding onto previously forested areas on steep slopes, and consequently erosion is destroying much of the farmland.

Dalsted (1988) performed a study using LANDSAT data and a GIS to evaluate sites for monitoring desertification. The location of the study was in South Mauritania. The GIS used for this study was one called Area Resource Analysis System, AREAS. Some of the layers included a map for forestry, soil and pasture. To develop a soil erosion hazard map, Dalsted, used various soil and ground cover variables and made interpretations from the soil survey that was done prior to the study. The parameters used to develop a soil erosion hazard map were: ground cover, slope, surface soil texture, soil structure and its perceived stability and existing erosion. Composite maps were then produced using the three variables of forestry, soil and pasture. Dalsted (1987) concluded that full use of a reconnaissance survey of resources could be made toward regional planning, management or development.

Hellden (1987), associated with the University of Lund, Sweden, carried out a study on assessing woody biomass, community forests, land use and soil erosion in Ethiopia. The study detailed the importance of using a GIS for such work. The major advantage of a GIS is the ability to integrate and analyse large amounts of data from different sources and with different themes, for computer based generation of new information layers, maps and statistics for planning. The USLE model was adapted for Ethiopian conditions and the main parameters used were land cover, precipitation characteristics and topography (slope length and gradient). These environmental factors were then assessed on a pixel by pixel basis in a series of steps, such that: LANDSAT scenery was classified for land use/land cover; existing soil maps were digitised, and slope gradient was obtained from topographical maps.

In all the cases cited above, a GIS was used for erosion hazard evaluation in a developing country, and certain variables were selected as factors that were primarily related to the problem. The four variables that were most commonly chosen were: soil, precipitation, topography (slope length and gradient) and land cover/use. Agricultural research has clearly indicated that there are five crucial factors, affecting erosion. They are as follows:

a.) intensity and quantity of precipitation

b.) structural resistance of the soil to erosion

c.) the morphology of the land

d.) types of crops grown

e.) management of the land

(Lewis and Berry, 1988).

Stocking and Elwell (1973) criticised Fournier's (1960) erosion hazard map for Africa, which was based solely on climate and slope, and no attempt was made to include additional varaibles (which have been identified in experimental plot studies) such as soils, cover and human influences. Stocking and Elwell (1973) in their work on soil erosion, in Zimbabwe, performed a quantitative study and used factor analysis to relate the various variables.

To summarise these findings, an article by Hudson (1978) should be mentioned at this point, as it dealt with the very realistic topic of, the problem of erosion prediction with insufficient data. One of the first factors mentioned was the fact that the USLE, in geographical terms, applies only to the Eastern part of the U.S. There is absolutely no justification for extrapolating the model to Europe or Africa or anywhere else (Hudson, 1978). Hudson defined various types of erosion; for example hillslope erosion due to precipitation, wind erosion and erosion in gullies. The main mathematical relation for erosion was defined as:

$$E = f\ (\text{rain, soil type, topography, management})$$

if E = Erosion and f = function.

Hudson ventured that in predicting erosion losses, the essential features to be considered were firstly the purpose and the scale of the exercise, and secondly the reliability, accuracy and availability of the data.

The Use of Aerial Photographs for Land Use/Erosion Studies

As part of the methodology in this study was to develop a land use map, a brief literature survey was conducted to note the different approaches in producing such a map.

A photo-interpretation study of erosion hazard and land use in Lesotho was performed by Makhanya (1978). The study area covered was about 36,650 ha. in western Lesotho. As agriculture was considered to be the mainstay of the economy, agricultural land use was classfied into settlements, cultivated land and rough grazing land. The air-photo's used were at scales of 1:30,000, 1:40,000 and 1:80,000, and were found to be adequate for land use mapping. Intensity of erosion and type of erosion were also mapped from the air-photographs. Production of erosion maps followed a series of stages: an average slope map was developed from orthophoto maps; another map classified slopes as either convex or concave; the first map was then superimposed on the latter, and factors such as length of slope and vegetation cover were taken into account to develop an erosion susceptibility map.

Adeniyi (1980) used sequential black and white aerial photographs to acquire basic urban land use change data for Lagos, Nigeria. The methodology used had two components - data acquisition and data handling. The primary data source was sequential aerial photographs (scales 1:40,000 and 1:20,000) and data interpretation was performed using a mirror stereoscope. The data was then transferred to a Base map using a Zoom Transferscope (ZTS). Finally the land use data were put into computer format by encoding the dominant land use for each 100 sq. m. grid cell.

In J.B. Campbell's book (1983), "Mapping the Land," the use of aerial imagery for land use mapping was discussed through all the different stages. Preparation of a land use map from aerial imagery was essentially a process of dividing the image into a mosaic of parcels assigned to a land use class. The book also mentioned the compatibility of a land use map with other data; that is land use information had its greatest usefulness when used with other information, which can be superimposed to form an unified, multi-faceted data set.

Mushala (1986) carried out a land systems and soil erosion study in Central Tanzania using multistage remote sensing. The mapping exercise was part of a general attempt to generate a data base for use in the control of accelerated soil erosion. The project used Landsat imagery as well as aerial photography. The surrogate features used by the remote sensing analyst in the assessment of soil conditions were land use and land cover. One of the main methods used to interpret land systems was selection of criteria such as the vegetation, land use patterns, drainage characteristics and topography. The criteria were all interpreted from the Landsat imagery or aerial photography. Topography and slope were the two elements found to exert the dominant control on the extent and severity of soil erosion (Mushala, 1986).

Most of the work reviewed utilized aerial photography or satellite imagery as a data source for mapping land use. Once these data were compiled, they were entered into a computer as a data layer, to be used in çonjunction with other maps. A procedure that paralleled Adeniyi's (1980) work was adopted for this study and will be discussed in more depth in the methodology chapter of this paper.

METHODOLOGY

The basic precept for developing a land capability classification, involves mapping each landscape attribute separately, and overlaying relevant maps to determine different combinations of attributes (Westmann, 1985). If this method is automated and includes collections of spatial data and data analysis, it is termed a Geographic Information System.

There are several approaches to the mapping of land capabilities used by resource analysts. Examples include the Gestalt method, parametric systems and mathematical combinations. The widely used parametric system was applied to the data in the ensuing methodology. In this technique, individual parameters or attributes (soils, vegetation, climate) are separately mapped and rated for suitability, and these ratings are combined into a grand index of suitablity (Westmann, 1985). See Figure 6.

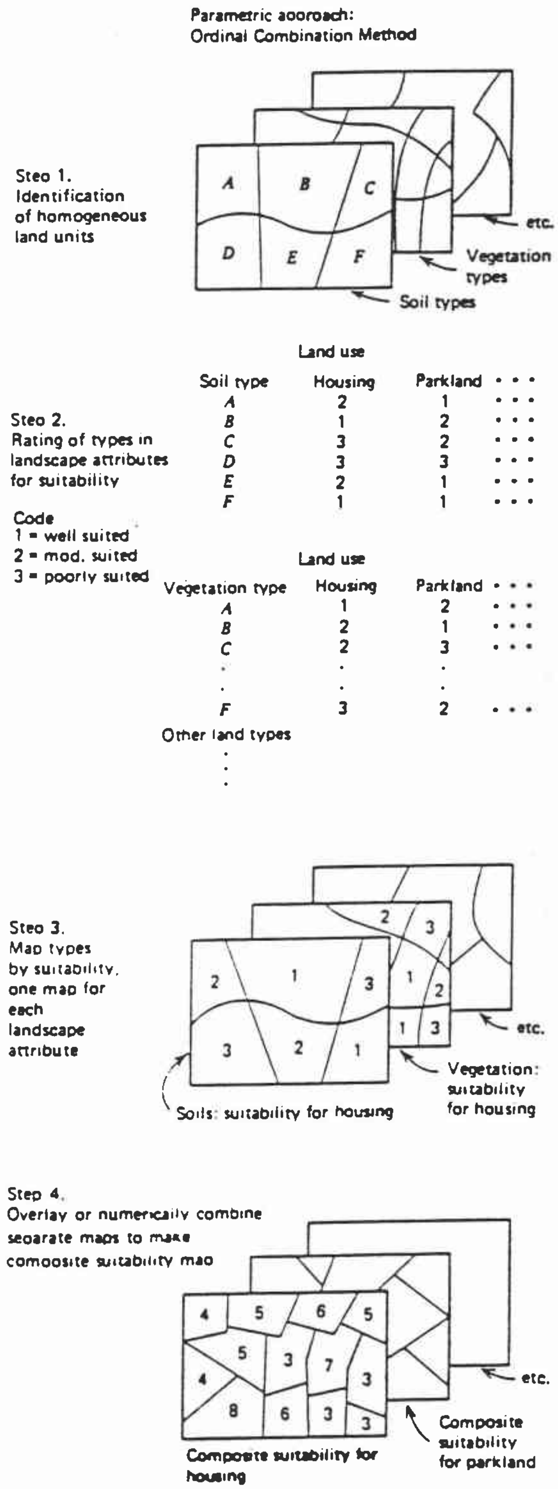


Figure 6. Diagram to Illustrate the Parametric Method (Source: Westmann, 1985)

Concept of a Geographic Information System

Spatial data analysis and manipulation is a common feature in many disciplines such as geography, geology, oceanography and environmental sciences. The most common medium for vector data, that is, coordinate based information, has been the paper map(Marble et.al., 1984). Over time, the need for analysis of data on a large scale has meant that retrieval of data from a paper map format has proved cumbersome.

In 1969, Ian McHarg, published a book "Design with Nature," that set a precedent for much of the work being accomplished today in environmental planning/resource management. The basic proposition employed was that any place can be conceived as the sum of historical, physical and biological processes (McHarg, 1969). Once each place was considered as a sum of processes that have social values then certain decisions could be made regarding the optimum use of an area. This latter concept, McHarg termed an area's intrinsic suitability. McHarg (1969) used a case study of Staten Island to demonstrate these principles. For each ecological factor a ranking system from high to low was established. Each data set was prepared on a transparent map sheet, the maps were coded in grey tones according to the condition being illustrated, and then by overlaying the transparent sheets a variation of grey tones indicated certain combinations of factors

(Lillesand and Kiefer, 1987).

In the case of the map overlay procedure, computer coding of the resource information and manipulation of the coded data greatly increases the efficiency over the manual method. A system that is designed to store, manipulate and display the data is describes as a geographic information system (GIS) (Lillesand and Kiefer, 1987). See Figure 7.

One of the main products of a GIS is a document. Documents are lists of data or graphics, that can be used by the researcher (Marble et al, 1984).

Data Entry and Conversion: Overview on Using AutoCAD, SURFER and IDRISI

Cartographic data to be used in conjunction with a computer can be basically of two types: raster or vector. Any picture or image can be created by either drawing a great number of straight lines or by using a number of closely spaced points to provide certain tones and shades (Carter, 1984). The use of straight line segments to create a picture or a map is known as vector graphics. In this mode, linear features such as rivers and roads are recorded as X,Y coordinate pairs (Monmonier, 1982). Raster graphics, on the other hand, are composed of a series of small squares/dots known as pixels (picture elements). See Figure 8 for a

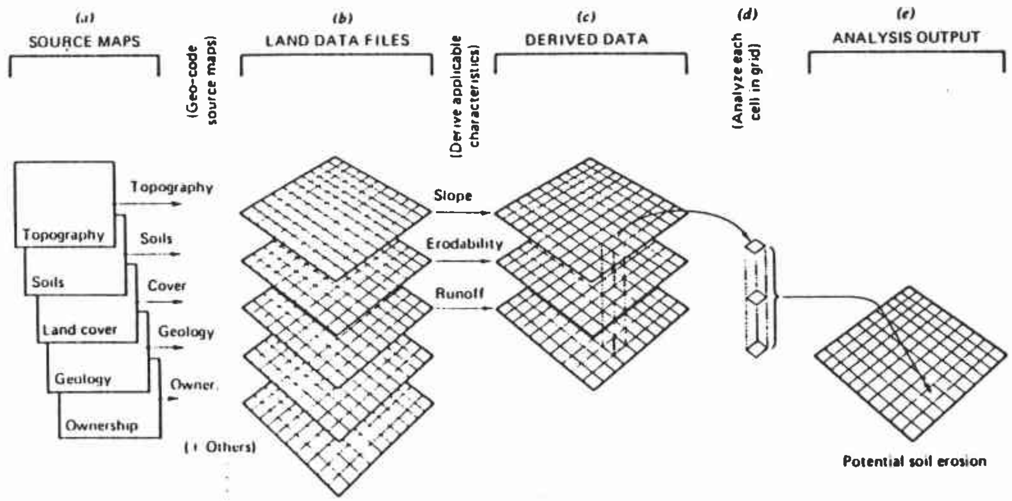


Figure 7. Various Stages in Using a GIS
(Source: Lillesand and Kiefer, 1987)

comparative illustration. An example of a raster device is the type of image that appears on the television screen.

Both vector and raster data representations are interchangeable, though not necessarily equivalent (Morehouse and Dutton, 1979). The first basic requirement, prior to conversion, is the classification of data. Classification is required because in a data grid cell, values can be measured on a continuous scale, and can represent samplings of continuous data distribution (Morehouse and Dutton, 1979). Although in the data capture/entry stages, raster scanning has the greatest potential, the most common format for computer storage and processing of data has been the vector format, as it is the more efficient of the two methods. However, mathematical manipulations with the data are often quicker in a raster system and thus algorithms are required for the conversion of features from a raster to vector format.

In the ensuing methodology, data collection from various sources was followed by data entry into the GIS system. Conversion of data into computer readable form involves digitising either manually or automatically. Digitisation is the process by which quantitative or spatial data are converted into machine readable form so that they can be stored and processed by the computer (Honeycutt et.al. 1980). An electromechanical digitiser

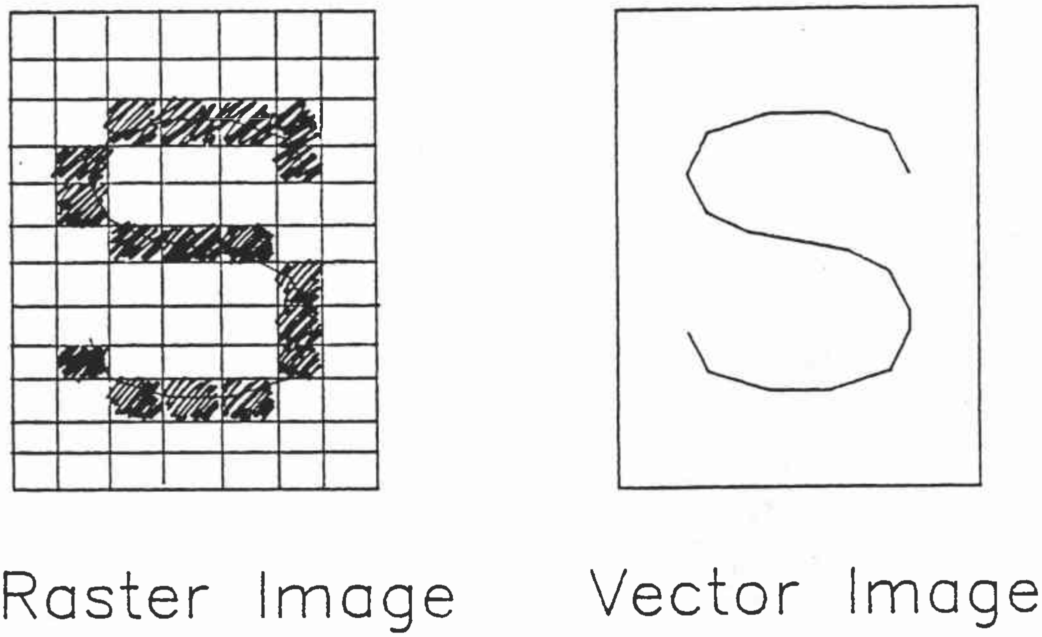


Figure 8. Comparative Illustration of Raster Data and Vector Data

was used for data entry. It is a flat tablet with an internal X,Y matrix and a cursor.

The computer cartography program, AutoCAD (ACAD) was used to enter the data, and proved to be the quickest method. AutoCAD, a vector based system, is a drafting package which can produce replicate drawings, and allows for editing and updating of the drawings. It also provides accurate comprehensive three dimensional data entry, storage and has some analytical capabilities. All three variables: soils, slope and land use were digitised using closed polygons affixed with topological labels and stored.

AutoCAD is not a GIS program, hence all the data had to be transferred to a GIS. The GIS software package that was used in this study was the raster based system, IDRISI. IDRISI, was developed at Clark University, Massachusetts, USA in 1987 and has been revised and updated since then. Characteristic of a geographic analysis system, it provides means for data entry, storage, management, display and analysis of raster images.

In order to transfer data from a vector to a raster based system, a gridding procedure is required. The AutoTOOLS, CADTOIDR program, developed by Riegelmann (1989) was used to extract and format the data for use in IDRISI. Vector to raster data conversion has two stages: transferring linear boundaries in the vector system to the raster and then filling in the interior cells. Initially, a polygon vertex cell is identified in the raster system. Cells between the vertex cells of a line segment bounding a polygon can be identified by calculating distances from the centers of intervening cells, to a straight line connecting the actual vertex points (Monmonier, 1982). See Figure 9.

The two variables that were initially transferred from ACAD to IDRISI were the soils and land use maps; and at a later stage a slope map was also transferred. See Appendix for list of commands.

The contour map digitised in AutoCAD had to be transferred from vector to raster mode, but had to go through an intermediary step which produced a digital elevation model (DEM). The AutoTOOLS program, CADTOSRF, developed by Riegelmann (1989) extracted and formatted the data for use in SURFER.

Another AutoTOOLS program, CADTOBLN, also developed by Riegelmann (1989), was used to transport a border from ACAD to SURFER. This program allows the user to select a boundary and then eliminate all the data outside or inside this boundary. A blanking file, created by this latter procedure, is necessary in SURFER in order to view only the data that are relevant to the user.

The SURFER program provides a flexible tool for creating high resolution two and three-dimensional

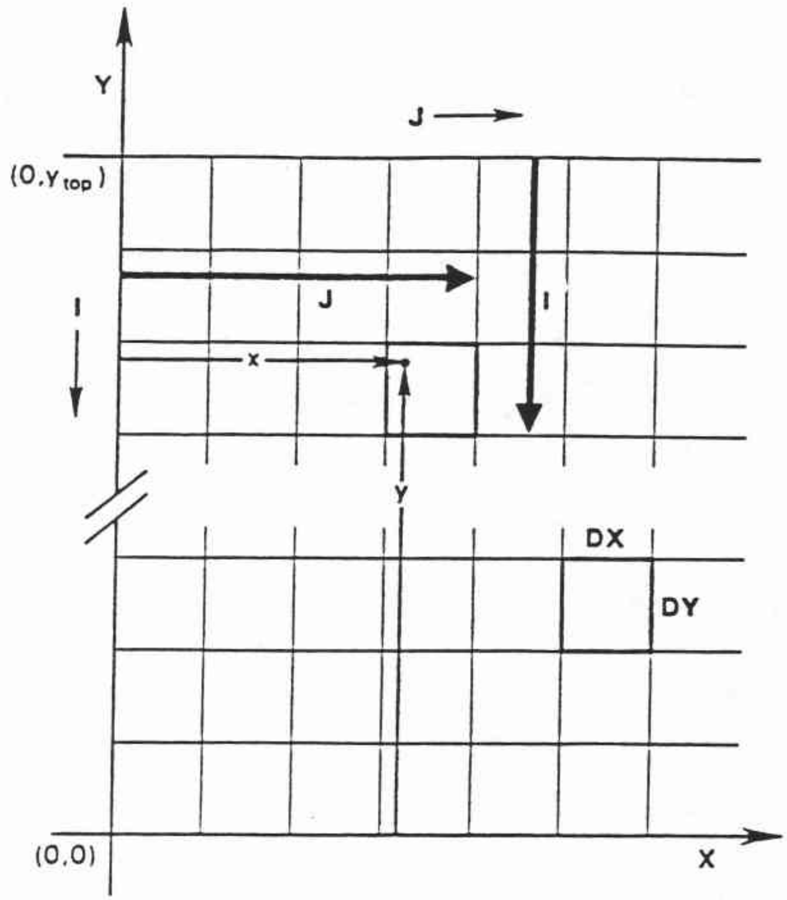


Figure 9. Transformation of Vector Data to Raster Data. Coordinates X,Y are Transformed to Grid Cell Coordinates I, J
(Source: Monomier, 1982)

graphics. The program has a variety of options for creating contour maps and surface plots of X,Y,Z data. Once the three-dimensional elevation model was developed in SURFER, the data were finally transferred to IDRISI for analysis purposes. The transfer was performed using the AutoTOOLS program SRFTOIDR, developed by Riegelmann (1989).

Preparing Data for Analysis in IDRISI. A sequence of steps had to be followed in the methodology, to match the different variables for the overlaying procedure in IDRISI. The sequence of steps is outlined in Figure 10, flow chart of the methodology.

The first step was the production of a slope map using the SURFER program. This step was conducted first, because changing the grid size in SURFER proved cumbersome, whereas with the CADTOIDR programme more flexibility in changing the resolution is possible. The SRFTOIDR program created an .INF (INFormation) file which reads as following:

Line # 1. Window minimum, X, Y coordinates

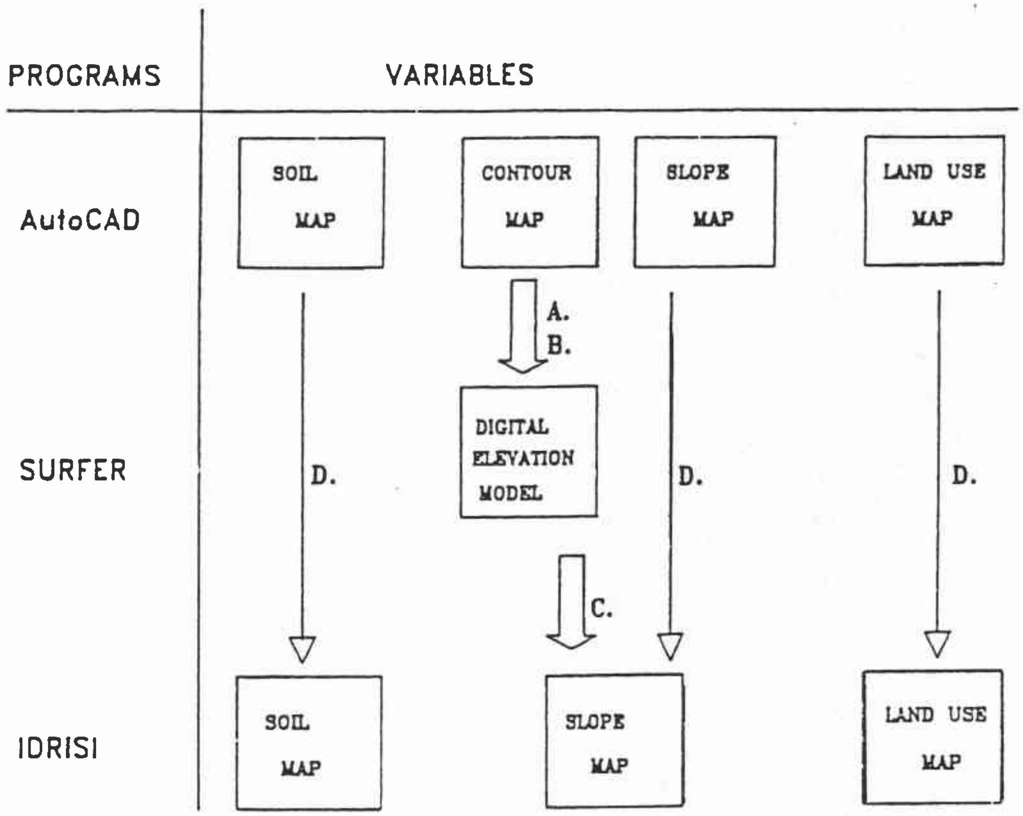
2. Window maximum, X, Y coordinates

3. Start point (upper left corner of data grid)

4. Rows

5. Columns

6. Grid transformation factor



A. Use of CADTOSRF program
   All contours must be labelled.
   Only contour layer on; border layer off.

B. Use of CADTOBLN program
   Border layer on.
   Blank data outside the border.

C. SRFTOIDR program makes .INF and .IMG file.
   Note the number of Rows and Columns.

→ Must be done first (A., B., C.)

D CADTOIDR program
  All polygons are closed and labelled.
  Window the image using the same minimum and maximum coordinates as given in .INF file (step C.).

Figure 10. Flow Chart of Methodology

The window minimum and maximum coordinates must be used when transferring data from AutoCAD to IDRISI. This guaranteed that each image was transposed to the same scale and position and could be aligned for the OVERLAY procedure.

Once all the images were transferred to IDRISI and the POLYRAS command had been used to convert data from vector to raster mode, it was noted that some pixels in each image were unclassified. In order to clean the gaps left between polygons after a vector to raster conversion, the FILTER option in IDRISI was used (Eastman, 1988). A 3-pixel by 3-pixel window moves across the image and the central pixel value is replaced with the most commonly occurring value in the window. At this stage the images were ready for analysis.

Variables Used

Vegetation, soil, landform or combinations of these factors have been used as indicators of a larger set of land characteristics in the different land evaluation systems in use around the world. For instance, they can be used to predict the suitability or vulnerability of the land for various uses (Westmann, 1985).

Most of the literature on soil erosion discusses the various parameters individually that affect erosion. As mentioned in the literature review chapter, the four most commonly cited variables that impact erosion are rainfall intensity, slope steepness, vegetation or land cover and the inherent resistance of a particular soil type to erosion (soil erodibility). Continual processes, like soil erosion, are correlated with the underlying structural features of the landscape (Westman, 1985).

Wischmeier and Smith (1965), in their internationally reputed work on the development of a soil loss model, used six variables in order to calculate annual soil loss. They were as following:

R = rainfall intensity   P = erosion control practices

K = soil erodibility

L = length of slope

S = slope angle

C = crop management practices

The four major variables chosen for their high imapct on erosion will be discussed in more detail at this point.

Variable I: Soil

Source of Data . A soil survey was performed by Simonson (1988), from the Soil Science Dept., Oregon State University, as part of the resource inventory and assessment work for the Cape Verde Watershed Development Project. The survey was a detailed study of the soils in the Picos and Seca watershed basins.

Simonson used the U.S. Soil Taxonomy (1,2) for describing and classifying the soils (Simonson, 1988). The survey involved several stages. Initially, observations along roads and select foot traverses were made. Soil samples were taken at several locations and analysed in the laboratory at Oregon State University. Aerial photos were also used for mapping the soil types. The survey was categorised as an Order 3 survey . Most of the soils found in this area were composites; that is a complex, or map unit composed of two or three soil series. Each soil is described according to its permeability, infiltration rate, water holding capacity and relative erodibility.

Technique Used. The soil map developed by Simonson (1988) was used as a variable in the GIS; it was digitised using the ACAD program. In order to transfer data from ACAD to IDRISI, each digitised unit had to be a closed polygon and affixed with a topological label (an integer).

In this case, the erodibility factor (K) was used as the integer value assigned to each polygon, as it gives an indication of the potential erodibility of a soil. The K factor represents the inherent susceptibility of each soil to detachment and movement of soil particles by rainfall and runoff from the bare soil surface (Simonson, 1988). This numerical value was first developed by Wischmeier and Smith (1978), and used to calculate soil loss in runoff per unit area, in the following equation:

A = RKLSCP, where A = soil loss/area.

Soil erodibility (K factor) is calculated with the use of nomographs. Usually a soil type becomes less erodible with a decrease in silt fraction (Wischmeier and Smith, 1978).

It must be noted that differences in the natural susceptibilities of soil to erosion are difficult to quantify from field observations; for example a soil with a relatively low erodibility factor may show signs of serious erosion if it occurs on long and/or steep slopes (Wischmeier and Smith, 1978). Hence, the K factor must be referred to in context with other parameters.

Each map unit, defined by Simonson (1988) had different proportions of soils and K factors. Thus an average value (K) was computed and used as in the following example.

Soil 5

	Soil Types	
Proportions of Soil (X) *	25% F	60%B
K factor (Y)	0.16	0.25
New K factor (XY)	0.04	0.15
Ave. K factor	(.04 + .15/2) = 0.19	

* Most of the soil units included 10-20% of soil units that were labelled as inclusions; the percentages were readjusted to disregard the inclusions. See new table of values.

Soil 5	Soil Types	
Readjusted % (X)	29.4% F	70.6% B
K factor (Y)	0.16	0.25
New K (XY)	0.047	0.176
Ave. K	0.223	

See Table 2, for a complete listing of New K factors for each map unit.

Initially, the entire map was digitised and labelled. This was found not only to be time consuming but the file, which was larger than 1 megabyte in size, became awkward to process. Hence the map was reclassified into soil erodibility classes. Simonson (1988) classed the K factors for the soil series of

Table 2, New K Factor Values

Map Unit	Readjusted %	Old K value	New K value
1	100%X	0.5	0.5
2	70.6%X 29%F	0.5X 0.16F	0.3999
3	47%F 29%B 23.5%X	0.16F 0.25B 0.5X	0.2652
4	47%B 35%F 17.6%X	0.25B 0.16F 0.5X	0.2615
5	70.6%B 29%F	0.25B 0.16F	0.2229
6	44%A 33%E 22%C	0.15A 0.16E 0.15C	0.1518
7	50%A 33%E 16.7%H	0.15A 0.16E 0.09H	0.1428
8	53%A 29%C 17.6%E	0.15A 0.15C 0.16E	0.151
9	58.8%A 41%C	0.15A 0.15C	0.1497
10	50%C 27.8%A 22%E	0.15C 0.15A 0.16E	0.152
11	58.8%C 41%A	0.15C 0.15A	0.1497
12	44%C 33%I 22%A	0.15C 0.13I 0.15A	0.1419
15	64.7%L 35.3%X	0.22L 0.5X	0.3185
16	50%L 39%W 11%X	0.22L 0.22W 0.5X	0.3058
17	59%W 41.2%L	0.22W 0.22L	0.2204
18	52%W 32%L 16%G	0.22W 0.22L 0.2G	0.2168
19	70.6%G 29%W	0.2G 0.22W	0.205
20	44%G 33%W 22%L	0.2G 0.22W 0.22L	0.209
21	41%G 35%O 23.5%W	0.2G 0.15O 0.22W	0.1862
22	55.6%T 44%I	0.15T 0.13I	0.1406
23	55.6%I 27.7%U 16.7%R	0.13I 0.18U 0.05R	0.131
25	66.7%K 33%W	0.27K 0.22W	0.2526
26	55.6%K 44%J	0.27K 0.14J	0.2116
30	62.5%Q 37.5%X	0.15Q 0.5X	0.2815
31	50%Q 33%N 16.7%X	0.15Q 0.17N 0.5X	0.2145
32	70.6%N 29%Q	0.17N 0.15Q	0.1635
33	68.8%M 31%N	0.15M 0.17N	0.1559
34	53T1 47%M	0.15T1 0.15M	0.15
36	53%N 47%S	0.17N 0.21S	0.1888
37	55.6%S 44%Y	0.21S 0.21Y	0.2094
38	100%V	0.2V	0.2
39	100%P	0.4P	0.4
43	66.7%I1 33%Z	0.13I1 0.19Z	0.149
44	53%T1 47%I1	0.15T1 0.13I1	0.141
45	100%R	0.05R	0.05
46	58.8%R 41%U	0.05R 0.18U	0.1032
47	100%V	0.2V	0.2
50	100%U	0.18U	0.18
51	63%Z 38.9%R	0.19Z 0.05R	0.139

Picos and Seca basins as follows:

Range of K	Definition
> 0.10	Low
0.11-0.24	Moderately Low
0.25-0.35	Moderate
0.35-0.5	High

The K factor values were rounded off to values of only one decimal place, to facilitate the reclassification of the soil map. Hence the following classification was used.

Map Unit	K factor	Topological Label
1	0.5 (High)	1
2,39	0.4	2
3,4,15,16,25,30		
5,6,8-11,17-21,26,31-34,	0.3	3
36-38,43,47,50	0.2	4
7,12,22,23,44-46,51	0.1 (Low)	5

The predominant soil erodibility for this basin appeared to be between 0.3-0.4, that is, moderately low to moderate erodibility. Simonson (1988) attributed these findings to the clayey texture and relatively low content of silt in these soils.

The reclassified map was then digitised, each map unit forming a closed polygon. Each map unit was labelled according to the K factor. The CADTOIDR program was used to format the data for use in AutoCAD. The soils map for Picos and seca basins, as it appeared in AutoCAD, before transferring to IDRISI can be seen in Figure 11. See Figure 12, for the identical image after it was transferred from IDRISI to AutoCAD (note the raster-based view).

Variable II: Slope

The presence of a slope on a topographic map is indicated by variations in contour lines. Much work has been done on hillslope evolution. The initial requirement for a slope is relief: a surface elevated sufficiently above base level so that stream incision can take place and slope forms can develop (Chorley et al, 1984). Strahler (1950) related the magnitude of relief to the steepness of slope.

Several factors influence topography, and climate is considered a major force that affects a certain locale. Davis (1930) developed the basic precept that hillslopes in humid climates are smooth and gentle, whereas hillslopes in arid climates are rough, steep, often with barren soil and sparse vegetation (Toy and Hadley, 1987). This factor is represented very markedly in the Cape Verde Islands, where the arid climate has led to the development of steep slopes.

The influence of slope on soil loss has been well

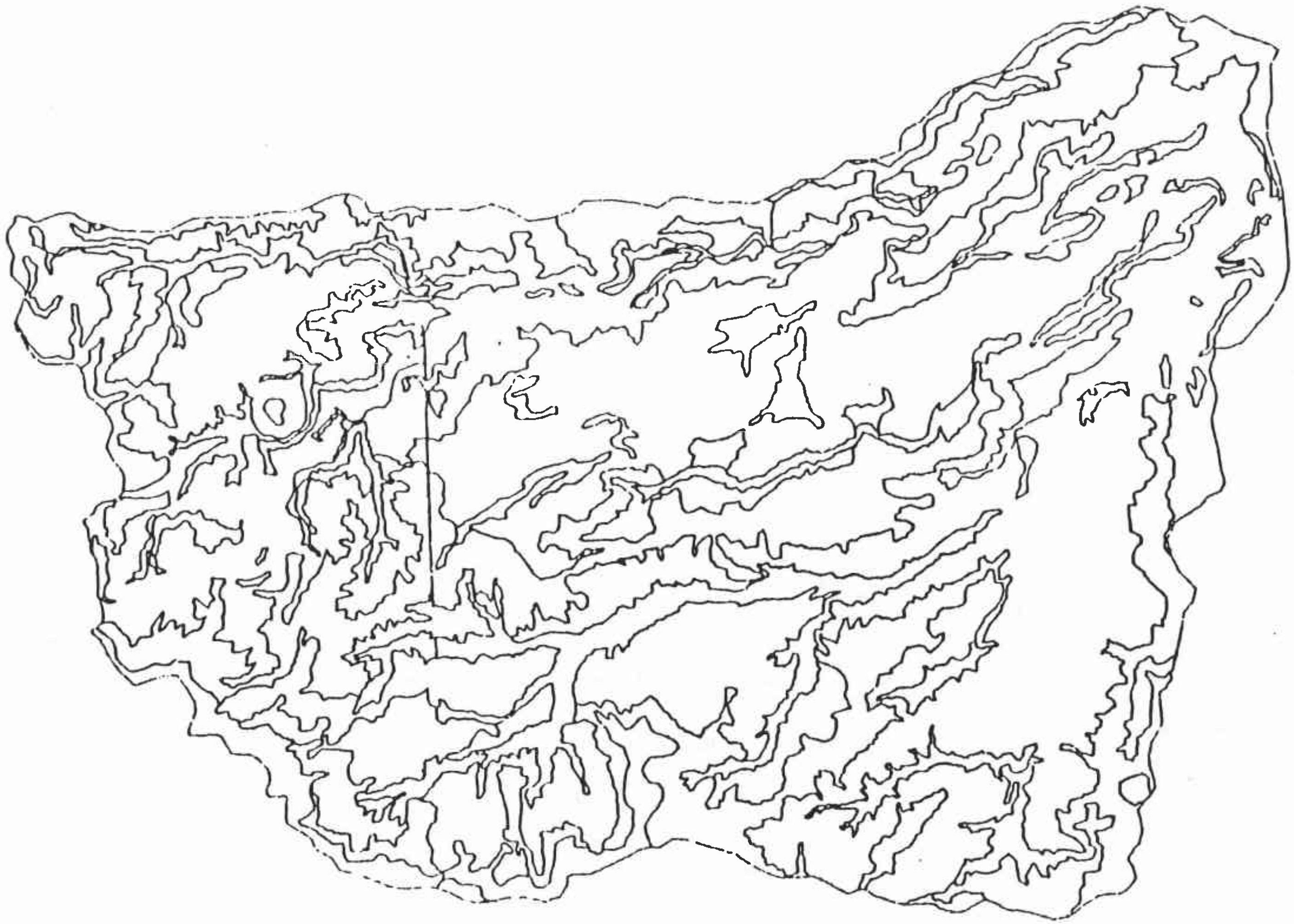


Figure 11. Soil Erodibility Map As It Appeared in AutoCAD Before Transferring it to IDRISI

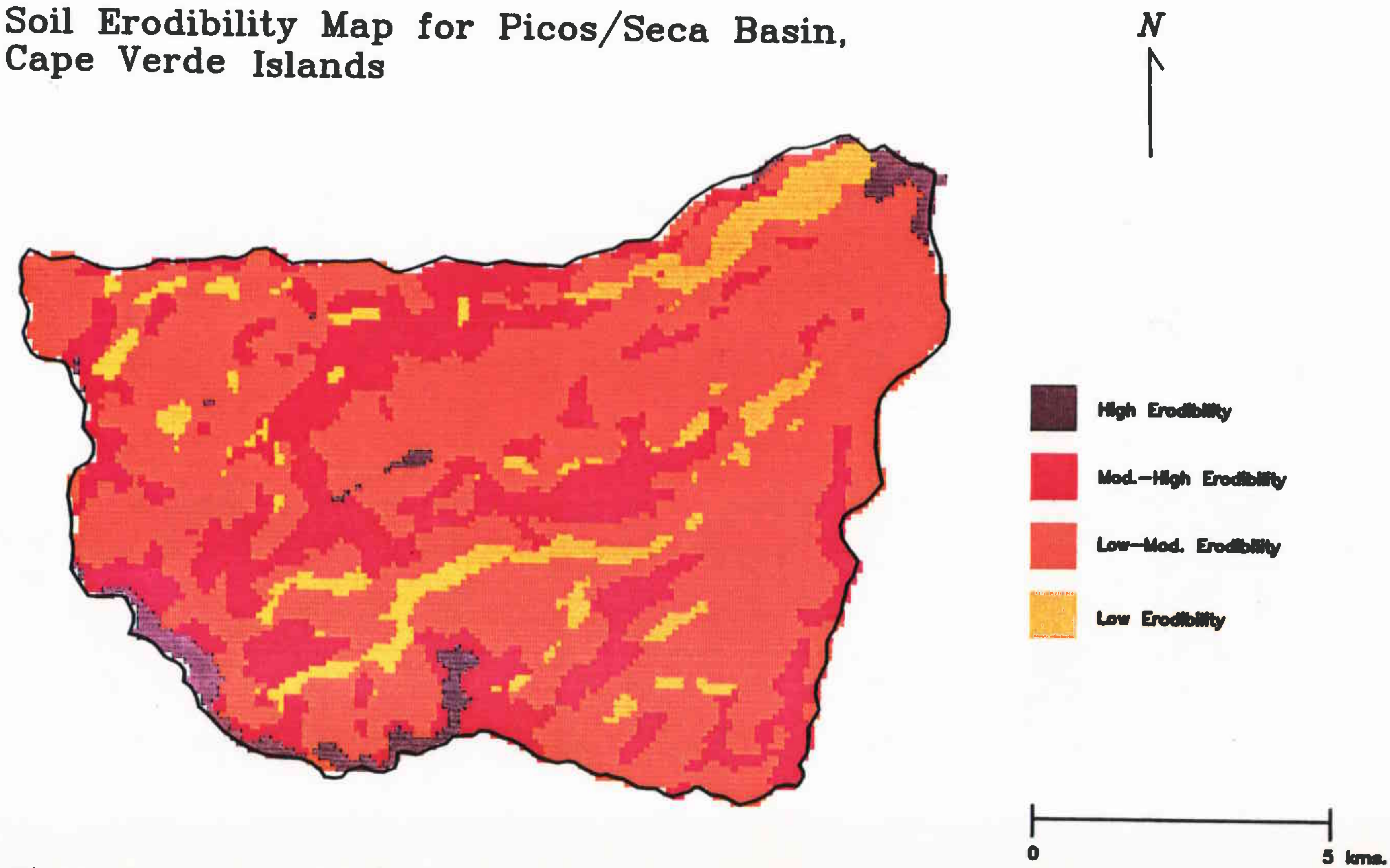


Figure 12. Soil Erodibility Map as Viewed in IDRISI (produced in AutoCAD)

documented. Steepness is measured as the angle between the horizontal and the slope, and is measured down the line of the steepest slope (Clowes and Comfort, 1982). Virtually all soil erosion or soil loss models include hillslope gradient and/or hillslope length variables, and if Hortonian overland flow is considered to be the norm for a disturbed land, then an increase in both these varaibles will result in a greater transport of soil particles by the flow (Toy and Hadley, 1987).

Experimental and field studies by the U.S. Dept. of Agriculture, as reviewed by Smith and Wischmeier (1962), indicate that erosion on slopes is a complex procedure (Chorley et al, 1984). The Universal Soil Loss Equation includes slope inclination and slope length. In this study, Smith and Wischmeier observed that as slope inclination increased, the length of slope exposed to vertically falling precipitation decreases (that is the precipitation is dispersed over a larger surface area). If this latter factor is equated to cosine of slope angle and if sine is used to express the gravitational force, then a sine-cosine product can represent the effect on hillslope erosion (Chorley et al, 1984). See Figure 13. This diagram illustrates erosion on a slope increasing to a peak at 45 degrees. The most rapid increase in erosion occurring with slopes between 25 -30 degrees.

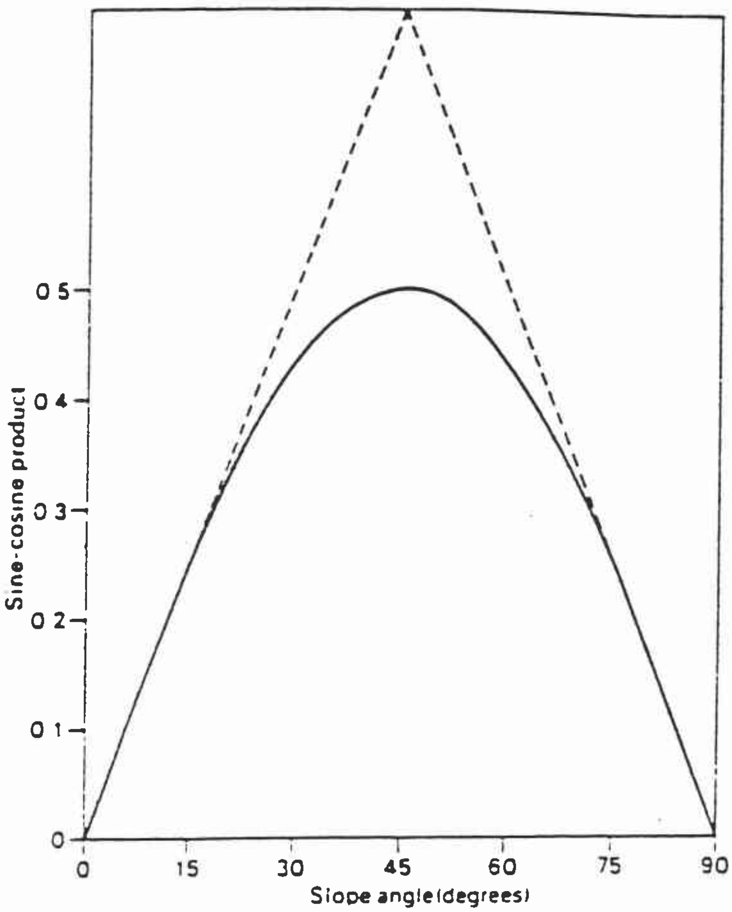


Figure 13. Slope Angle Effect on Hillslope Erosion
(Source: Chorley et.al., 1984)

Slopes of 45 degrees or more are usually free faces or cliffs; no appreciable thickness of regolith can accumulate on such slopes (Clowes and Comfort, 1982). Table 3, defines slope angles according to Young.

Table 3

Slope angle	Description	Nature
> 45	Cliffs	Usually free faces
30 - 45	Very steep	Steepest slopes on which debris lie.
18 - 30	Steep	Generally too steep for agriculture. Terracing in the tropics.
10 - 18	Moderately steep	Upper limit of mechanised cultivation
5 -10	Moderate	Soil erosion in dry areas.
2 - 5	Gentle	Often depositional areas, flood plains.
< 2	Level	Depositional, flood plains.

(Source: Clowes and Comfort, 1982)

Generally, water is considered the most effective agent of hillslope erosion, and can produce four types of erosion: rainsplash, sheet erosion, rill erosion and gully erosion.

Technique Used. Two methods were involved in developing a slope map. One method used a computer program to compute slope values, while the other method entailed a manual analysis of topographical data.

Both methods relied on the 1:25,000 topographic quad maps of Santiago Island as the basic source. The two methods are outlined below.

a.) Computer Analysis

The contours from the topographic quads for the Picos and Seca basin were digitised. The contours were affixed with elevation data values and were used for interpolation of a slope map. See Figure 14 for illustration of Contour Map (contours are in meters) as digitised in AutoCAD.

The digital elevation model building process utilised the following six software programs: AutoCAD, CADTOBLN, CADTOSRF, SURFER, SRFTOIDR and IDRISI. The AutoCAD programme was used to enter the contours data. Initially every 50 meter contour was digitised. As the SURFER program only processes 9,999 data points, some contours had to be eliminated. The minimum elevation entered was 50 m. and the maximum elevation was 900 m. The contours were labelled according to elevation prior to being transferred to the SURFER program.

Various grid size limits were experimented with in SURFER, the default size of 25 x 19 being the coarsest resolution and the highest resolution being

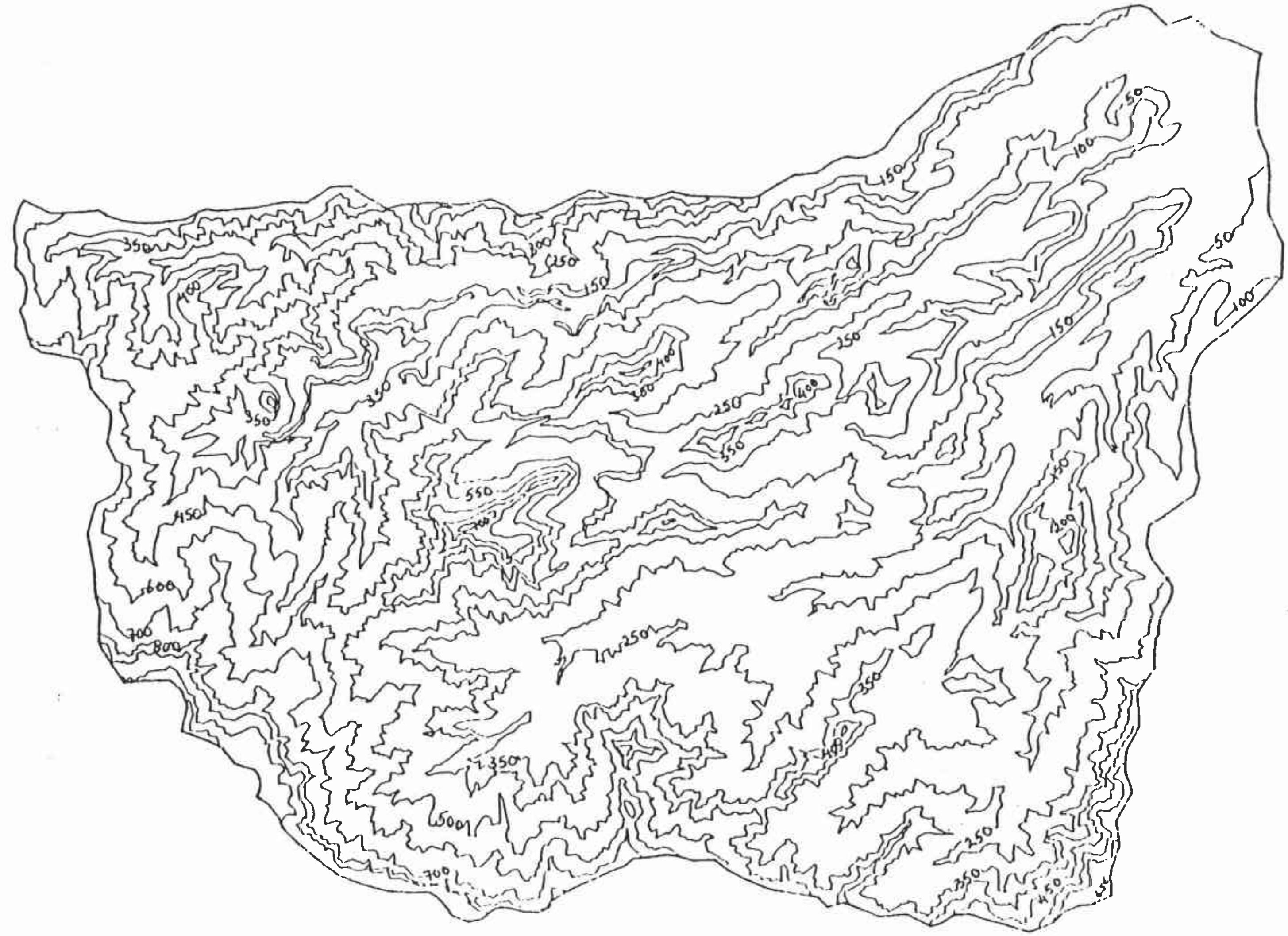


Figure 14. Contour Map of Study Site in AutoCAD (contours in meters)

200 x 147. The larger the grid size, the longer the time required for the gridding process (the latter grid resolution required approximately 24 hours to process). However, large grid sizes resulted in the final image being more accurate. See Figure 15 for a DEM with grid size of 40 x 55.

The digital elevation model (DEM) produced in SURFER was then transferred to the GIS, IDRISI, using the AutoTOOLS program SRFTOIDR, developed by Riegelmann (1989). The SRFTOIDR program creates .IMG and .INF files which are the first files to be used in IDRISI.

IDRISI, has a module, SURFACE, that analyses slope gradients (in degrees or %) and/or slope aspect classification from data in a DEM. The resulting slope map depicted most of the slopes as being either 0 degrees or 80 degrees and above.

Since this appeared to be a problem with inaccuracy, the data was gridded with different resolution sizes. Hence a variety of grid sizes from 25 x 19 to 200 x 147 were attempted. None of these options improved the problem. Hence the three-dimensional view in SURFER of Z values alone was viewed and it was noted that in areas where there was a large distance between contour lines, these areas appeared completely flat, whereas in areas where the contours were spaced closely together, the slopes appeared almost vertical. See Figure 16.

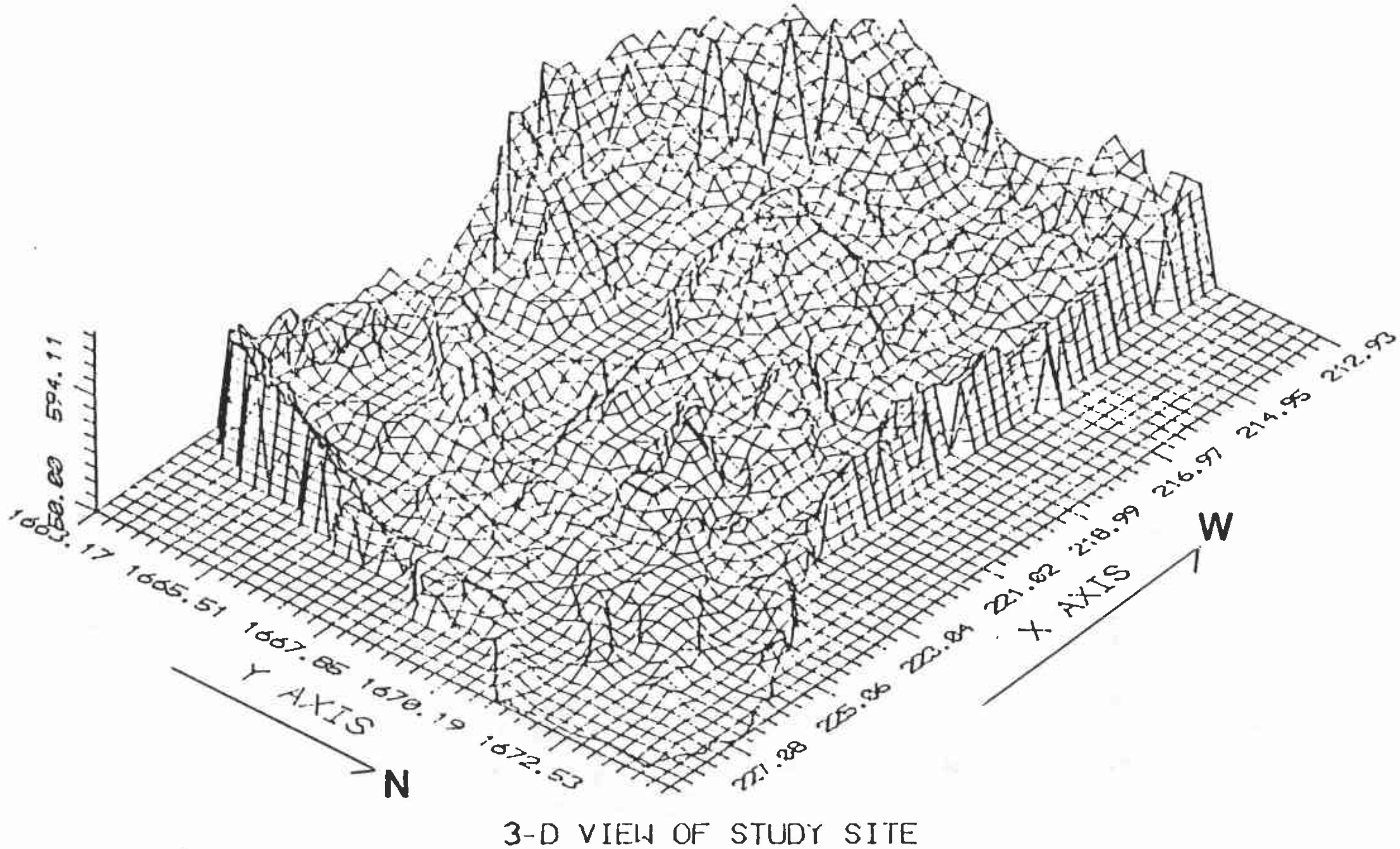


Figure 15. Three-Dimensional Image of Study Site as Created in SURFER

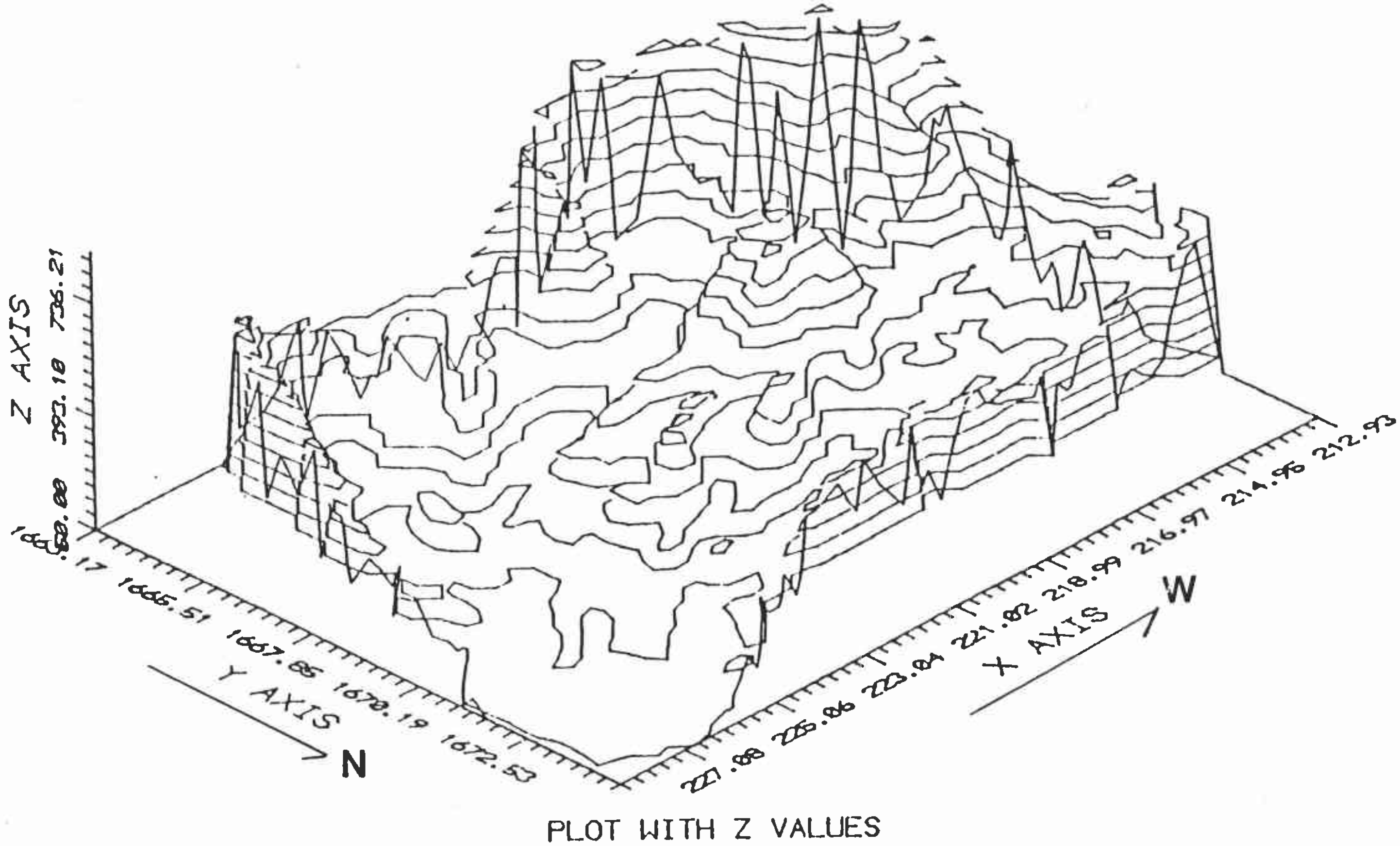


Figure 16. Three Dimensional Image of Study Site With Only Z Values as Created in SURFER

The hypothesis was made that the SURFER interpolation algorithm had created the exaggerated results, due to the following logic: all pixels that fall between two contour lines are labelled with a 0 value (or no data), hence the more space between contour lines the more 0 values and this is later translated into a slope of 0 degrees by the IDRISI module SURFACE. See Figure 17 for an illustration of this concept.

As this method resulted in inaccurate data, several options were available at this point. Developing a slope map from visual interpretation was considered to be the most efficient method.

b.) Visual Interpolation

This step produced a slope map with the more traditional technique of using a topographic map to visually classify contour spacings into slope groups. Slope can be measured as a ratio, angle of slope in degrees, or percecent. Slope can be calculated as in Figure 18.

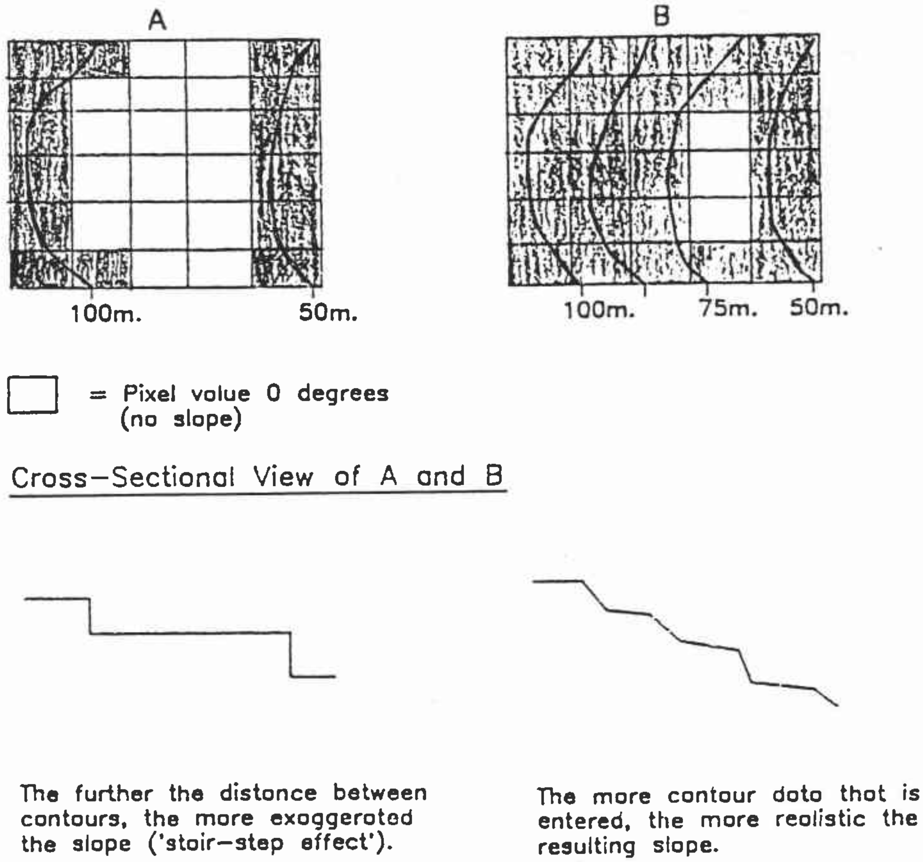


Figure 17. Interpolation Algorithm in SURFER

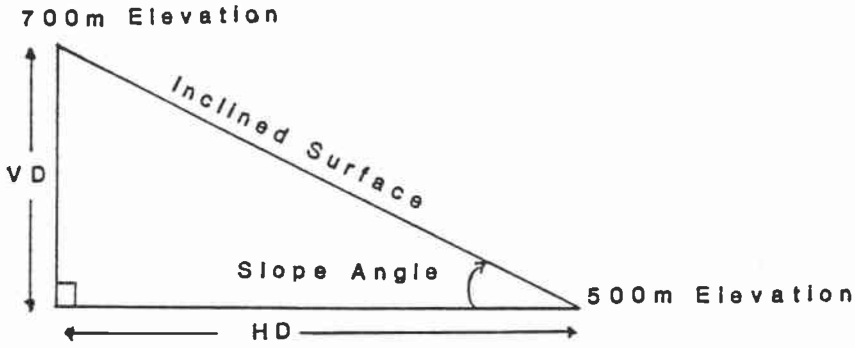


Figure 18

(Source: Mintzer and Messmore, 1984)

Slope Ratio = VD/HD

Slope Angle (in degrees) = arctan (VD/HD)

The basic means of determining percent of slope is accomplished through the use of topographic maps with scales of 1:50,000 or larger scale. Attention must be paid to the map scale, contour interval, relief features and scaling distances from the source map (Mintzer and Messmore, 1984). The most efficient method involves the use of a slope calculator.

A slope calculator is a simple piece of equipment, constructed of stiff transparent plastic with a hexagon drawn on it. Surrounding the hexagon are various contour spacings and their equivalent slope angle (see Figure 19).

The general equation for determining contour spacing at various slope percentages on maps of

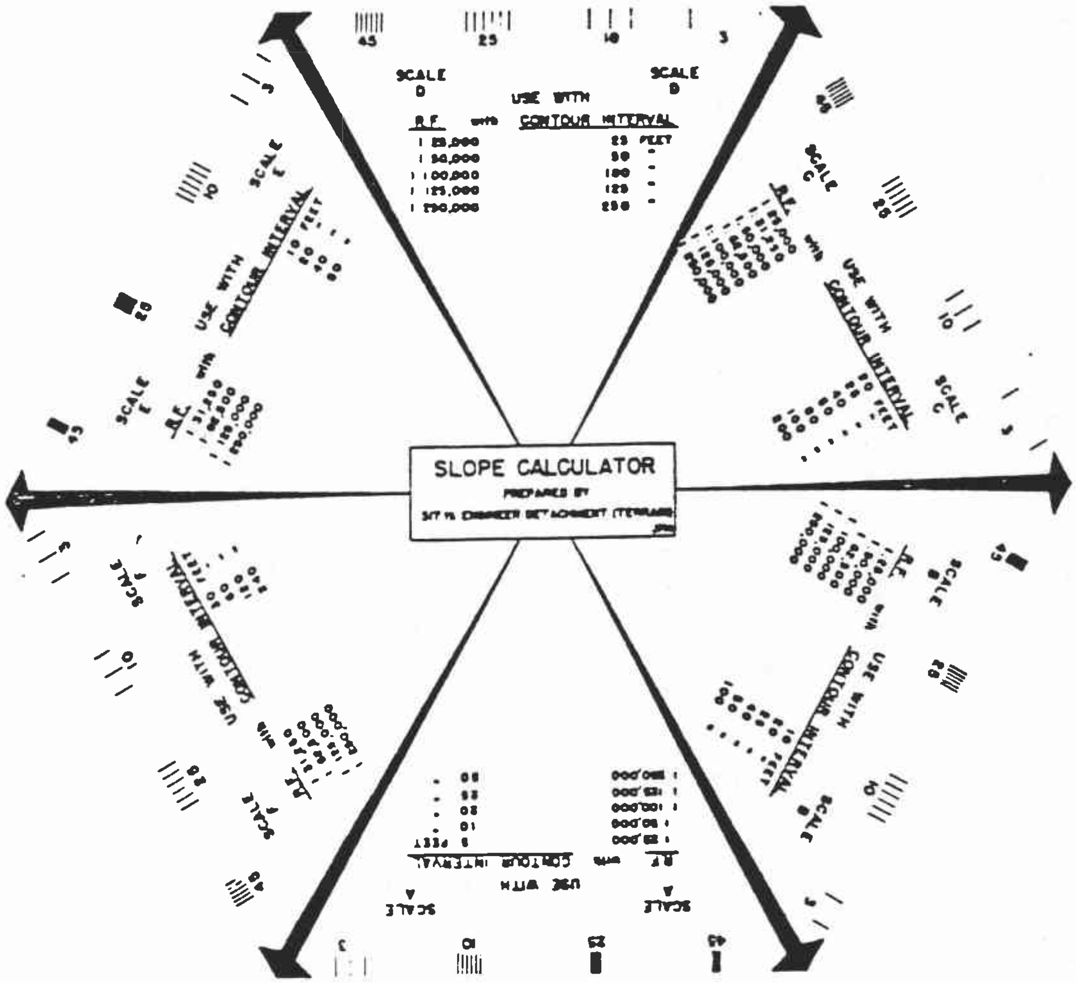


Figure 19. Slope Calculator
(Source: Mintzer and Messmore, 1984)

differing scale is as follows:

Contour line spacing =

$$\frac{100}{\%\ \text{slope}} \times \text{contour interval (CI)} \times \text{map scale (RF)}$$

Using this equation the contour line spacings for certain slopes were calculated for a topographic map with scale 1:25,000 and 10 m. contour intervals. The results are as following:

Contour spacing	Classification	Slope Gradient
> 4.7 mm.	A	0-5 degrees
4.7 - 1.9 mm.	B	5-12 "
1.9 - 1.1 mm.	C	13-20 "
1.1 - 0.57 mm.	D	20-35 "
0.57 - 0.28 mm.	E	35-55 "
< 0.28 mm.	F	> 55 "

These categories were then arranged around the hexagonal shaped template. See Figure 20.

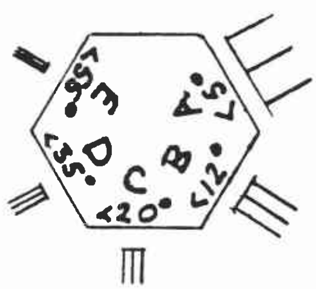


Figure 20. Slope Calculator Used in the Methodology

This slope calculator was moved around the topographic quad and aided in visually estimating contour spacings in order to classify areas into slope classes.

The final map produced was a detailed slope map. It was time consuming to digitise and awkward for manipulations. Hence the slope gradient classes were generalised/ re-grouped based on Young's slope classes as related to steepness of slope and erosion/agriculture practices.

According to Young's description the first class of slope angle where erosion will occur is 5-10 degrees and the next class, 10-18 degrees, should be the upper limit for any type of cultivation. Hence this group was combined to be one group representing the class where erosion would first occur. In addition, the most rapid increase in erosion occurred between 25-30 degrees, as stated by Chorley and Schumm (1984). Thus the new groupings were as following:

Classification	Slope gradient
A	0-5 degrees (none-little)
B	5-20 degrees (mod.-high)
C	20-35 degrees (high)
D	> 35 degrees (very high)

The final groups E and F were also merged together, as erosion peaks at 45 degree slopes or cliff faces. This new classification was used to redraw a generalised slope map from the intial detailed map. The resulting map was digitised in AutoCAD. Each polygon was labelled with an integer value. This map was then transferred to IDRISI, using the CADTOIDR programme. See Figure 21 for Slope Map.

Variable III: Land Use

The term land use as defined by Lillesand and Kiefer (1979), relates to the human activity associated with a specific land surface (Stancioff et al, 1985). There is no one ideal classificataion of land use and land cover, as there are different perspectives in the classification process and the process itself tends to be subjective, even when a numerical approach is used (Anderson, 1976). As any land use map is specific to the requirements of a decision maker, land use/cover classification systems vary, depending on the project.

Land use as a variable in erosion models represents the human impact on erosion. As early as 1972, a U.S.AID report cited that, "improper land-use practices" were considered to be the major cause of the Sahel drought's becoming a famine (Frank and Chasin, 1980). One of the main considerations in this case between land use and soil erosion was considered to be the percent of vegetation cover.

The presence of vegetation has three major effects on the underlying soil: a.) the return of vital minerals

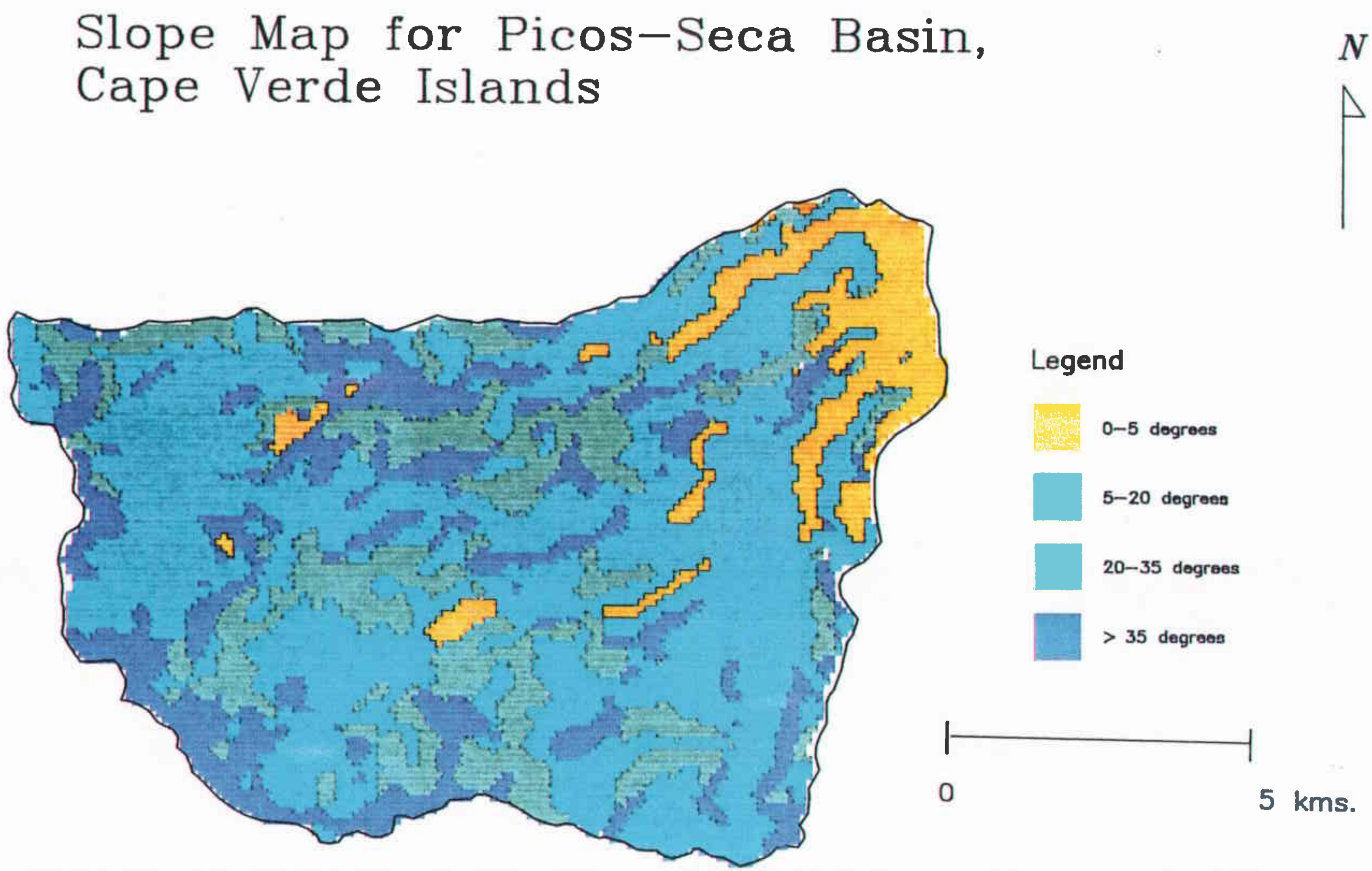


Figure 21. Final Slope Map as Viewed in IDRISI (produced in AutoCAD)

to the soil surface via leaf fall; b.) vegetation lowers the leaching potential of precipitation and c.) vegetation protects the soil surface from the erosive action of rainfall (Hallsworth, 1978). In Wischmeier and Smith's (1978) erosion model, the variables of crop management (C) and conservation practice (P) are the factors that are controlled by man.

Runoff and erosion are known to increase rapidly on soils with less than 70% vegetation cover and in semi-arid areas where vegetation cover is less than 20-30%, runoff/erosion are related to the amount of bare ground (Evans, 1980).

The land use map published in 1981 for Cape Verde was not used in this study as a more site specific land use study was considered relevant.

Source. The main data source for this map was color infra-red aerial photographs. The air photos were taken during May 1988, the dry season in Cape Verde. Hence the classification is based on a seasonal factor. Any type of intensive cropping that appeared on the photos had to be irrigated agriculture. Non-irrigated agriculture (dryland farming or grazing) thus constituted all other type of land cover, and appeared as sparsely vegetated areas. Table 4 describes the classification system used.

Technique used. A very generalised land use classification system was developed, that was at the same time specific to the twin watersheds of Picos and Seca. Riegelmann (1989) in his study of the Boca Larga watershed, a smaller sub-basin of Picos and Seca, divided land use into two basic categories: irrigated and non-irrigated agriculture (dryland farming or grazing). In the Picos and Seca study site, the amount of naturally occurring vegetation is negligible and hence the prevalent land use is some form of agriculture (or grazing). In order to facilitate the use of this study in conjunction with Riegelmann's study, as a potential reference source, the basic framework for land use classification developed by Riegelmann was continued. However, the land use map in this research had to relate to soil erosion hazard, and thus the relationship between land use and the morphology of the land was also emphasized.

Table 4 describes the classification system developed for the Picos-Seca watershed. The erosion risk classification for the land use classes was based on discussions with Dr. Rosenfeld, Ed Riegelmann and Joao Mendez, who have worked in the study site area. The qualitative decisions were also made based on vegetation cover provided by each class. For instance, the irrigated agriculture groups (C1 to C3) all provided a moderate to high intensity of vegetation cover (60 -

Table 4 Land Use Classification for Study Site

Class	Description	Slope	Intensity	Interpretation Keys
C1	Irrigated agriculture along river banks. Most agriculture in study site located along river banks. As the color infra-red photo's were taken during the dry season, agriculture or vegetation that flourished had to be irrigated or dependent on groundwater sources.	Slight gradient 0-5	Moderate to Intense*	Tones of bright red.
C2	Some irrigated agriculture was located on slopes; for example, sisal on cliff faces or forested slopes.	All slopes 5-45	Sparse to Moderate*	Tone of bright red or pink.
C3	Irrigated agriculture on Achadas, often occurring next to settlements and along roads. Does not occur over large areas of study site.	Slight; Achada is a plateau.	Moderate*	Bright red

* Intensity of vegetal cover

Table 4 contd.

Class	Description	Slope	Intensity	Interpretation Keys
S1	Settlements: a cluster of houses-4 to 5 minimum. Often surrounded by cultivated plots of land. These plots were cultivated in an organised manner, Settlements were also located near Arretos or roads/trails. This was all rural settlement, as it was low intensity. Settlement in this class was not as frequent as in other classes.	Floodplains 0-5	Low to Moderate (density of population).	White rectilinear features, appearing as clusters.
S2	Same as S1, but more frequent in occurrence.	Gentle to steep.	-	Same as S1
S3	Settlement on Achadas; often adjacent to raods.	Flat tablelands	-	Same as S1
A	Arretos: stone embankments to prevent erosion. These soil terraces were easily visible as striped features. Arretos were barren of crops, because it was the dry season.	Slight to Intense	Low to Moderate frequency of occurrence.	Striped features; dark blue and grey tones.

Table 4 contd.

Class	Description	Slope	Intensity	Interpretation Keys
B	Barren or non-used lands; for example, volcanic plugs or rock faces.	45	-	Blue-grey features, with no red tones (no vegetation).
NI	All other land that was not classified into any of the other categories, irrespective of morphology. This group covered a large percent of the land and was rarely found on floodplains, but more often on slopes and Achadas. The land appeared to be used for grazing or it was dryland farming.	Not related	Low intensity vegetal cover.	Spotted appearance (stippled) of red tone.

100%), and would therefore represent low erosion potential. However, the slope factor, for instance of the C2 class, would increase the risk of erosion for this group. The non-irrigated category had low intensity vegetation cover (10 - 60%) and the barren class had 0% vegetation cover. These two classes were considered to be of high to severe erosion risk. A settled area included not only houses/ buildings, but the surrounding one or two acres. The areas surrounding each settlement were observed to be cleared of vegetation, that could be a result of tethering livestock in the area or due to the initial clearing of the land for construction. Thus, if a settlement occurred on a slope (S2), the settlement/clearing would pose a higher risk to erosion than if the settlement occurred on level land.

There are two main types of local soil conservation features in the watershed: "Arretos" and "Banquetas." They are both soil terraced features. The "Arretos," however, were the only soil conservation practice that was classified and delineated on the photographs, as they were large, clearly visible units. Because the photographs were taken during the dry season, most of the "Arretos" were bare of vegetation cover and they were considered to be high erosion risk areas, but due to their terraced nature, the class was denoted a moderate erosion risk.

The technique used to develop the land use map followed Adeniyi's (1980) basic outline. The primary data source was color infra-red air photographs of scale 1:11,000, that were interpreted (using a stereoscope). Initially acetate overlays were made for each stereopair, and the photos were interpreted according to the classification system. Traditional interpretation techniques, such as tonal variation and patterns, were used. Only the information within a central core of each photo was considered valid for interpretation, as radial distortion occurred along the margins of the photo. The data were then transferred to a base map using a Zoom Transfer Scope (ZTS). The ZTS was used to scale the photos from 1:11,000 to the 1:25,000 base map. Using the equation stated in the ZTS Instruction Manual, the combination of map lens and photo lens that would match the map scale to photo scale was calculated. The following equation was performed:

$$S = \text{matching scale} = \frac{\text{Photo Scale (R.F.)}}{\text{Map Scale (R.F.)}}$$

$$= 11{,}000 \,/\, 25{,}000$$

$$= 0.44$$

The photo magnification used was 0.75x - 5x (with the Zoom knob setting at 1.5x) and the map magnification set at 2x.

The reference points used for this transfer were roads, rivers, groups of settlement and physical features such as volcanic plugs. As Adeniyi (1980) outlined in his study, the transfer of land use data from the photos to the base map using a ZTS can prove difficult, as reference features such as roads and rivers will have changed their alignment over time.

The level of interpretation for the map was designated as Level IV, according to the U.S.G.S. standards set for land cover/use classificataion. Level IV is as following:

Level	Base map Scale	Photo Scale	Min. Polygon Size	Min. Polygon Width	Sources Required for Land Use Delineations
IV	1:24,000 1:6,000	1:20,000 1:6,000	2.5 acres 1 acre	125 ft. 50 ft.	25% Photo 50% Other Source Material 25% Ground Truth

See Figure 22 for Land Use Map as Viewed in IDRISI (produced in AutoCAD).

Variable IV: Rainfall Intensity

The role of the kinetic energy of the raindrop in soil detachment has long been recognised as one of the main factors affecting erosion (Lal, 1976). A wide body of literature exists, documenting the relationship between rainfall intensity and the amount of eroded

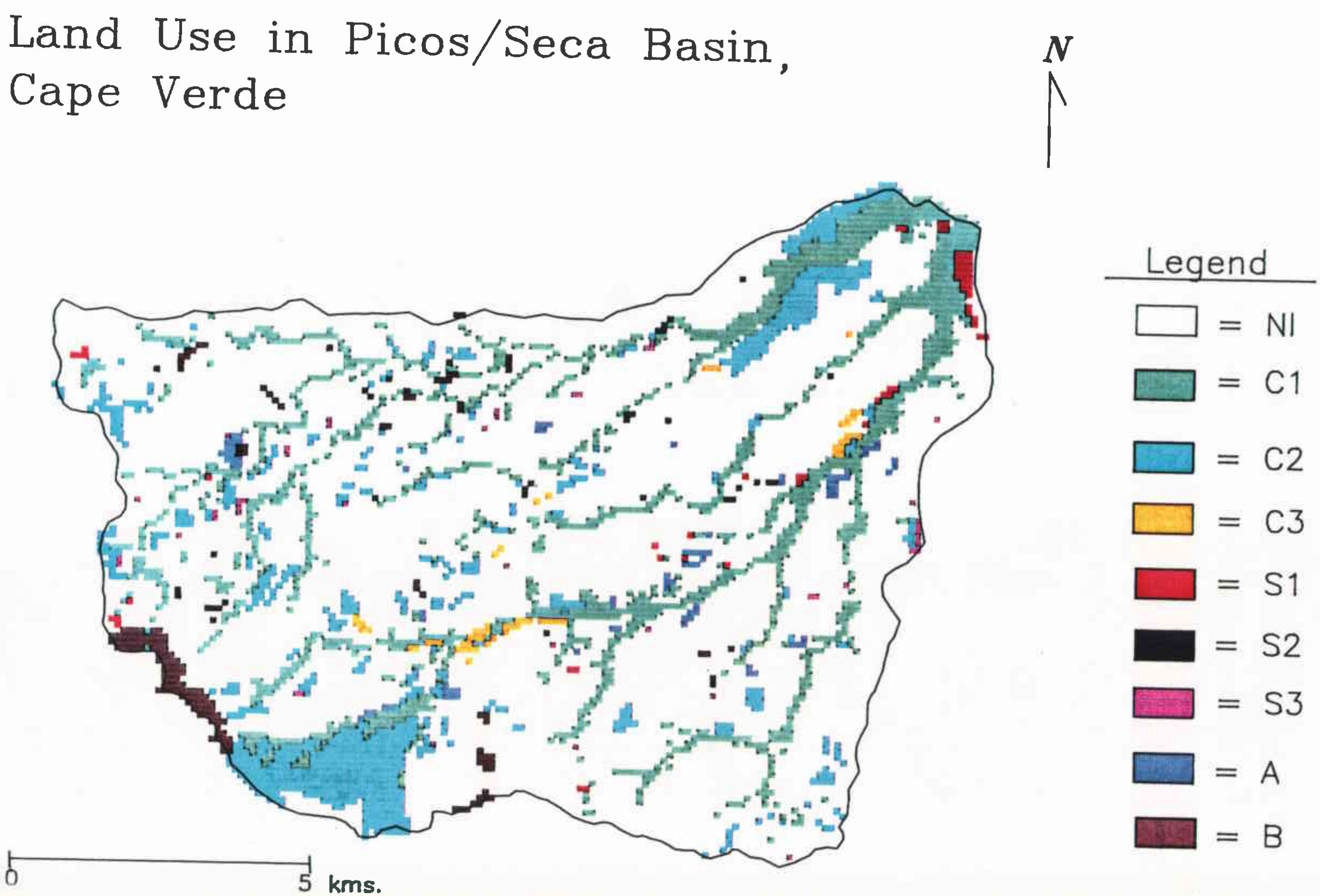


Figure 22. Land Use Map as Viewed in IDRISI (produced in AutoCAD)

soil. Wischmeier (1955) while developing a soil erosion model (the USLE) reported that the combination of rainfall energy and quantity of rainfall was the most important variable affecting soil erosion (Lal, 1976). Rainfall intensity is a measure of the amount of rainfall that falls in a given period of time, normally mm./hour (Lenhart, 1987). The general relationship is that the greater the precipitation intensity for a rainfall event, the greater the runoff. A quantitative relationship between the product of the kinetic energy of the storm and the 30-minute intensity (also defined as EI) was established to be the most significant correlation with the soil loss. This product is termed the erosivity of a soil. Erosivity is the potential ability of rain to cause erosion (Hudson, 1981).

Although the EI index is the best known method of calculating the erosivity of precipitation events, the index has not been entirely satisfactory, especially for tropical storms (Lal, 1976). Many rainfall indices using rainfall intensity have been proposed as more suitable for the tropics. Tropical rainfall events are characterised by high intensity, large drop size and high winds (Lal et.al., 1978). The precipitation intensity used to calculate the EI index is approximately < 50 mm./hour, but storms of much higher intensity occur in the tropics, thus indicating the EI index needs re-evaluation.

Many tropical countries also have insufficient records of rainfall intensity. This was a major drawback of the precipitation data for the Cape Verde islands. The instrumentation required to measure rainfall intensity is expensive, and Lenhart (1987) reported that on inspection of data, it was evident that most of the stations on Santiago Island had not been operational in recording rainfall intensity for a long period of time or that many events were not recorded (Lenhart, 1987). Eleven stations had installed pluviographs and of these only five were located in the Picos and Seca basin. See Figure 23 for location of rainfall stations. See Table 22 in Appendix for rainfall intensity data.

Several reasons can be given for the insufficient precipitation intensity data. The National Agricultural Research Institute (INIA) is a young organisation, responsible for collecting and analysing precipitation data. Prior to its existence, there was no such organisation to serve this function (Lenhart, 1987). The lack of equipment was also a drawback for rainfall data collection and in the case of equipment failure, there was no local source of repair.

The intensity data were read from the pluviograph charts available. Interpretation error plus instrument error resulted in about 15% total error for the data.

Sattell (1987), in his review on rainfall

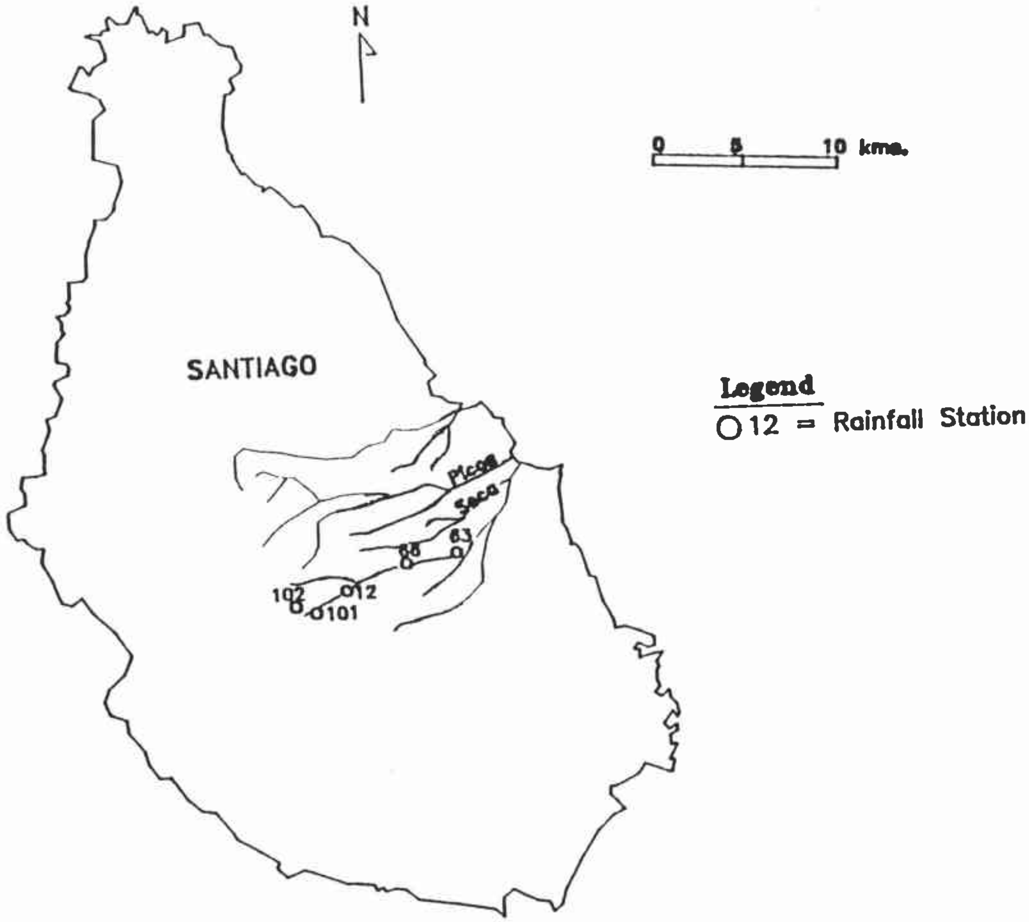


Figure 23. Location of Rainfall Stations that Recorded Rainfall Intensity, Within the Study Site
(Source: Lenhart, 1989)

erosivity, noted that precipitation on the islands is quite varied. The limited data and erratic nature of the rainfall in Cape Verde may preclude the use of some of the techniques used to generate R values (erosivity) from daily, monthly or yearly rainfall (Sattell, 1987). This factor was reiterated in a study by Lal et.al. (1978) where it was stated that erosivity estimates from rainfall amount (daily, monthly and annual) were at best an approximation and only to be used with caution (Lal et.al., 1978). They concluded that an erosivity index for the tropics should be dependent on an empirical relation involving kinetic energy, rainfall intensity, wind velocity and sand splash (Lal et.al., 1978).

Lenhart (1989) in his research developed linear regression models of rainfall intensity vs. total event precipiation for Santiago island. The correlation coefficients (0.30) indicated a poor fit on a linear basis (Lenhart, 1989). Faures (1987) developed curves for determing the recurrence intervals of different intensity levels and duration. A recurrence interval of 10 years for a 15 minute maximum intensity of 100 mm./hour was the result of this latter work (Lenhart, 1989).

<u>Study Site</u>. It was discovered that of the eleven stations with rainfall intensity data, only five of them were located within the watershed boundaries. They were

all situated in the south-western section of the watershed. It is possible to relate intensity to daily precipitation with statistical methods, in order to extrapolate intensity data to a greater temporal and areal extent (Lenhart, 1987). However, the limited amount of data and the localised situation of the stations did not lend itself to extensive extrapolation for the rest of the watershed. Jim Lenhart, from the Dept. of Agric. Engineering, Oregon State University, who gathered the precipitation data for the Cape Verde Watershed Project also emphasised the limitations of performing statistical analysis with the limited intensity data.

Finally, the three variables entered in AutoCAD were soil erodibility, slope and land use. Once all the variables were transferred from AutoCAD to IDRISI, data manipulation could proceed.

ANALYSIS

Data Analysis With a GIS

Data analysis within a GIS can consist of several functions that deal with the transformation of data, mathematical/statistical analysis, reclassification and overlaying. See Figure 24 for a hierarchical diagram.

Of the various analytical functions, the overlaying option is one of the most powerful capabilities of a geographic information system. Conceptually, it can be defined as, "the ability to 'overlay' different 'layers' of data on top of one another (Honeycutt et.al., 1980). The main arithmetic technique used for this procedure is Boolean logic. Boolean algebra uses the operators AND, OR, XOR, NOT, to compute if a certain condition is true or false (Burrough, 1988). See Figure 25 to illustrate the concept of Boolean logic using Venn diagrams.

The data to be analysed are initially weighted according to value/impact with an integer or real number, prior to overlaying, in order that the final output is ranked. The overlay method is faster and easier using a raster system, as the overlaid variables are compared cell by cell and a new matrix produced (Honeycutt et.al., 1980).

A common example is that of a planner/researcher trying to locate areas where a given land use occurs on a

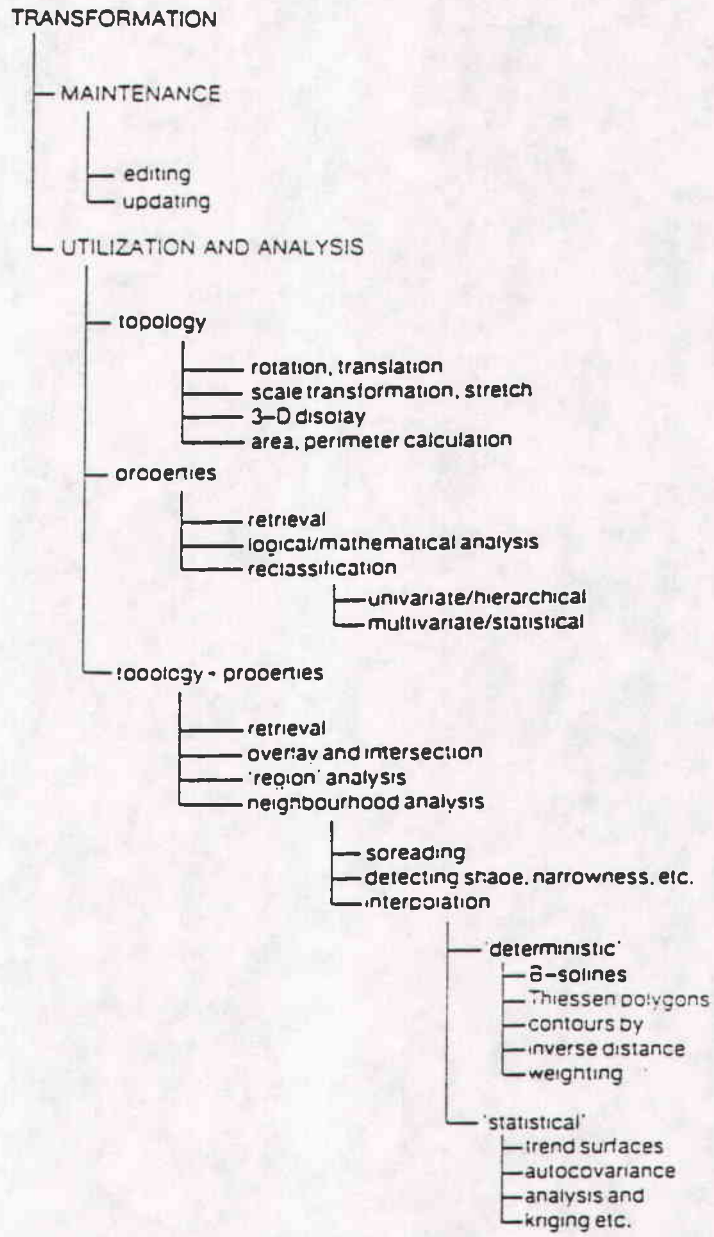


Figure 24. Hierarchical Representation of Functions in a GIS
(Source: Burrough, 1988)

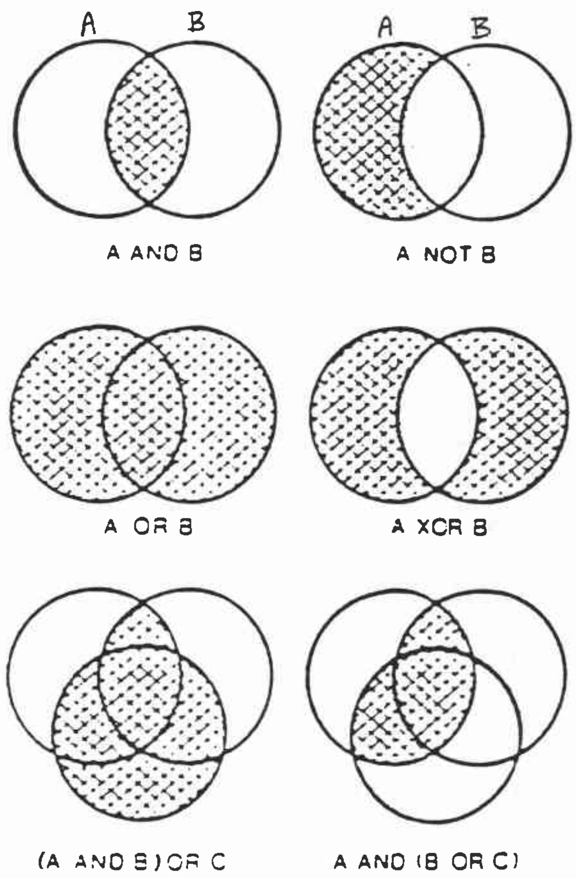


Figure 25. Venn Diagrams to Illustrate the Concept of Boolean Logic
(Source: Burrough, 1988)

particular soil. The soil information will be encoded on one map, and the land use data on another (Burrough, 1986). The result of overlaying the two maps using the Boolean operator AND, will be an image where all polygons containing both the particular land use and soil type are depicted. See Figure 26 to illustrate this.

This technique was used for the analysis of the three variables used in this methodology. IDRISI was used for this function. The OVERLAY module in IDRISI covers most cases where more than one input image is required for an operation (Eastman, 1988). The other module in IDRISI, used at a subsidiary level in conjunction with OVERLAY, was the RECLASS function. This latter function performed a reclassification of an image, either by an equal interval classification, or through a user-defined scheme (Eastman, 1988). It was used mainly to reclassify data into more generalised groups for ease of computation and processing.

Analysis

The analysis phase of this methodology was directed at a simple procedure that would involve overlaying the variables in order to locate areas that had specific conditions that pose an erosion hazard. For instance, a combination of a soil with a high erodibility factor, on a slope of angle 45 degrees, and non-irrigated agriculture (or grazing land) would be considered a high risk area for

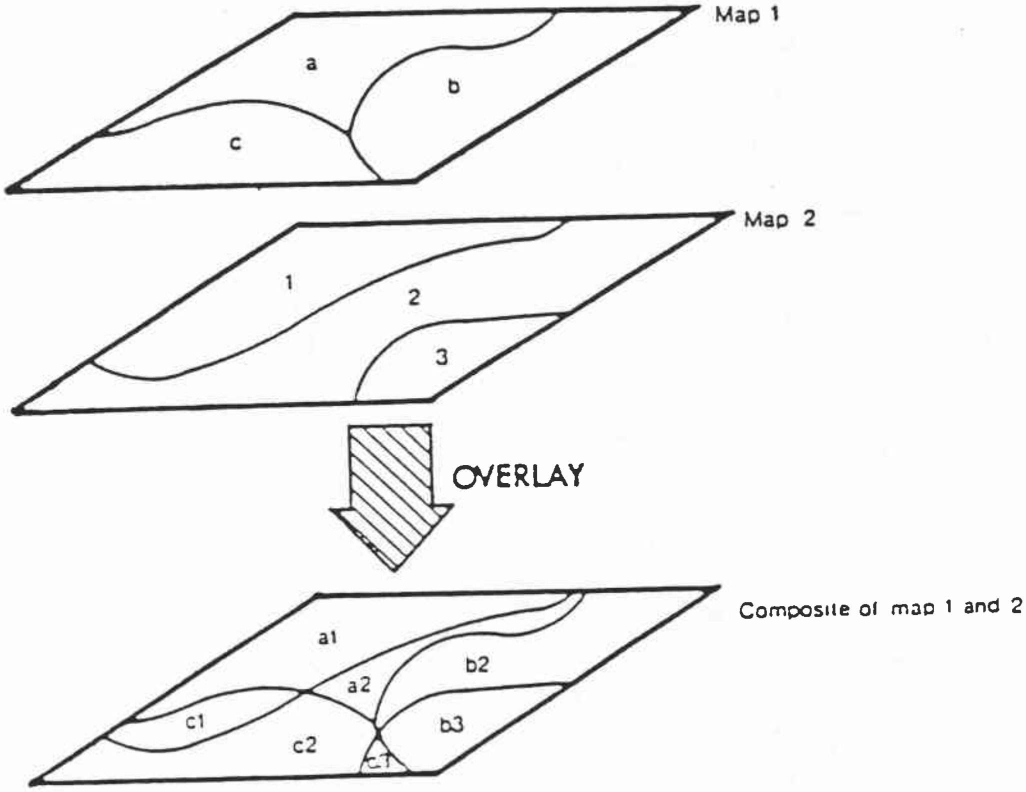


Figure 26. Illustration of Boolean Function AND in a GIS
(Source: Honeycutt et.al., 1980)

erosion.

Before the analysis was started, the categories for each variable were given general weightings (non-numeric) in terms of erosion hazard. They are as following:

Table 5

Variable I

Soil (Value)	Erodibility	Risk Factor
1	0.5	Severe
2	0.4	High
3	0.3	Moderate
4	0.2	Moderately Low
5	0.1	Low

(Simonson, 1988)

Table 6

Variable II

Slope (Value)	Angle degrees	Risk Factor
1	0 -5	None to Low
2	5 - 20	Moderate
3	20 - 35	High
4	> 35	Severe

(Young, 1972)

Table 7

Variable III

Land Use (Value)	Category	Risk Factor
0	NI	Severe
1	C1	Low
2	C2	Moderate
3	C3	Low to Moderate
5	A	" "
6	S1	Low
7	S2	Moderate
8	S3	Low
9	B	Severe

As described earlier, the overlay technique in a GIS enables the researcher/planner to view the different variables as shared entities. This in turn allows the researcher/planner to make qualitative decisions regarding the new values or identity of the initial data.

Once all the variables were set up for analysis in IDRISI, it was necessary to study the histograms for the various images. See Tables 8, 9 and 10. The histograms of the different variables illustrate certain features for each variable. For instance, the histogram for the soil map shows that the largest group in this variable was class four, with an erodibility of 0.2 or moderately low. The histogram for the slope image shows the largest class being

Table 8, Histogram of Soil Variable (produced in IDRISI)

Class	Lower Limit	Upper Limit	Frequency	Prop.	Cum. Freq.	Cum. Prop.
0	0.00	0.999	6768	0.3271	6768	0.3271
1	1.00	1.999	0	0.0000	6768	0.3271
2	2.00	2.999	498	0.0241	7266	0.3512
3	3.00	3.999	3490	0.1687	10756	0.5198
4	4.00	4.999	8673	0.4192	19429	0.9390
5	5.00	5.999	1262	0.0610	20691	1.0000

Class width = 1.0000
Display minimum = 0.0000
Display maximum = 5.0000
Actual minimum = 0.0000
Actual maximum = 5.0000
Mean = 2.3358

Table 9, Histogram of Slope Variable (produced in IDRISI)

Class	Lower Limit	Upper Limit	Frequency	Prop.	Cum. Freq.	Cum. Prop.
0	0.000	0.999	6986	0.3376	6986	0.3376
1	1.000	1.999	1125	0.0544	8111	0.3920
2	2.000	2.999	7196	0.3478	15307	0.7398
3	3.000	3.999	2693	0.1302	18000	0.8699
4	4.000	4.999	2691	0.1301	20691	1.0000

Class width = 1.0000
Display minimum = 0.0000
Display maximum = 4.0000
Actual minimum = 0.0000
Actual maximum = 4.0000
Mean = 1.6606

Table 10, Histogram of Land Use Variable (produced in IDRISI)

Class	Lower Limit	Upper Limit	Frequency	Prop.	Cum. Freq.	Cum. Prop.
0	0.000	0.9999	17296	0.8359	17296	0.8359
1	1.000	1.9999	1839	0.0889	19135	0.9248
2	2.000	2.9999	1054	0.0509	20189	0.9757
3	3.000	3.9999	69	0.0033	20258	0.9791
4	4.000	4.9999	0	0.0000	20258	0.9791
5	5.000	5.9999	100	0.0048	20358	0.9839
6	6.000	6.9999	61	0.0029	20419	0.9869
7	7.000	7.9999	40	0.0019	20459	0.9888
8	8.000	8.9999	62	0.0030	20521	0.9918
9	9.000	9.9999	170	0.0082	20691	1.0000

Class width = 1.0000
Display minimum = 0.0000
Display maximum = 9.0000
Actual minimum = 0.0000
Actual maximum = 9.0000
Mean = 0.3541

two, which is moderate slope of 5 -20 degrees. In both these images class 0 represents pixels surrounding the image that indicate no data. However, the largest group for the land use map was 0, which in this case represented the Non-Irrigated Agriculture class as well as pixels with no data attributed to them.

Of the three variables, the two with the fewer categories, that is soil and slope, were chosen to be the first to be overlaid. As the OVERLAY operation in IDRISI involves Boolean computations, it is easier to interpret resulting values if the initial values are all whole number integers. Thus, each variable's lower limit was designated as 1 using the RECLASS option.

The two options with the OVERLAY command that were selected as most pertinent to the concept of overlaying maps to locate areas of specific value, were ADD and MULTIPLY. The ADD option adds the values of corresponding pixels from the first and second image. The MULTIPLY option multiplies values of corresponding pixels from the first and second image. On binary images, this latter option produces a Boolean AND operation (Eastman, 1988).

Results

Using the ADD option in IDRISI, the soil map was overlaid with the slope map. The resulting image produced a range of values from 1.00 to 10.9999. See Table 11 for

Table 11, Histogram od ADD Function in IDRISI

Class	Lower Limit	Upper Limit	Frequency	Prop.	Cum. Frq.	Cum. Prop.
0	1.000	1.999	6668	0.3223	6668	0.3223
1	2.000	2.999	7	0.0003	6675	0.3226
2	3.000	3.999	119	0.0058	6794	0.3284
3	4.000	4.999	175	0.0085	6969	0.3368
4	5.000	5.999	270	0.0130	7239	0.3499
5	6.000	6.999	1811	0.0875	9050	0.4374
6	7.000	7.999	6627	0.3203	15677	0.7577
7	8.000	8.999	3991	0.1929	19668	0.9506
8	9.000	9.999	983	0.0475	20651	0.9981
9	10.000	10.999	40	0.0019	20691	1.0000

Class width = 1.0000
Display minimum = 1.0000
Display maximum = 10.0000
Actual minimum = 1.0000
Actual maximum = 10.0000
Mean = 5.1964

histogram of ADD operation. To illustrate the ADD operation, and designate erosion risk factors to each new value, a matrix of numbers was set up. See Table 12, the Matrix of Resulting Values using ADD option.

Table 12

+	Slope 1	2	3	4	5
Soil					
1	2	3	4	5	6
2	3	4	5	6	7
3	4	5	6	7	8
4	5	6	7	8	9
5	6	7	8	9	10
6	7	8	9	10	11

Due to the fact that final values were duplicated (_) several times from different combinations of original values, the resulting image had erroneous data in terms of erosion risk potential.

Therefore, the MULTIPLY option, as recommended by Eastman (1987) was the more relavant analytical operation for the overlay purpose. The soil map was multiplied with the slope map and the resulting image produced a range of values from 1.0 to 30.9999.

It was noted at this point that the MULTIPLY option produced a similar problem in that final values were duplicated (_). See Table 13 for the Matrix of Resulting

Values Using MULTIPLY.

Table 13

x	Slope				
	1	2	3	4	5
Soil					
1	1	2	3	4	5
2	2	4	6	8	10
3	3	6	9	12	15
4	4	8	12	16	20
5	5	10	15	20	25
6	6	12	18	24	30

One method considered, to alleviate this problem, entailed reclassifying the second image values to a completely different range of integers, so that when the two images were multiplied, there would be less likelihood of the product values being duplicated. Therefore, the slope variable values were reclassified. The new set of integers had to be a higher range of numbers than the first image values, in order to have products that were not duplicated. Thus the slope map was reclassified to have values 10.0 to 14.0 (to replace 1 to 5).

The MULTIPLY option was repeated with the soil map and the resulting matrix was satisfactory. See Table 14.

Table 14 Matrix of final values

x	Slope				
	10	11	12	13	14
Soil					
1	10	11	12	13	14
2	20	22	24	26	28
3	30	33	36	39	42
4	40	44	48	52	56
5	50	55	60	65	70
6	60	66	72	78	84

The interpretation of these values was then possible, and each one was designated with a class of erosion risk. For instance, soil with value 2 (0.5 erodibility, high risk) multiplied by slope value 14 (over 35 degrees), equaled a value of 28, which would be designated as a very high risk erosion category.

Each value from 10.0 to 84.0 was interpreted and designated a erosion risk class from none to severe. The classifications were made based on subjective decisions regarding the risk potentials of each value from the variables being multiplied. The resulting categories are listed in Table 15.

Table 15 Matrix of values and corresponding risk potentials

X	Slope				
	10(ND)	11(NL)	12(M)	13(H)	14(S)
Soil					
1(ND)	10(ND)	11(NL)	12(M)	13(H)	14(S)
2(S)	20(S)	22(L)	24(M)	26(S)	28(S)
3(H)	30(H)	33(L)	36(M)	39(S)	42(S)
4(M)	40(M)	44(L)	48(M)	52(M)	56(S)
5(LM)	50(LM)	55(NL)	60(L)	65(M)	70(H)
6 (L)	60(L)	66(NL)	72(L)	78(L)	84(M)

ND = No Data

NL = None to Low

L = Low

LM = Low to Moderate

M = Moderate

H = high

S = Severe

The range of integer values from this overlay was too large for quick analytical purposes, and the values were regrouped according to their risk potential. The new image had the range 1.0 to 6.0 as following:

Risk	Old Value	New Value
No Data	10	1
None-Low	11, 55, 66	2
Low	22,33,44,50,60,72,78	3
Moderate	12,24,36,40,48,52,65,84	4
High	13,30,70	5
Severe	14,26,28,39,42,56	6

Analysis II

The next stage in the analysis was the overlaying of the final variable, the land use map with the already existing soil/slope image. As the multiply option was used again for this final analysis, the land use map had to be reclassified to have a new range of values so that multiplication would not result in duplicate values.

As the land categories were initially grouped according to their potential erosion risk, the reclassification of the range from 0 to 9 involved reducing the number of groups to only four categories based on erosion potential. See Table 16.

Table 16 Reclassification of Land Use image

Land Use	Risk	New Values
C1	Low	Low = C1, S1, S3 = 10
C2	Moderate	Low to Moderate = C3 A = 11
C3	Low-Moderate	Moderate = C2, S2 =12
NI	Severe	Severe = NI, B = 13
A	Low-Moderate	
S1	Low	
S2	Moderate	
S3	Low	
B	Severe	

This new land use variable with only four classes was overlaid with the soil/slope image. The resulting image had values ranging fom 10.0 to 78.0. In order to interpret each value, a matrix of values was computed. It was noted however that two values of 60.0 resulted from two different value/variable multiplications.

Hence the land use image was reclassified again to a higher range of values, from 14 to 17 (to replace values 10 to 13). Once this new image was multiplied by the soil/slope image, none of the resulting values were duplicated. The matrix of values for this final overlay procedure is outlined in Table 17.

Table 17, Matrix of final values for Soil/Slope x Land Use

x	Land Use			
	14	15	16	17
Soil/Slope				
1	14	15	16	17
2	28	30	32	34
3	42	45	48	51
4	56	60	64	68
5	70	75	80	85
6	84	90	96	102

Each value had to be interpreted according to its erosion risk potential.

It is standard practice to judge the hazard of soil erosion under the worst possible conditions: that is, bare soil, with no vegetation cover, and no soil conservation practice (Huddleston and Kling, 1984). For instance a soil/slope value of 6 (severe erosion risk) multiplied by a land use value of 17 (that is non-irrigated agricultural land or barren, with severe erosion risk) would equal a value of 102; this combination of soil/slope and land use would pose a severe erosion risk. In this manner, each combination was designated an erosion risk. See Table 18 for final interpretations.

Table 18

Values from image	Interpreted Erosion Risk
14	No Data
15-17, 28,30,42,45,56,70	Low
32,34,48,51,60,75,84	Low- Moderate
64,68,90	Moderate-High
80,85,96	High
102	Severe

This last image was finally reclassed according to the above erosion risk groups. Hence the values ranging from 14 to 102 were grouped into values from 0.0 to 5.0. This final image thus depicted areas of erosion risk according to the variables of soil, slope and land use. This image was transferred back to AutoCAD, using the program IDRTOCAD, for plotting. See Figure 27 for final Erosion Hazard Map for Picos-Seca Basin, Cape Verde.

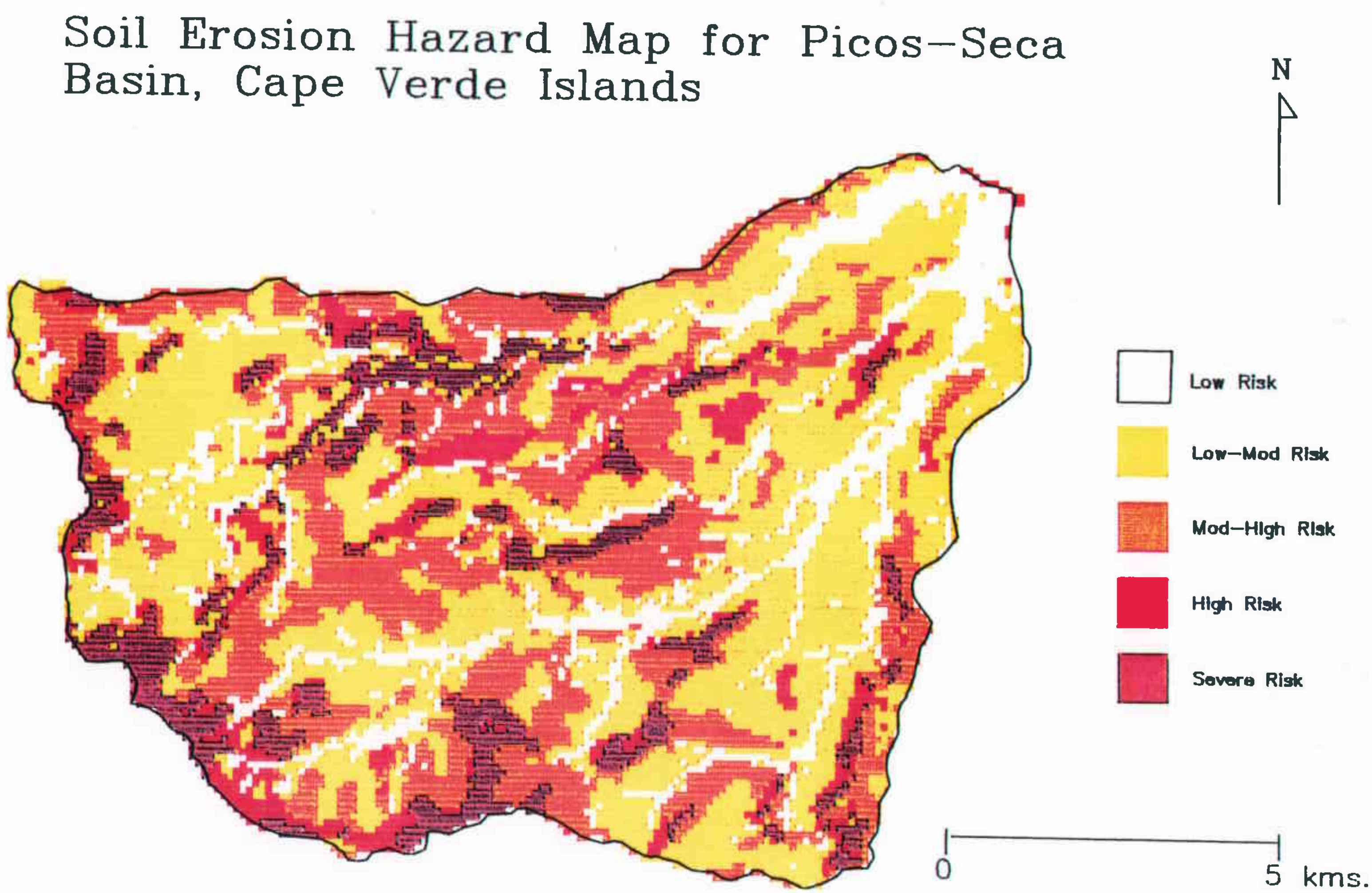


Figure 27. Final Output: Soil Erosion Hazard Map for Picos and Seca Basins, Santiago Island, as Viewed in IDRISI (produced in AutoCAD)

DISCUSSION

Summary

The two major aspects of this research were accomplished once the analysis was completed. A methodology for the integration of three types of software was developed in addition to the production of a soil erosion hazard map for the Picos and Seca watershed.

This research was based on earlier work performed by Riegelmann (1989). It involved the use of three major software packages and several other subsidiary programs that acted as links between each of the main programs. A summary of the software packages used and their inter-relationship is described in Figure 28.

A logical and detailed sequence of steps had to be ascertained for the use of the system in order to produce accurate maps/data (see Appendix for step by step procedure). The basic procedures as described by Riegelmann (1989) were followed and appended.

The most widely used method of soil loss prediction by conservationists in the U.S. is the U.S.L.E. developed by Wischmeier and Smith in the late 1950's (Mitchell and Bubenzer, 1980). Although the actual soil loss equation of the U.S.L.E. was not used in this research, the variables outlined by the U.S.L.E. as factors contributing to soil loss were used. The sources of the variables for soil and slopes were mainly from maps and the land use

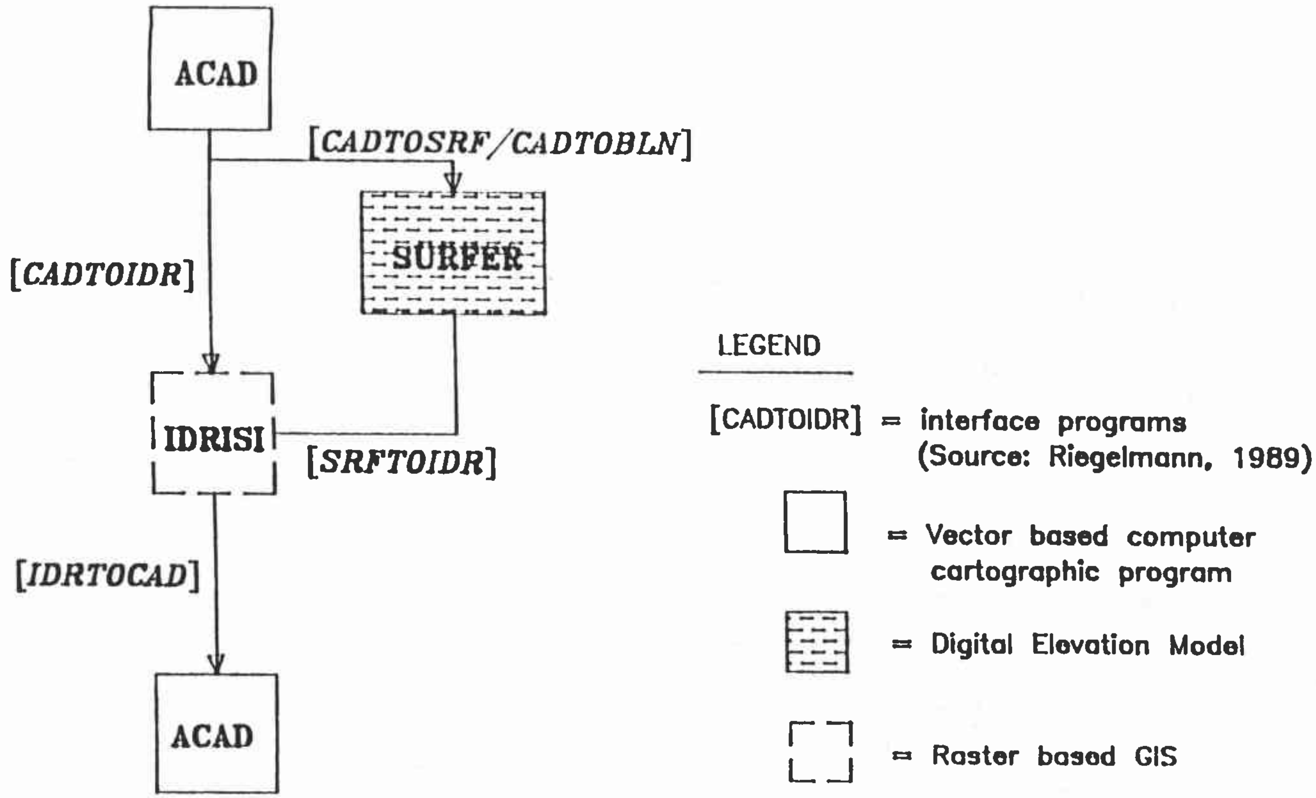


Figure 28. Summary of Methodology Used in the Research

information was obtained from air-photographs. In the final analysis, rainfall intensity could not be used, due to lack of extensive data.

The most efficient method of entering large amounts of data was accomplished by digitising appropriate maps, using the AutoCAD software package (a vector based system). The contour variable was the only one that had to be transferred to the D.E.M. program SURFER, to develop a slope map. This step was performed prior to transferring any of the other data to IDRISI as the final grid resolution was dependent on the one specified within SURFER.

Data analysis followed, after all the images were transferred into IDRISI. This stage of the research involved overlaying the maps and subjectively interpreting certain variable combinations according to their erosion risk potential.

Following the mapping of the indices of landscape value, contiguous cells that optimize particular weighted objectives are chosen (Westmann, 1985). One of the drawbacks of using a GIS and the parametric system is that the construction of indices results in lost information or information is often extrapolated beyond the data base.

Interpretation of Erosion Hazard Map

The knowledge of the distribution of erosion hazards in a region is an important aid to resource and land use planning (Stocking and Elwell, 1973). The soil erosion hazard map produced in the final analyses has very little impact or implications for management purposes, if studied as a single entity. Thus the following brief discussion will outline some interpretations of the map.

A general description of the erosion hazard map indicates that areas of low risk are situated in the floodplain zones near the mouth of the Picos and Seca rivers, and in the valley floors in the upper reaches. The moderate erosion risk areas were located on the slopes adjacent to the river channels, and in the highland areas (the northern boundary of the watershed).

The zones representing areas of high erosion risk were located in the south-western corner of the watershed. Finally, the sectors with severe erosion risk were also located in the south-western corner of the watershed; that is areas with high relief, steep slopes, and sparse vegetation cover. There were also some patches of this erosion class found in the area between the two rivers.

The AREA command in IDRISI, calculates the area for each category of an image (in varying units). Table 19, below depicts the area under each soil erosion risk category.

Table 19

Category	Area in Sq. Kms. (not to scale)	Percent
1 (low)	14.7	12.5
2	51.53	43.7
3	30.26	25.6
4	8.77	7.4
5 (severe)	12.64	10.7

As evident from Table 19, the total area of the watershed in this case is 118 sq. km. The areal values calculated in IDRISI are therefore not to scale. This increase in area is attributed to the process of windowing in on the image, prior to transferring the data from AutoCAD to IDRISI. The border of the image must be in contact with the window frame for each image, in order that transferring the image is to scale. See Figure 29.

A window frame with specific coordinate values had to be used for each individual image. As each image was digitised separately, imprecise digitising resulted in slight variations of area size and hence not all the images gave a complete "fit" to the window frame. The areal values from Table 19, were therefore readjusted proportionately to their corrected values. See Table 20.

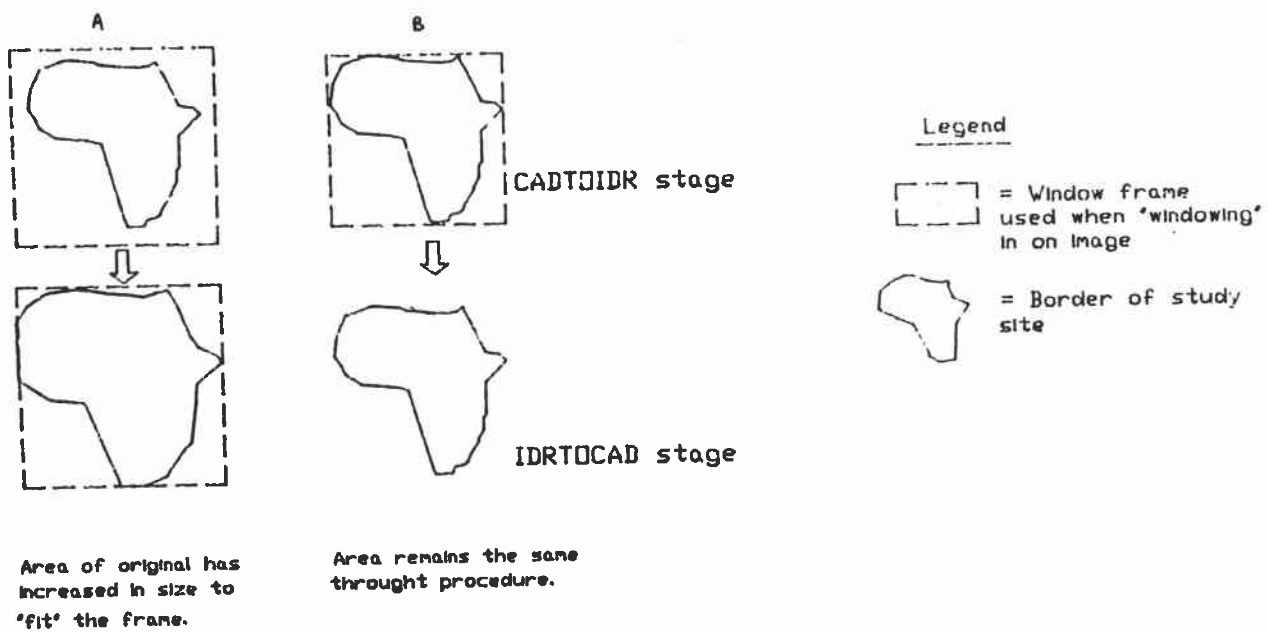


Figure 29. The Incorrect Method (A) and Correct Method (B) Involved in Maintaining the Same Scale Throughout the Methodology

Table 20

Category	Area(sq.kms.)*	Percent
1	13.7	12.5
2	48.04	43.7
3	28.21	25.6
4	8.18	7.4
5	11.78	10.7

$$* \quad \text{Readjusted area} = \frac{\text{Original Area}}{118 \text{ sq. km.}} \times \text{Area of Category}$$

These results indicate that a large percent of the watershed is susceptible to moderate-high erosion and the rest of the area appears to be susceptible to high-severe erosion risk.

In order to perceive areas requiring immediate attention for planning/conservation versus those that are low impact areas, the results of the erosion hazard map were divided into the individual variables and plotted against erosion risk, in tabular form. See Figure 30, Matrix of Values. If the method by which the erosion hazard map is developed involves identifying the major factors and their impact on erosion, then planners can explain in precise terms the conditions that result in certain forms of erosion which could increase or decrease the erosion hazard (Stocking and Elwell, 1973).

The matrix enables a planner to view the different

SOIL (K value)	SLOPE (degrees)	LAND C1	S1	S3	USES C3	A	C2	S2	NI	B	EROSION CLASS
0.1	0–5	•	•	•							None–Low
0.1	0–5				•	•					Low
0.1	0–5						•	•	•	•	Low–Mod
0.1	5–20	•	•	•	•	•					Low
0.1	5–20						•	•	•	•	Low–Mod
0.1	20 – 35	•	•	•	•	•					Low
0.1	20 – 35						•	•	•	•	Low–Mod
0.1	>35	•	•	•							Low
0.1	>35				•	•					Low–Mod
0.1	>35						•	•	•	•	Mod–High
0.2	0–5	•	•	•	•	•					Low
0.2	0–5						•	•	•	•	Low–Mod
0.2	5–20	•	•	•	•	•					Low
0.2	5–20						•	•	•	•	Low–Mod
0.2	20 – 35	•	•	•							Low
0.2	20 – 35				•	•					Low–Mod
0.2	20 – 35						•	•	•	•	Mod–High
0.2	>35	•	•	•							Low
0.2	>35				•	•					Low–Mod
0.2	>35						•	•	•	•	High
0.3	0–5	•	•	•	•	•					Low
0.3	0–5						•	•	•	•	Low–Mod
0.3	5–20	•	•	•							Low
0.3	5–20				•	•					Low–Mod
0.3	5–20						•	•	•	•	Mod–High
0.3	20 – 35	•	•	•							Low
0.3	20 – 35				•	•					Low–Mod
0.3	20 – 35						•	•	•	•	Mod–High
0.3	>35	•	•	•							Low–Mod
0.3	>35				•	•					Mod–High
0.3	>35						•	•			High
0.3	>35								•	•	Severe

Figure 30. Matrix of Variables Plotted Against Erosion Risk

SOIL (K value)	SLOPE (degrees)	LAND USES									EROSION CLASS
		C1	S1	S3	C3	A	C2	S2	NI	B	
0.4	0–5	•	•	•	•	•					Low
0.4	0–5						•	•	•	•	Low–Mod
0.4	5–20	•	•	•							Low
0.4	5–20				•	•					Low–Mod
0.4	5–20						•	•	•	•	Mod–High
0.4	20–35	•	•	•							Low–Mod
0.4	20–35				•	•					Mod–High
0.4	20–35						•	•			High
0.4	20–35								•	•	Severe
0.4	>35	•	•	•							Low–Mod
0.4	>35				•	•					Mod–High
0.4	>35						•	•			High
0.4	>35								•	•	Severe
0.5	0–5	•	•	•	•	•					Low
0.5	0–5						•	•	•	•	Low–Mod
0.5	5–20	•	•	•							Low
0.5	5–20				•	•					Low–Mod
0.5	5–20						•	•	•	•	Mod–High
0.5	20–35	•	•	•							Low–Mod
0.5	20–35				•	•					Mod–High
0.5	20–35						•	•			High
0.5	20–35								•	•	Severe
0.5	>35	•	•	•							Low–Mod
0.5	>35				•	•					Mod–High
0.5	>35						•	•			High
0.5	>35								•	•	Severe

Fig. 30. contd.

combinations of variables that lead to high risk or low risk areas. For instance if a decision had to be made, regarding the appropriate type of land use in an area with a soil K factor of 0.4 and slope 5-20 degrees, then using the chart, a land use of C1, S1 or S3 would be appropriate, as this would pose only a low risk to erosion.

A further column of information could be added to the matrix to indicate areas more susceptible to different types of erosion. The four basic types of erosion recognised in the field are rainsplash, sheet erosion, rill erosion and gully erosion. Evidence indicates that all four types of erosion will increase with an increase in slope gradient, minimal vegetation cover and high intensity precipitation. Runoff and erosion increases rapidly on soils with less than 70% vegetative cover (Toy and Hadley, 1987).

In fieldwork, performed by Riegelmann (1989) for the Picos/Seca basin, an evaluation of about 126 sites was done for a channel reach inventory. Each site had a description of the existing erosion types. These sites and corresponding erosion types were mapped and compared to the soil erosion hazard map. Ground photographs of each site were also used as verification for erosion classes. For instance, the potential for erosion around settled areas could be clearly observed on the photos because of the denuded land surrounding each settlement.

Options To Improve Methodology/Analysis

Various options exist for different steps in the methodology and analysis that could improve on the accuracy and results obtained in this research. The methodology in this research was chosen on a time-efficiency factor. Alternate pathways for following the methodology will be presented.

The first major step in improving the results of this research would involve the reduction of the amount of data to be processed. All source maps could be divided into smaller sections and dealt with individually. Table 21, gives a full account of the main limitations encountered during the research and options suggested to improve on the methodology.

Recommendations Based on Output

Riegelmann (1989) and Lenhart (1987) in their recent reports mentioned recommendations regarding soil conservation measures and improving the technical basis for such work. The basic recommendations, reiterated, are as following:

1. Bank protection structures need to be built.
2. A large scale afforestation program if implemented for the high relief areas of Santiago, would reduce the soil erosion considerably.

Table 21 Option for Improving Methodology/Analysis

Section of Methodology	Limitations	Options
Sources of Data:		
1.	All the topographic maps were in poor condition and information (eg. contour lines) had been erased off. Hence some inaccuracy was incurred in using these maps.	Use updated, more recently published topographic maps, if available.
2.	Only three variables were used for the GIS. This limited the scope of the final interpretations.	The more variables that are used, the more realistic the final map will be.
3a.)	The color infra-red photo's used were useful in observing areas of rill and gully erosion but did not show areas of sheet erosion. This posed a limitation on the use of the photo's for erosion mapping. All interpretations from air-photo's require ground truthing to be considered accurate.	Ground truthing of of all photo interpretation, required to verify verify data.

Table 21 contd.

	Limitations	Options
Data Entry:		
6.	The slope map was not created successfully using the SURFER to IDRISI technique. This was due to the fact that there was insufficient detailed contour data entered into the SURFER program for analysis.	a.) Divide watershed area into four sections and digitize each separately. b.) Overlay grid onto watershed area, categorise each cell and manually enter the data (using a Word Processing program) in correct file format for IDRISI.
7.	It was difficult to import and create a border in AutoCAD, once all the images were transferred back from IDRISI. See Appendix.	When transforming the data from AutoCAD to IDRISI, need to window in on image so that the image border contactsthewindow border. This will ensure the same scale through out all the programs.

Table 21 contd.

	Limitations	Options
b.)	The land use map developed for the study site was only valid for the dry season experienced in Cape Verde.	It would be useful to compare the results of this land use map, with one developed from photo's taken during the wet season. Also a chronological study of land use over a certain time frame, might provide more information on land use on the islands.
4.	The rainfall intensity data was inadequate for use as a variable. The lack of this variable posed a major limitations in the usability of the final erosion hazard map.	Total rainfall data needs to be researched as a variable. Statistical analysis of data is required.
5.	There was too much information for each variable, which necessitated a generalisation of each factor, which inevitably reduced the accuracy.	Each variable could be divided into smaller sections dealt with separately.

3. Extension programs are required to instruct local farmers on the hazards of erosion, and implementing soil conservation practices (Riegelmann, 1989). The traditional cropping systems require alterations to account for soil protection.

4. Reconstruction of Arretos and Banquetas that are presently ineffective as terrace structures.

The need for erosion control practices depend on a soil's potential for erosion and the most intensive crop that can be grown (Huddleston and Kling, 1984). As this study is specific for the Picos-Seca watershed, and for the time frame of the dry season (just prior to the onset of the rains), the recommendations made will be specific for this study.

Some basic conservation measures for agricultural purposes include retention of standing stubble or stubble mulch; diversion terraces; no-till or fallow season and controlled grazing (Huddleston and Kling, 1984). All these techniques could be used to improve present agricultural practices in the watershed, especially those occurring on slopes. Another solution to negating the potential for erosion in the non-irrigated agriculture areas, would be to reduce grazing in these areas and increase the vegetal cover.

Conclusion

Soil erosion is an extreme form of soil degradation in which natural geomorphological processes are accelerated to rates ten and one thousand times faster than normal conditions (Morgan, 1984). With an erratic rainfall pattern, steep terrain, and lack of natural vegetation, the Cape Verde Islands are prime environments for erosion and soil degradation (natural or man-induced).

A first step toward rational and ecologically sound land use in this region is to inventory the types and extent of present degradation of vegetation and soil (Rapp, 1986). It is hoped that this study will make available new information on areas of erosion hazard, for the island of Santiago, Cape Verde.

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APPENDICES

Appendix A: Procedural Guide

This procedural guide for the integral use of AutoCAD, SURFER and IDRISI, is an addition to the Appendix in Riegelmann's (1989) work and should therefore be used in conjunction with the earlier work.

Procedure for Slope Variable

AutoCAD:

1. Digitise contours using PLINE*
2. Each contour must be labelled with an elevation value. Use command ELEV.
3. If image has a border, the border should be digitised as a closed polygon.
3. Create two layers. One layer for the border and one for the contours.
4. If all data was digitised in version 9.0 AutoCAD, then the variable flatland has to be set to 0, as follows:
>SETVAR
VARIABLE: FLATLAND
FLATLAND <1>: 0
5. Turn layer with border OFF.

Cadtosrf:

1. The Cadtosrf program creates a _____.DAT file to be used in SURFER.
1. Load Cadtosrf, as follows:
> (LOAD"CADTOSRF")
> CADTOSRF
ENTER NEW DATA FILE NAME> (Enter file name)
CHOOSE DATA BY SELECTING OR CHOOSE ALL> (Enter S)
2. Choose S to select data to be transformed.
3. Use WINDOW command to window in on image.
4. Make sure image border is in contact with window "frame."
5. Create a .BLN (Blanking) file, to blank data either inside oroutside a border polygon.
6. To create a .BLN file, enter as follows:
> (LOAD"CADTOBLN")
>CADTOBLN

Dos:

1. Check all data files developed in previous stage, as follows:
> TYPE _______.DAT MORE

*PLINE - all words in CAPITALS are commands
2. The .DAT file should have three columns of information:
X Y Z

where X and Y values are coordinates and the Z value is the topological data value.

3. Check the .BLN file:
> TYPE ________.BLN MORE
4. The .BLN file should have only two columns of information.

Surfer:

1. GRID -INPUT
XTERNAL-TEXT (enter name of .DAT file created)
EDIT - check that all the data in columns A,B, and C are correct.
SAVE
2. GRID - OUTPUT-change output grid file to ASCII
- DUPLICATE -ignore duplicate points
- BEGIN

3. Modify .GRD file with .BLN file
GRID - INPUT
-XTERNAL - TEXT (enter name of .BLN file)
-SAVE
GRID - MODIFY
- BLANK - change default OUT.GRD to a new name ______.GRD

4. View the 3-D model using the SURF option

Srftoidr:

1. Enter SURFER _______.GRD file name

Procedure for Soil and Land Use Variable

AutoCAD:

1. All units must be closed polygons
2. Each polygon must be labelled with an integer value
3. Create two layers. One layer for the border and one for the variable values.
4. If data was digitised in AutoCAD version 9.0 then

variable flatland has to be set to 0, as follows:
>SETVAR
VARIABLE: FLATLAND
FLATLAND <1>: 0
5. Turn layer with border OFF.

Cadtoidr:

1. Window in on image
2. Border of image needs to contact window "frame."
3. Multiply unadjusted rows and columns by some factor that would give the same grid rsolution as created for the slope variable in SURFER.

Idrisi:

1. >INITIAL - creates an .IMG file
   >DOCUMENT V - creates a .DVC (or document) file
   >CONVERT - converts ascii data to binary
   >POLYRAS - converts polygon data to rasterd data
   >COLOR A or HISTO S - to view the image

2. Reclassify images, using RECLASS to simplify them
3. OVERLAY - use option MULTIPLY

Procedure for transferring all images from IDRISI back to AutoCAD for presentation purposes

Idrisi:

1. The _____.IMG file to be transferred must have the same name as the original _____.INF file.
2. CONVERT the file type from binary mode to ascii mode.

Idrtocad:

1. Enter the ______.IMG file

AutoCAD:
To import a border onto the image from Idrisi:

1. Use a _______.DWG file that has the border required, and make sure the layer with border is ON.
2. Turn OFF all other layers.

3. >BLOCK
>BORDER (name of new file)
INSERT BASE POINT: 0,0
SELECT: BORDER
4. >OOPS -will redraw border
5. >WBLOCK
FILE NAME: ________.DWG (enter file name used in step #1 above)
BLOCK NAME: BORDER
6. >END

AutoCAD:
To draw image that has been transferred from Idrisi

1. Main Menu Option - Edit
- Enter new Idrtocad file name
2. Allow full image to be recreated on screen.
3. >LAYER - MAKE
new name :BORDER
4. >INSERT
BLOCK NAME:_______.DWG (enter the same file name used in step #5)
INSERTION POINT: 0,0

Appendix B: Rainfall Intensity Data

Table 22 Rainfall Intensity Recorded in Picos/Seca Basin

Location	Year	EI30 (mm/hr.)	Total Precip. (mm.)	Duration (hrs.)	Mean Intensity (mm.hr.)
12	72	1	1	5	0
12	72	3	2	6	0
12	72	5	6	4	1
12	72	7	3	12	0
12	72	3	2	1	3
12	73	4	3	5	1
12	73	1	2	7	0
12	73	3	6	13	0
12	73	16	22	7	3
12	73	24	17	3	6
12	73	19	37	9	4
12	73	38	53	9	6
12	73	4	3	15	0
12	73	11	7	2	3
12	74	2	5	7	1
12	74	4	8	10	1
12	74	8	6	2	4
12	75	4	8	7	1
12	75	6	9	8	1
12	75	16	9	3	3
12	76	14	13	6	2
12	76	19	30	24	1
12	76	55	50	10	5
12	76	6	16	17	1
12	78	5	17	6	3
12	79	7	12	3	4
12	80	48	49	5	10
12	80	11	20	21	1
12	81	21	27	6	5
12	81	8	35	11	3
12	81	26	21	6	4
12	81	28	32	5	6
12	82	3	12	13	1
12	82	10	12	7	2
12	82	18	15	6	2
12	82	14	8	3	3
12	82	28	86	20	4
12	82	6	19	11	2
12	82	11	13	10	1
12	82	6	14	15	1
12	82	34	57	8	7
12	83	4	25	20	1
12	83	60	57	8	8
12	83	34	135	13	10
12	84	24	32	9	4
12	84	8	17	7	2

Table 22 contd.

Location	Year	EI30	Total Precip.	Duration	Mean Intensity
12	84	6	17	11	2
12	84	26	14	1	18
12	84	16	54	8	7
12	84	50	285	15	20
12	84	6	11	8	1
12	84	24	35	12	3
12	84	10	26	15	2
12	84	4	8	8	1
12	85	18	25	7	4
12	85	78	51	4	13
12	85	16	8	1	16
12	85	15	32	10	3
12	85	12	24	8	3
12	85	16	46	13	4
12	85	18	18	6	3
12	85	32	33	4	8
12	86	46	75	27	3
12	86	36	115	21	5
12	86	46	56	5	11
12	86	21	84	32	3
12	86	80	72	7	10
12	86	43	72	5	14
12	86	37	43	27	2
12	86	63	104	18	6
12	86	20	12	3	4
63	82	7	30	19	2
63	82	12	52	8	6
63	83	54	100	11	9
63	83	40	107	13	8
63	84	38	75	6	12
63	84	26	14	1	14
63	84	40	226	24	9
63	84	8	68	9	8
63	85	32	22	7	3
63	85	38	44	19	2
63	85	12	30	14	2
63	86	29	27	4	7
63	86	60	109	17	7
63	86	52	81	5	16
63	86	36	19	1	25
63	86	24	43	4	12
63	86	17	27	4	7
63	86	42	28	6	5
63	86	34	27	6	5
63	86	17	10	2	7
63	86	46	74	9	8
63	87	56	93	8	12

Table 22 contd.

Location	Year	EI30	Total Precip.	Duration	Mean Intensity
66	82	6	14	9	2
66	82	18	35	5	7
66	84	61	125	7	19
66	84	20	35	17	2
66	84	18	12	1	12
66	84	56	243	27	9
66	84	18	56	31	2
66	85	26	18	5	4
66	85	13	21	3	8
66	85	14	41	14	3
66	85	21	17	6	3
66	85	22	19	2	13
66	86	18	23	8	3
66	86	34	50	5	10
66	86	23	25	6	4
66	86	20	10	0	40
66	86	25	59	9	7
66	87	48	66	3	22
91	80	23	32	4	8
91	80	60	109	10	11
91	82	16	30	11	3
91	82	7	30	43	1
91	83	7	78	49	2
91	84	16	34	13	3
91	84	6	15	12	1
91	84	16	14	2	9
91	85	14	12	4	3
91	86	3	11	10	1
101	82	8	11	3	4
101	82	14	57	23	2
101	82	32	75	17	4
101	82	22	36	5	7
101	83	50	38	2	25
102	84	7	18	10	2
102	84	64	309	24	13
102	84	24	20	2	11
102	84	9	26	16	2
102	84	18	46	24	2
102	85	10	17	7	2
102	85	8	16	8	2
102	85	56	95	8	13
102	85	13	15	8	2
102	85	9	29	7	4
102	85	8	23	9	3
102	85	17	60	16	4
102	85	28	35	5	7
102	85	20	30	4	7

Table 22 contd.

Location	Year	EI30	Total Precip.	Duration	Mean Intensity
102	86	76	92	23	4
102	86	26	84	29	3
102	86	26	29	8	4
102	86	16	19	3	6
102	86	26	64	24	3
102	86	19	51	13	4
102	86	62	69	8	9
102	86	72	130	7	19
102	86	20	35	16	2
102	86	56	96	20	5