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DEVELOPMENT OF METHODS AND TECHNIQUES FOR LAND RESOURCE SURVEYING FOR ERITREA

By

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Declaration

I, the undersigned, hereby declare that the work contained in this dissertation is my own original work and has not previously in its entirety or in part been submitted at any other university for a degree.

Signature..................

Date..19/12/2000

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ABSTRACT

The purpose of this study was to assess the present land resource surveying methods and techniques used in Eritrea, to evaluate different methods and techniques of land resource surveying which are currently in use in various parts of the world, to design improved methods and techniques of land resource surveying for Eritrea and to indicate the importance of cost- effective ways of land resource surveying in achieving optimal land use. A literature survey of methods and techniques of soil, rangeland, and agro-climatic survey was done in-depth. An analysis was conducted on the present resource surveying methodologies and techniques used in Eritrea. International publications on land resource surveying methods and techniques were studied and evaluation of their appropriateness for Eritrea was conducted. Finally an appropriate and affordable set of land resource surveying methodologies and techniques are proposed for Eritrea. The main conclusion of the study is to adapt international methods and techniques of resource surveying which are appropriate under the country's socio-economic and technical conditions. Developing local methods and techniques under present condition is not possible due to various reasons.

CHAPTER ONE

INTRODUCTION

" The land is man's most valuable resource. It is indeed much more than this: it is the means of life without which he could never have existed and on which his continued existence and progress depends" (Dale & McLaughlin, 1988). However, wastage and destruction of land have continued. More recently the need for thoughtful and careful stewardship of the land together with the more intensive use and management of its resources, has emerged as a matter of major global concern. This has led to the need for land resource data. These data are important for various activities, for land use planning, for policy makers, for land administrators and also for individual citizens.

Surveys of land resources such as climate, water, soils, land forms, forests and rangelands are needed to avoid costly mistakes and to improve efficiency of investment. Valid techniques and methods have been developed for all types of resource survey (Young, 1998). These methods and techniques could be appropriate and more useful for developed countries because developed countries have all the required resources at hand. On the other hand developing countries lack most of the resources that are needed for surveys due to a shortage of trained manpower and lack of funds.

It was estimated that the USA would spend 90 billion dollars during the years 1986-2000 on the collection and management of spatially related information. For Third World countries, the potential for spending enormous sums of money on the development of their own systems is limited only by their lack of available funds. In Canada it has been calculated that 50 dollars per head of population are spent each year on surveying and mapping. Yet even 50 cents per person could barely be afforded in many countries of the Third World where the average per capita income of the poor is often less than a dollar a day (Dale & McLaughlin, 1988).

Such countries like Eritrea can least afford to waste resources on inefficient resource surveys. Therefore in this paper we examine and develop appropriate and cost effective methods and techniques of resource surveying for Eritrea.

1.1 Description of the study area

1.1.1 General Facts about Eritrea

Eritrea became an independent state in May 1991 and the Eritrean population confirmed its support for independence in an internationally supervised referendum held in April 1993. This was followed by the recognition of the new state by many countries and its subsequent membership in regional and international organizations as an independent state.

The 30 years of devastating and protracted war and years of recurrent drought before Eritrea achieved independence left the country in shambles, with much of its infrastructure and the productive base destroyed. Further exacerbating the situation was the failure of the former colonial regimes to check the adverse development trends and gross socio-economic mismanagement.

The government of Eritrea is now faced with the immense challenge of reconstruction. It has to rehabilitate and transform the war devastated socio-economic system while at the same time laying a sound foundation for its further development. The government of Eritrea is currently engaged in a continuous effort to set up and strengthen appropriate institutions to implement integrated economic development policies based on principles of market economy (NewAfrica, 1999).

1.1.2 Location

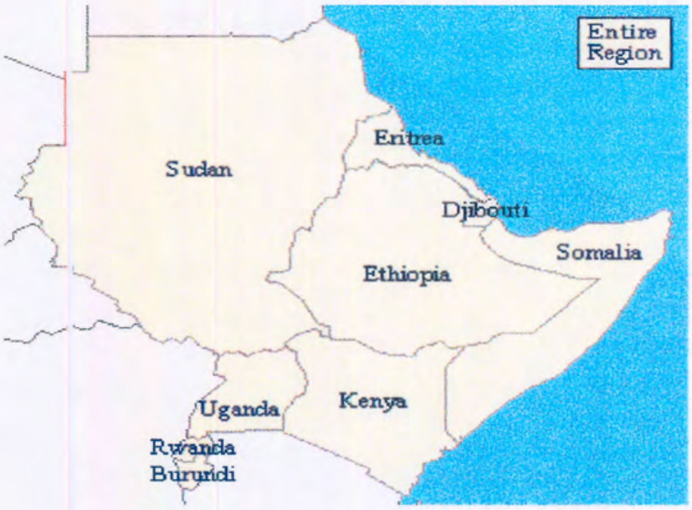

Fig. 1.1 Map of the Eastern Africa region (FAO, 1996)

Eritrea, located in the Horn of Africa, is bounded on the northeast and east by the Red Sea, on the southeast by Djibouti, on the south by Ethiopia and on the west and northwest by Sudan (Figure 1.1). It is located between 12 and 18 degrees North and between 36 and 44 degrees East (CIA, 1999).

Eritrea's Red Sea coastline extends for about 1200 kilometers from Ras Kasar at its northern border with Sudan, to Dar Aiwa, a point south of the port of Assab on the southern Red Sea entrance of Bab al Mandab (Figure 1.2). The total area of Eritrea is 121320 square kilometers and it includes 355 islands lying off the coast of the port town of Massawa with a total area of 1452 square kilometers. Dahlak Khebir is the largest island of the Archipelago (CIA, 1999).

Fig 1.2 Map of Eritrea (NewAfrica, 1999)

1.1.3 Topography

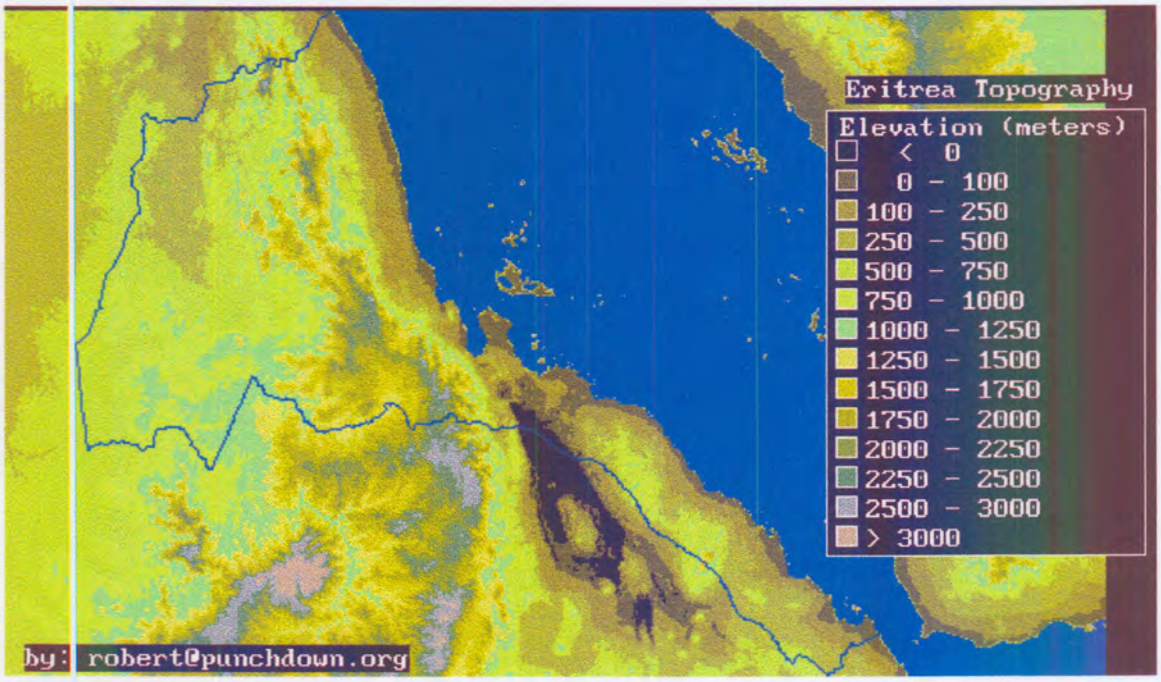

Fig 1 3 Eritrea Topography (Van Buskirik, 1999)

Eritrean topography is dominated by the extension of the Ethiopian north-south running highlands, descending in the east to a coastal desert plain and in the northwest to flat to rolling plains (Figure 1.3). The highest elevation is Embasoira (3018m) and the lowest is near Kulul with in the Denakil depression (-130m) (CIA, 1999)

1.1.4 Climate

1.1.4.1 Average annual rainfall

Eritrea is currently an arid to semi-arid agricultural and agro-pastoral country. Agricultural production, which comprises the majority of the national economy, is constricted mostly by the low availability of water resources either as rainfall, runoff or ground water.

The geographic variations in Eritrean rainfall distribution are extreme, with areas of 1000mm annual rainfall and 200mm of annual rainfall separated by as little as 15km (Van Buskirik, 1999).

Total annual rainfall tends to increase from north to south, from less than 200mm at the northern border with Sudan to more than 700mm in a restricted area on the southern border with Ethiopia. A small area on the eastern escarpment known as the green belt receives over 900mm on average (FAO, 1994).

Like the rest of Sahelian Africa most of Eritrea receives it's rainfall from the SW monsoon in the summer months from April to October. Small rains fall in April and May, and the main rains follow in July with the heaviest total precipitation in July and August. Only the coastal plains and the southern part of the eastern escarpment of the central highlands have a winter rainfall (FAO, 1994).

1.1.4.2 Temperature

Temperatures in Eritrea range from hot and arid adjacent to the Red Sea to temperate sub-humid in isolated micro-catchments within the Eastern high land escarpment area. Altitude is a major factor in determining temperature with, in general, mean annual temperature falling by approximately 1 degree Celsius for each 200m rise in elevation (Table 1.1).

Table 1.1: Temperature regimes of Eritrea (FAO, 1994)

Temperature Regimes (relative)	Elevation Ranges (m)	Area (sq.km)	Mean annual Temperature(^{0}C)
Very hot	< 0 – 500	40,705	29 - 26.5
Hot	500 – 1000	47,454	26.5 - 24
Warm	1000 – 1500	15,982	24 - 21.5
Mild	1500 – 2000	11,623	21.5 - 19
Cool	> 2000	5,073	< 19

1.1.5 The agro-ecological Zones (AEZ)

Six major agro-ecological zones are identified, based on broad similarities of moisture and temperature regime, natural vegetation cover, soils and land use. The major zones are each divided into a number of ago-ecological units based on more specific differences of landform, soil type, land cover or land use. Altogether 55 agro-ecological units are recognized and defined (Ministry of Land, Water and Environment of Eritrea, 1997). The six agro-ecological zones are (Figure 1.4, p10):

I. **Moist Highland**: The location of this zone is the central and southern highlands; including Rora and Hagar plateaux. It covers an area of 897,920 hectares and it has landforms of undulating to rolling plateaux, partly dissected, with hills, valleys, ridges and escarpments. The dominant altitude is from 1600-2600m. The mean annual rainfall ranges from 500-700mm with an annual temperature of 15-21^{0}C and potential evapotranspiration of 1600-1800mm. In this zone the dominant vegetation is bushland and shrubland with remnant *Juniperus procera* and *Olea africana*. The dominant soils are Cambisols, Luvisols, Lithosols, Regosols and Vertisols. The dominant crops are barley, wheat, teff, sorghum, maize, finger millet and pulses. This zone comprises 10 agro-ecological units.

II. **Arid Highland:** The location is northern the highlands, excluding Rora and Hagar plateaux. It covers an area of 310,100 hectares and it has landforms of steep escarpments and mountains, with dissected plateaux and rolling hills. The dominant altitude is 1600-2600m. The mean annual rainfall ranges from 200-500mm with a mean annual temperature of 15-21^{0}C and potential evapotranspiration of 1600-1800mm. The dominant vegetation is sparse shurbland, with scattered bushland and woodland. The dominant soils are Lithosols, Cambisols, Calcisols, Regosols and bare rock. The major crops are sorghum, pear millet and barley. This zone comprises 3 agro-ecological units.

III. **Moist Lowland:** The location is southwestern Eritrea and upper Mareb valley. It covers an area of 1,970,000 hectares and it has landforms of undulating to rolling plains with outlying hills, including the lower part of western escarpment with ridges and valleys. Its dominant altitude is 500-1600m. The mean annual rainfall ranges from 400-1600 with a mean annual temperature of 21-28^{0}C and the potential evapotranspiration is 1800-2000mm. The dominant vegetation is savanna woodland with Acacia and broad leaf species bushland. The dominant soils are Cambisols, Vertisols, Fluvisols, Luvisols, Lithosols, and Regosols. The major crops grown are sorghum, sesame, cotton, finger millet, pear millet and maize. It comprises 8 agro-ecological units.

IV. **Arid lowland:** The location is northern Eritrea, excluding the coastal strip and extreme northwest and lower part of eastern escarpment. It covers an area of 4,179,550 hectares with landforms of flat to rolling plains with outlying hills and mountains and the dominant altitude is from 400-1600m. The mean annual rainfall is ranging from 200-500mm with a mean annual temperature of 21-29^{0}C and evapotranspiration of 1800-200mm. The dominant vegetation is shurbland and bushland with scattered woodland and Hyphenae palm along the rivers. The dominant soils are Calcisols Cambisols, Fluvisols and Lithosols. The major crops grown in this area are sorghum and pear millet. This AEZ comprises 12 agro-ecological units.

V. **Sub-humid Escarpment**: The location is the central eastern escarpment. It covers an area of 103,000 hectares with landforms of steep escarpment with mountains and valleys and the dominant altitude is 600-2600m. The mean annual rainfall is ranges from 700-1100mm with a mean annual temperature of 16-27^{0}C and evapotranspiration of 1600-2000mm. The dominant vegetation is *Juniperus procera* and *Olea africana*. The dominant soils are Lithosols, Cambisols and Fluvisols. The major crops grown in this area are maize, sorghum, coffee and barley. This AEZ comprises 3 agro-ecological units.

VI. **Semi- desert:** The location is the coastal area, islands and area northwest of the Barka Sawa River. It covers an area of 4,730,100ha with landforms of flat to rolling plains with outlying hills and mountains, volcanic calderas, dune fields and evaporates basins. The dominant altitude is -100-200m. The mean annual rainfall is less than 200mm with a mean annual temperature of 24-32^{0}C and potential evapotranspiration of 1800-2100mm. The dominant vegetation is grass and local

Acacia mellifera. The dominant soils are Calcisols, Solonchacks, Lithosols, Cambisols, Fluvisols, Regosols and Andisols. This zone is not suitable for crop production. This AEZ comprises 19 agro-ecological units.

It must be kept in mind that the AEZ has been prepared with limited field checks. Therefore, for "some of these data accuracy is questionable particularly that of soils" (Ministry of Land, Water and Environment of Eritrea, 1997).

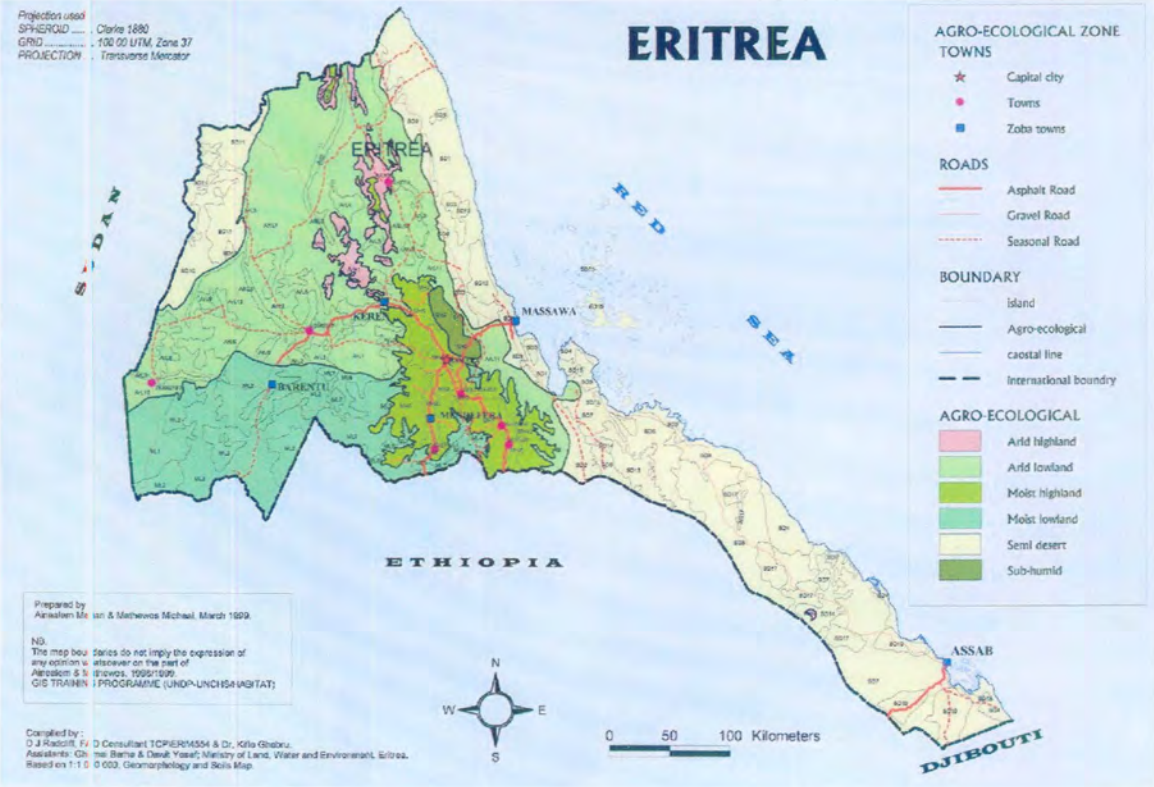

Fig 1.4 Agro-ecological zones in Eritrea (Ministry of Land, Water and Environment of Eritrea, 1997)

1.1.6 Vegetation

There are five vegetation classes for each temperature zone that are based on very rough estimates of mean annual vegetative productivity (Figure 1.5). Table 1.2 describes the types of vegetation and their biomass production.

Table 1.2: Description of vegetation type in Eritrea (Van Buskirk, 1999)

Vegetation	Biomass production	
	Kg/ha/year	Class
Desert	0-500	Extremely low
Grass land	500-100	Low
Open bush and Savannah	1000-1700	Low to medium
Open forest and brush	1700-2600	Moderate
Deciduous forest and thick deciduous brush	> 2600	Relatively high

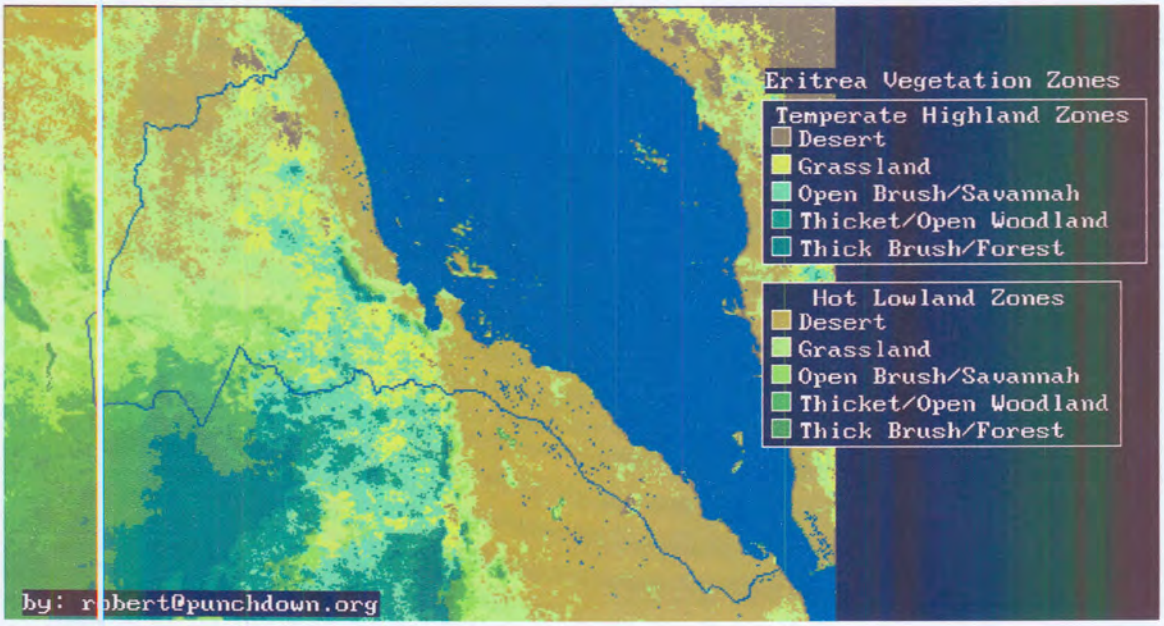

Fig 1.5 Type of vegetation in Eritrea (Van Buskirik, 1999)

1.1.7 Water Resources

Eritrea falls into three drainage basins. The Mareb-Gash and Tekeze-Setit rivers drain into the Nile Basin. The rivers of the eastern escarpment and the Barka-Anseba system form part of the Red Sea Basin while a narrow strip of land along the southeastern border drains into the closed Denkel Basin (FAO, 1994).

The Tekeze-Setit river Basin has a catchment area of 68,751km^2, of which more than 90% lies within Ethiopia. The Eritrean portion of the catchment comprises the Right Bank of the river over a distance of some 60km upstream from the Sudanese border. Estimates of mean annual runoff of the Setit to the Sudan border range from 5,800 to 8,000 million m^3 (FAO, 1994).

The Mareb-Gash is a narrow, westward oriented basin covering 24,000km^2 of Eritrea from the southern part of the Central Highlands to the Sudanese border. Estimates of mean annual flow range from 890 to 1440 million m^3 (FAO, 1994).

The Barka and Anseba rivers arise on the northwestern slopes of the Central Highlands and flow northward to a confluence close to the Sudanese border in the extreme northwest of Eritrea. The area of the basin is 41,700km^2.and the mean annual runoff has been estimated at 360 million m^3 (FAO, 1994). The Red Sea Drainage Basin comprises numerous small rivers originating from the eastern escarpment. No hydrometric data exists.

No systematic investigation of groundwater has been carried out in Eritrea. Evaluations of these resources have been based on interpretations of aerial photography and satellite imagery. Amounts of groundwater have been estimated, not measured.

1.1.8 Soils

The dominant soil types in Eritrea are: Arenosols, Solonchacks, Leptosols, Calcisols, Lixisols Luvisols, Gypsisols, Cambisols, Fluvisols, Nitisols, Vertisols and Regosols (FAO, 1994). There is considerable diversity in the properties and potentials of Eritrea's soils. The soils reflect the topography and geology of the area and the history of intensive cultivation (Figure 1.6). Shallow Leptosols and bare rock dominate the escarpments and steep sided hills and mountains. The principal cultivated soils comprise Cambisols, which are partially weathered soils and show an increase in clay down the profile; and Vertisols and related vertic Cambisols, which are deep dark soils of relatively good inherent fertility. The Cambisols and Luvisols are usually associated with schist, gneiss and granite and occur throughout the highlands. Soils formed on granites usually have sandier texture and are less fertile than those developed from schist or gneiss.

Vertisols and vertic Cambisols are formed on basalt and occur mainly in the south-western part of the highlands, on the plateau from Adi Quala to Tera Emni and on the Tselema plain (Ministry of Agriculture of Eritrea, 1998).

Soils of the western escarpment are similar to those of the highlands except that steeper slopes give rise to a higher proportion of Leptosols. Vertisols are either absent or very localised in valley bottoms. Luvisols and Cambisols are likely to be more weathered than on the highlands, but may have been less intensively cultivated, so nutrient levels may not be that dissimilar. In the western lowlands towards the border with Sudan the terrain becomes flatter and soils comprise mainly vertic Cambisols with significant areas of Fluvisols (Ministry of Agriculture of Eritrea, 1998). Nitisols in Eritrea covers a small area. These soils are important because they are deep, well drained and stable against erosion. According to ISSS Working Group RB (1998a) large areas of Nitisols occur in Ethiopia.

In most lowlands the arid conditions and depressions favour the accumulation of carbonates and sometimes soluble salts in the soils. Calcisols replace Luvisols and Cambisols, as conditions become drier. On the Red Sea plains Solonchaks with high salt content, predominate, while in the Denkalia area some Andosols may occur associated with recent volcanic activity. Leptosols dominate the mountains, escarpment and hills of the Eastern Escarpment Zone. Significant areas of Fluvisols occur in the major river valleys, and in alluvial fans below the escarpment slopes. These Fluvisols are usually fertile because they receive regular deposition from flooding and many are either presently irrigated, or may have potential for irrigation development (Ministry of Agriculture of Eritrea, 1998).

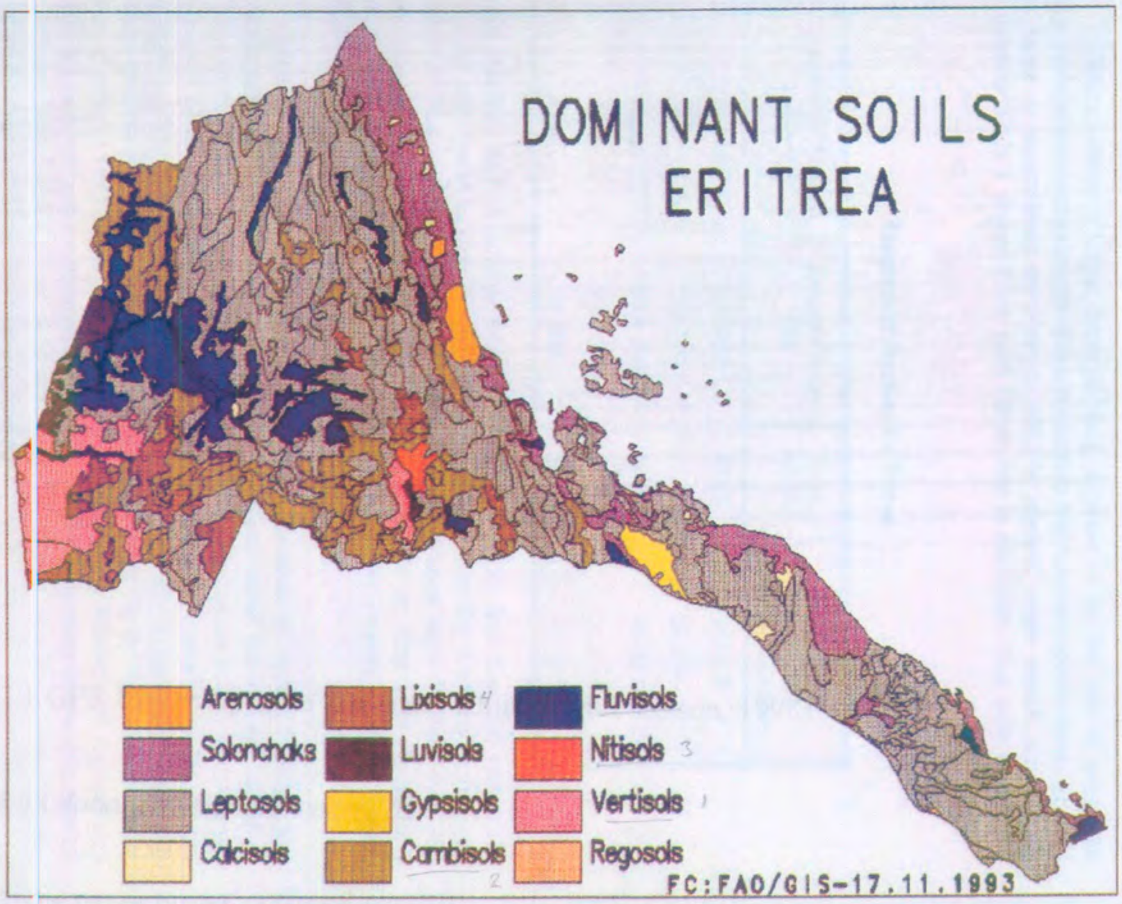

FIG 1.6 Dominant soils of Eritrea (FAO, 1994)

1.1.9 Land Use

There are no accurate figures on current land use within Eritrea. Table 1.3 represents the best estimate arrived at by FAO in 1994 for the area under each broad land use category. Of Eritrea's 12.1 million hectares total land area just under 2.1 million hectares i.e 17.4% has been provisionally assessed as having potential for rainfed and irrigated crop production (FAO, 1994).

Table 1.3 Land use categories (FAO, 1994)

Land use	Hectares	Percentage of Total
Cultivated land rain fed	470,000	3.42
Irrigated land	22,000	0.18
Disturbed forest	53,000	0.43
Forest plantation	10,000	0.08
Woodland and Shurbland	673,000	5.52
Browsing and Grazing	6,967,000	57.16
Barren land	4,047,000	33.21
Total	12,242 ,000	100.00

1.1.10 Population

Eritrea has a population of about 4 million of whom about 1 million live abroad, mainly due to political crises that prevailed in the country for the past several decades (NewAfrica, 1999).

The original inhabitants of present day Eritrea were the Kunama and the Nara. They presently inhabit the area between the Gash and Setit river in western Eritrea as the result of pressures first from Hamitic tribes from the northern Nile basin of the Sudan and later from Semitic peoples migrating from southern Arabia around 700-800 BC. These latter two groups intermingled with the original inhabitants to make up most of the population of present-day Eritrea (NewAfrica, 1999). At present the nine distinct ethnic groups are as follows: Afar, Kunama, Beja, Bilen, Nara, Rashaida, Saho, Tigre, and Tigrinia.

More than 65% of the population lives in highlands of the country (previous provinces like Hamasien, AkeleGuzai, and Seray), which cover only 16% of the territory, because the mountains and highlands offer much more favourable climatic and ecological conditions for agriculture that the surrounding lowlands (Hurni, 1992). These attracted early human settlers to the highlands of the country.

1.1.11 Economy overview

The economy is largely based on subsistence agriculture, with over 70% of the population involved in farming and herding (CIA, 1999). The small industrial sector consists mainly of light industries with old technology. Domestic output is substantially augmented by workers' remittance from abroad. Government revenues come from custom duties and taxes on income and sales. Road construction is a top priority. Eritrea has long term prospects for revenues from the development of offshore oil, offshore fishing, and tourism. Eritrea's economic future depends on its ability to master fundamental social and economic problems (CIA, 1999).

1.1.12 Infrastructure

1.1.12.1 Roads

The country has a network of roads that are currently under renovation and repair. Asphalt all-weather roads connect the capital Asmara with one of the principal Eritrean ports, Massawa and several other provincial towns. In addition, there are hundreds of kilometers of dirt roads linking administrative and trade centres as well as seasonal roads connecting various parts of the country.

1.1.12.2 Power and water supply

The supply of electric and water for domestic and industrial use is currently state-owned. Substantial efforts are under way to modernize and expand both services in order to meet current requirements more efficiently and to accommodate new investment demands.

1.1.12.3 Telecommunication

The Eritrean telephone system connects almost all cities and towns in the country. A newly installed satellite communication network has made direct telephone dialing with the rest of the world possible.

1.2 Objectives of this study

The overall objective of this study is to develop appropriate methods and techniques of land resource surveying for collecting the basic data required for effective land use planning in Eritrea.

Specific objectives are:

- To study the present land resource survey methods and techniques used in Eritrea
- To evaluate different methods and techniques of land resource survey which are currently in use in various parts of the world.
- To design improved method and techniques of land resource surveying for Eritrea
- To indicate the importance of cost-effective ways of land resources surveying in achieving optimal and sustainable land use.

1.3 Research methodology

This research consists of three parts:

I. Analysis of the present resource surveying methodologies and techniques used in Eritrea. These data were collected from government and none-government reports, surveys, statistics, publications, records and personal documents. The main sources of information were the Ministry of Agriculture of Eritrea, the Ministry of Land, Water & Environment of Eritrea and FAO.

II. Analysis of international publications on land resource surveying methods and techniques and evaluation of their appropriateness for Eritrea.

III. Synthesis of an appropriate and affordable set of land resource surveying methodologies and techniques for Eritrea.

CHAPTER TWO

BASIC CONCEPTS OF LAND RESOURCES SURVEY

2.1 Definition of land

"Land is an area of the earth's surface, the characteristics which embrace all reasonably stable, or predictably cyclic, attributes of the biosphere vertically above and below this area including those of the atmosphere, the soil and the underlying geology, the hydrology, the plant and animal population, and the results of past and present human activity to the extent that these attributes exert a significant influence on present and future uses of the land by man" (FAO, 1976).

The definition obviously includes all land resources, both natural and man-made, of a clearly permanent or cyclic nature. Permanent artificial structures such as dikes, canals, roads or stable terraces are also considered as a part of land. Several institutional factors, however, are not included in the concept of land (Vink, 1975).

Davidson (1992) stated that in a scientific sense this definition is far from satisfactory since an assessment of relevant characteristics is necessary before land can be defined. However, it is inappropriate to try to define land in a scientific way. The theoretical definition in terms of the function of the land in the particular ecological system should ultimately be achieved. The FAO statement therefore provides clear guidance on how land can be interpreted.

2.2 Land resources

Land resources include all those features and processes of the land which can in some way be used to fulfil certain human needs (Vink, 1975). To study land resources in general is very wide, but it can be done with major simplification. It is easier therefore to

study land resources from a more defined standpoint. In this paper the emphasis is more on natural land resources which are more relevant for agricultural purposes.
Vink (1975) indicted that for agriculture the most important land resources are climate, relief and geological formations, soils, water and vegetation.

2.2.1 Climate

The processes of exchange of heat and moisture between the earth and the atmosphere over a long period of time result in conditions which we call climate. Climate is more than a statistical average; it is the aggregate of atmospheric conditions involving heat, moisture and air movement (Critchfield, 1983). Extremes must always be considered in any climatic description in addition to the means, trends and probabilities. Climate covers a range of factors such as precipitation, solar radiation, temperature, humidity, wind and atmospheric circulation. The sun provides almost all the energy which is applied to land use (Vink, 1975).

There is a difference between weather and climate: weather is the day to day state of the atmosphere and pertains to short-term changes in conditions of heat, moisture and air movement (Critchfield, 1983). Climate is the long-term average describing what generally happens (Chetner, 1996). A long period of observation is necessary to understand the expected climate. Like weather, climate also changes, but very gradually. A 30-year period is normally used to describe the present climate because it is long enough to filter out short-term fluctuations, but it is not overridden by any long-term trend in climate (Chetner, 1996).

All other land resources have their impact on land use within the general context of a given climate. Even so many of land resources have been, and are, influenced by climate during their formation. Climate is one of the main genetic factors in the formation of relief and soils. It is the main agent determining the water balance in geohydrology and hydrology. Finally climate largely determines the nature of the natural vegetation in any given area (Vink, 1975).

2.2.2 Soils

The soil is the interface between the atmosphere and lithosphere (the mantle of rocks making up the earth's crust). It also has an interface with bodies of fresh and salt water (collectively called the hydrosphere). The soil sustains the growth of plants and animals and so forms part of the biosphere (White, 1977).

The definition soil varies according to the user. For agriculturists, the important factors in soil focus on the upper one or two metres of the solum, which are important to plant growth. Civil engineers consider soil a structural material with definable physical and chemical properties that can be manipulated for construction purposes (Winegardner, 1996).

2.2.3 Relief and geological formations

Geological formations, in mountains and hilly areas, as well as in flat alluvial areas, determine the main materials and structure of land. They determine the main features of the relief, including altitude, which is an important ecological factor, as well as the general directions of both surface and subsurface waterflow. Geological formations also have a decided influence on the formation and degradation of soils and the landscape (Vink, 1975).

The influence of relief on agricultural land use is multifaceted. Relief is the expression of the interaction of several different phenomena and the processes within the earth's crust and on its surface. Its forms and dimensions are primarily related to geological formation and to the climate, both past and present, which have either directly or indirectly acted upon these formations (Vink, 1975).

2.2.4 Water resources

Most of the earth's water is the salt water of the oceans, and much of the fresh water is locked away in icecaps or deep in bedrock. For practical purposes, water resources consist of 1% of the earth's water that is cycled as rainfall, soil moisture, evaporation, groundwater, rivers and the hydrological cycle (Young, 1998). There are two interlocking cycles, both starting with evaporation from the seas to the atmosphere. The first, shorter cycle is from rainfall into the soil and then as evaporation and plant transpiration back to the atmosphere. This is sometimes called "green" water. The second cycle or "blue" water follows the longer path from the rainfall through soil, moisture, groundwater and river to the sea. By convention only blue water from groundwater and rivers is considered as water resources, the direct use of rainfall in rainfed agriculture being treated as a climatic resource (Young, 1998).

2.2.5 Vegetation

Vegetation includes all natural and semi-natural vegetation which is not purposely and continuously manipulated by man for any of his systematic land uses (Vink, 1975). Natural or semi-natural vegetation is characterised by a great variability of species, which are well adapted to the ecological conditions under which they have developed. They are therefore internally stable, that is occasional disturbances within the ecosystem are easily compensated by the system itself without running into danger of disequilibrum (Vink, 1975).

2.3 Land resource surveys

Land resource survey refers to the description, classification and mapping of the physical environment: climate, water, geology, landform, soils, vegetation and fauna (Young, 1998). Any assessment or evaluation of land resources is possible only if there has been the collection of basic land resource data (Davidson, 1992). Land resource surveys are needed in situations where farming experience is not available, when new areas of land are brought into cultivation and when new kinds of use are introduced to existing farms. The first of these was at the forefront of attention from the 1950s to 1970s, the latter is more often the case in recent years as unused land becomes scarce (Young, 1998).

Surveys have two main functions: Firstly, avoiding mistakes, such as growing water-demanding crops on sites prone to drought, can make immense savings in development costs and secondly to improve efficiency of land use and management (Young, 1998).

Valid techniques have been developed for all types of resource surveys. However information on basic land resources is scarce in many developing countries and their institutional capacities to collect the required information are weak. The extent to which surveys have been applied in land use planning is far from satisfactory. Therefore, proper resource surveying is essential for sustainable agricultural development for developing countries.

CHAPTER THREE

LAND RESOURCE SURVEYING METHODS AND TECHNIQUES

3.1 Soil surveying

3.1.1 What is soil surveying?

A soil survey describes the characteristics of the soils in a given area, classifies the soils according to a standard system of classification, plots the boundaries of the soils on a map and makes predictions about the behaviour of soils (Van Wambeke & Forbes, 1986; Soil Survey Staff, 1993).

The focus of soil survey traditionally has been towards agriculture and the soil is usually taken to be the natural medium within which plants will grow (Davidson, 1992). However an assessment of the properties of soils and their response to management is required in agriculture and forestry, for decision making in rural land development projects and for many engineering works. Therefore the practical use of soil survey is to enable more numerous, more accurate, and more useful predictions to be made for specific purposes (Dent & Young, 1981).

3.1.2 Planning a soil survey

3.1.2.1 Objectives

The first decisions to be made are the location and the extent of the area to survey and the objectives of the survey. The objectives of any kind of survey must be specified and how the findings are to be presented must be done in consultation between the survey organization and the client (Dent &Young, 1981). The objective of the survey determines the scale at which the survey has to be conducted and the definition of the mapping units (Laker, 1994).

3.1.2.2 Scale and level of intensity

The cost of survey is directly related to the scale. The decision made on publication scale, viewed in the light of available knowledge of soil and terrain and of experience in comparable surveys, provides the basis for estimating staff, time and budget requirements (Dent & Young, 1981). The map scale must be large enough that areas of the minimum size can be delineated legibly. The chosen map scale also depends on the user perspective. The intensity of the survey determines the scale of the map (Van Wambeke & Forbes, 1986; Soil Survey Staff, 1993).

The scale of available aerial photographs or topographical field sheets may influence the scale of a field survey (Dent & Young, 1981). However, it is preferable and best to conduct a survey on base maps 2 - 2.5 times the scale of the intended final map (Young, 1976). The map scale directly affects the accuracy with which points on the ground may be represented (Forbes, Rossiter & Van Wambeke, 1987).

Young (1976) indicated six ranges of scale or levels of intensity for soil surveys and maps. These are as follows:

Syntheses (Compilation): These are broad (small) scale soil maps based on abstraction from other surveys plus, where gaps in coverage render it necessary, additional field work. Inference scales are usually 1: 1 000 000 or smaller.

Exploratory: These are not soil surveys in the strict sense in that they do not attempt full coverage of the area. The purpose of exploratory surveys is to obtain a rapid general appraisal of an area (Landon, 1991). They are carried out by road and track or helicopter without attempting uniform coverage. Scales vary from 1:2 000 000 to 1: 5 000 000

(Young, 1976). The intensity of observations vary greatly, depending on the specified development, the nature of the terrain, and the data already available (Landon, 1991).

Low intensity (Reconnaissance surveys): These are the smallest scale of survey to achieve coverage of the whole survey area. Usually scales of 1: 500 000 to 1: 120 000 are included (Young, 1976). Reconnaissance surveys are used to locate and give initial assessment of areas for more intensive studies or to locate and investigate areas which are unlikely to justify the costs of more detailed studies (Landon, 1991).

Medium intensity (Semi-detailed surveys): These cover the scale range 1: 100 000 to 1: 30 000, typically 1:50 000. Survey is by air photograph interpretation combined with a substantial amount of field survey (Young, 1976).

High intensity (Detailed): These cover the scale range 1: 25 000 to 1: 10 000 inclusive. They are produced mainly by field survey. The usual mapping units are soil series and phases of series (Young, 1976).

Very high intensity (Intensive): These are at scales larger than 1: 10 000. Grid or systematic traverse methods of field surveying are commonly employed. Mapping may be soil series and phases or additionally parametric maps of individual soil properties (Young, 1976). It is appropriate for detailed mapping of small areas (a few hectares to about 1 000 ha), for example, forest inventory plots or experimental fields, irrigation schemes, horticultural enterprises or civil engineering works. The basic information for such a detailed soil map is obtained by intensive sampling of the area, whereby air photograph interpretation plays an orientating role only (Breimer, Van Kekem, & Van Reuler, 1986). This kind of survey is very time and labour consuming and hence expensive, but it is essential for successful planning at project or farm level.

3.1.2.3 Collection of basic information

The first step to be taken in a soil survey after the objectives, extent and mapping scale have been defined, is to collect existing information about the survey area on the following items (Breimer, *et al.* 1986):

Topography: Topographical base maps at different scales, especially those larger than the final publication scale.

Climate: Complete data records from the nearest meteorological stations; publications on climate that include the survey area.

Geology: Geological maps and their reports; publications; other geological information.

Vegetation: Vegetation maps and reports; publications on flora, etc.

Hydrology: Hydrological data or hydrological maps and publications.

Present land use: Present land use of the study area.

Maps and publications of data must be collected. Information about and soil data contained in reports of any previous soil studies in the area must also be collected.

3.1.2.4 Soil classification and mapping legend

Prior to fieldwork the soil classification system must be decided. Most countries have developed their own system of soil classification for general-purpose surveys, each adapted to the range of soils found in the country (Dent & Young, 1981). The choice of a soil classification system should be based on the cost effectiveness, for purposes of international correlation and transfer of technical knowledge and to place soil units distinguished in a recognized soil classification. Most importantly the classification system must be able to accommodate the important soils of the survey area in a meaningful and useful way.

There is no generally accepted soil classification system, however FAO set out to construct an international legend which aimed to be a common denominator of existing national schemes while adequately accommodating the major soil patterns of the global soil cover to ensure it's geographic relevance (Driessen & Dudal, 1991). In 1998 the international union of soil sciences (IUSS) decided that the World Reference Base for Soil Resources (ISSS Working Group RB, 1998b), an updated version of the FAO system, should be used as international reference soil classification system. The idea is not that WRB should replace national soil classification systems, but should serve as an umbrella through which national systems can "communicate" with each other (Laker, Personal communication). The big problem with the major international systems, like the FAO system and the USDA's soil Taxonomy (Soil Survey Staff, 1999), is that they are well developed for the continents at relatively high latitudes, like North America and Europe, and fairly well for the humid tropics only. Classification of the special soils of the more arid old landscapes between 23^0 and 35 ^{0} northern latitude and between 23^0 and 35^0 southern latitude are very poorly and incompletely catered for in these systems. However WRB is a little bit better in this regard, but still also needs improvement (Laker, Personal communication).

Dent & Young (1981) indicate that the nature of the mapping legend will be discussed between the surveyor and client at the planning stage of soil survey. The purpose of the survey, the anticipated nature of the country and above all, the scale of the survey will determine whether soil-landscape units, soil alone or only selected soil properties are likely to form the better basis for defining map units. Decisions on the relative extent to which simple mapping units are to be employed will be based on previous experience in a similar type of country. Such decision can only be provisional, since the nature and complexity of the soil pattern is not yet known.

3.1.2.5 Staff and equipment

Highly qualified and trained soil surveyors are needed for good quality maps. Even if the cost of hiring an experienced soil surveyor is high it is essential to have an experienced surveyor who is familiar with the study area at least as team leader to guide less experienced team members (Dent & Young, 1981).

In order to ensure the best performance in the field the soil surveyor should be well equipped and provided with the necessary handbooks. Before making any field trip the surveyor should consult a checklist. Breimer *et al.* (1986) indicate the checklist to be as follows:

I. Maps and aerial photos of the study area.

II. Auguring, digging and sampling materials and equipment such as soil augers, spade, shovel, pick, machete, sampling bags, strings, labels, pH measuring kit, conductivity measuring kit, container of distilled water and 10% HCl solution are required.

III Soil description material and equipment such as map holder, notebook, altimeter, compass, clinometer, hand lens, sand scale, HCl and NaF dripping bottles, Munsell soil colour chart, tape, etc.

3.1.2.6 Supporting services

The requirement for laboratory studies must be established at the planning stage because they are expensive and time consuming relative to field observation. In any soil survey, physical, chemical and mineralogical analyses are important to be carried out on representative modal profiles after fieldwork. Therefore it is required to study the requirements in terms of laboratory facilities and other necessary factors beforehand (Dent & Young, 1981).

At the planning stage it is also important to plan the cost of travel, accommodation and basic facilities, food and water supplies, local technical staff and labourers and cost of health care (Dent & Young, 1981).

The importance of a well-equipped and staffed drawing office for compilation of the final maps and word-processing facilities and staff for preparation of the survey report should not be forgotten (Laker, Personal communication).

3.1.2.7 Timing of survey

Once decisions have been made about the objectives and design of the survey, supporting services and the relations of the soil survey activities to the other integrated studies, a work schedule is drawn up for each phase of the project from mobilization of staff to production of the final report (Dent & Young, 1981). Allowance should be made for adverse climatic conditions during rainy and/or hot seasons and for periods of local holidays (Landon, 1991). Planning of time is important in order to obtain the optimum balance between various activities and to ensure that the work is completed within the time and economic budget allowed. A general mistake is to allocate **far** too little time, and consequently also funding and manpower, for the compilation of the final maps and especially of the final reports (Laker, Personal communication).

3.1.3 Field methods and research phase

3.1.3.1 Distribution and density of observation sites

The required intensity of field survey to produce an accurate map at the required scale can only be determined on the ground (Dent and Young, 1981). The density of observations depends on the objectives, scale of map, and variability of soils of the survey area. The distribution of observation sites, and to some extent their density, is also determined by the survey approach, i.e. whether a fixed grid, free grid or free survey strategy is used.

Fixed grid survey

In this kind of survey observations are regularly spaced to produce a rectangular grid over the survey area. This is appropriate for large-scale intensive surveys, in which the usefulness of air photo-interpretation and the surface expression of soil classes is limited and where the high density of observation demands precise plotting of sites (Dent & Young, 1981). The use of aerial photos and surface expression is limited because of the high density of observations and precise plotting of sites (Western, 1978).

It is also the most economical approach for areas with very complex soil patterns, especially where external features such as topography cannot help to identify soil boundaries. This particularly the case on the alluvial plains (Western, 1978). It is also the only feasible approach for detailed soil survey in dense bush where transects have to be cut.

An advantage of a fixed grid survey is that it requires less experienced staff than the other approaches, where subjective selection of observation sites are made (Dent & Young, 1981). The disadvantage is the inherent inefficiency of a fixed grid system, in which a significant proportion of observations may fall on or near soil boundaries, where they are classed as indeterminate intergrades or near other non-representative sites such as local depressions roads and villages, so that none of them can assist in mapping (Western, 1978; Dent & Young, 1981). "This approach is the most wasteful and time consuming way of making a soil survey" (Western, 1978).

Free grid survey

In a free grid survey observations are made along grids but not according to rigidly fixed patterns Free grid surveys can be used in detailed and large-scale surveys. Free grid survey varies from fixed survey because here observations are conducted along the grid but not at equal distance and the grids are not parallel to each other. This approach speeds up the process of surveying by avoiding inaccessible and unrepresentative sites. It improves accuracy of location of delineation boundaries and makes efficient use of features such as changes in topography, etc. However this approach may need more experienced and highly trained surveyors (Dent & Young, 1981; Ellis & Mellor, 1995).

Free survey

In free survey the surveyor uses his/her judgement of the objectives of the survey and all the available air photo and ground evidence to locate profile observations at the most useful and representative sites. Each observation thus produces the maximum useful information. The density of observation is adjusted according to the requirements of the survey and complexity of the soil pattern. Free survey requires good field sheets, either aerial photographs or detailed topographic maps (Dent & Young, 1981). It is mainly used for semi-detailed to small-scale surveys. Accuracy is strongly dependent on the judgement of highly trained, experienced surveyors.

Integrated survey

Conventional soil survey, in which the surveyor proceeds from field to field, putting down auger boring, is thorough but extremely slow. There is no way that it could meet the needs the quick identification of promising areas for opening up new land for the settlement of communities or farmers. A solution was found in integrated survey methods (Young, 1998).

The method of integrated surveys, or land systems method, is based on mapping units of the total physical environment that can be distinguished on air photographs (Young, 1976). This method is largely used in reconnaissance surveys with mapping at scales of 1:1 000 000 to 1:250 000. The method becomes less useful at medium scales and cannot be used for large-scale (detailed) mapping (Davidson, 1992).

The South Africa land type survey approach is one of the best methods of integrated survey in the world. This approached was employed in South Africa at scale of 1: 250 000 for the purpose of determining the agricultural potential of the country (Land Type Survey Staff, 1984). The approach is based on systematic compiled natural resource inventory namely climate, soil type and terrain form. The procedures of land type survey approach are: First, all existing information, maps and satellite imagery, relevant to the terrain, soil and climate of the area should be collected and studied. Secondly excursion of the study area should be conducted to delineate terrain type. Each terrain type should have homogenous form and slope. Finally, the soils in each terrain type should be identified, each with uniform terrain and soil pattern should be delineated. Description of representative soil profiles is vital for further laboratory investigation. A separate map showing the distribution of climate zone should be drawn. This should be superimposed upon the pedosystem map to arrive at a map of land type. Therefore the land type approach can be an effective and appropriate method of survey for developing countries.

Two principal mapping units are employed, the land system and the land facet. The land system is an area with a recurring pattern of topography, soil, and vegetation with relatively uniform climate. The land facet is an area within which, for most practical purposes environmental conditions are uniform (Dent &Young, 1981).

Integrated surveys are the best and cost-effective methods to conduct land resources survey at reconnaissance scale for developing countries which still need resource inventories at national scale to identify promising areas for development (Young, 1998). It must be kept in mind that once a promising area for project development or settlement has been identified, the integrated survey cannot be used for feasibility studies and even less for actual project development (Laker, Personal communication). Its information is far too general and vague for these. For project or settlement development planning detailed soil surveys of the selected promising areas are required. Time and funds should not be wasted on detailed surveys of areas with no or little development potential however (Laker, Personal communication).

3.1.3.2 Site description and selection

The properties of a soil profile is determined and described in the field and analysed in the laboratory. Data for a soil profile are of little value unless there is reasonable confidence that the profile is truly representative of some class of soil (Hodgson, 1978).

Description of soil profiles is time-consuming and requires high manpower and other resources. Therefore it is very important to select the most representative modal site for profile description. Traditionally the soil surveyor selects representative profiles intuitively for the particular purpose in hand by studying and examining the soils of the region concerned (Hodgson, 1978). Although the surveyor uses his or her judgement to select representative profiles, it is also essential to investigate and apply statistical checks to find proper representative profiles.

After selecting the site carefully and after digging the profile pit it is essential to describe it's environment in detail. There are three main reasons for this (Young, 1976; Hodgson, 1978):

I. To indicate of what the soil is typical,

II. To be able to relate the site factors , which often influence soil formation, to the soil profile and

III. Because potential land capability and to some extent current land use are influenced by both site and soil factors.

A site description usually includes indexing data to enable the site to be traced again later and connected with its records. It indicates of what it is typical, land use, for example soil class, slope, vegetation, and factors which affect soil genesis (Hodgson, 1978; Breimer *et al.*, 1986). A generalized proforma (Table 3.1) for recording and indexing the characteristics of a soil site is given by Hodgson (1978).

Table 3.1- Generalized proforma for recording the characteristics of a soil site (From: Hodgson, 1978).

Index data

Profile No. Observer Date

Grid Reference Soil class

Latitude & Longitude

Locality, map or air photographs number

.

Site characteristics

Relief

Elevation

Slope and aspect

Regional relief

Micro relief

Climate and weather

Geomorphologic development or age of site:

Soil erosion and deposition

Drainage of site (including flooding)

Land use and vegetation

Geology or soil parent material

Rock out crops

Fauna

Present land use

The soil surface

Surface stoniness

Soil surface form and condition etc

General soil information

Soil moisture regime class, presence of salt and alkali

3.1.3.3 Location

The most detailed and perceptive soil descriptions are of little use unless you know where you are. This needs to be determined to within about 2mm on the field sheet (Dent & Young, 1981). The position of a site can be surveyed or estimated in various ways. Where accurate large-scale maps of terrain with abundant man-made features are available it is possible to place a soil profile on the map by pacing or measuring from two more landmarks or alternatively by using a compass or more accurate surveying equipment (Hodgson, 1978).

3.1.3.4 Recording and observations

Each profile description, even the briefest should be given a number and this should be entered on the field sheet with the site location. Where aerial photographs are used as field sheets, site locations may be marked with a pinhole, although these may be difficult to see. Where a topographic base map is used, coded information may be written in colour pencil or ink on the field sheets. If the field sheets are to be interpreted by others, a key must be provided and the surveyors must adhere to it (Dent & Young, 1981).

3.1.3.5 Sampling

In soil survey the term sample refers to small specimens of a soil taken to represent a soil horizon or other body of soil for some purpose (Hodgson, 1978). No detailed profile description is complete without some supporting laboratory data, and it is usual to take soil samples for several kinds of investigation (Hodgson, 1978; Dent & Young, 1981). Samples from a profile are normally taken from each master horizon (Dent & Young, 1981).

Before taking a sample, the soil surveyor must decide upon the horizon boundaries very carefully and "draw" them on the face with knife or mark with pegs. It is essential to decide whether the survey sampling require the whole horizon or just its center, that is whether a horizon extending from 50cm to 100cm depth is to be sampled in the 60-90cm or 70-80cm range (Dent &Young, 1981).

Hodgson (1978) stated that three main kinds of samples are taken from individual soil horizons for laboratory studies: disturbed bag samples for particle size, chemical and other analyses; undisturbed core samples for physical measurements and box samples for micro-morphological studies.

All horizon samples should be labeled with a unique profile number and sampling depth accurately and legibly (Hodgson, 1978; Dent & Young, 1981). If samples have to be dispatched by airfreight, drying, grinding and separation of the coarse fraction by a 2mm sieve may be performed at field base to reduce weight and bulk (Dent & Young, 1981).

3.1.4 Mapping

3.1.4.1 Map unit

A map unit is a collection of areas defined and named the same in terms of their soil components or miscellaneous areas or both. Each map unit differs in some respect from all others in a survey area and is uniquely identified on a soil map (Van Wambeke & Forbes, 1986; Soil Survey Staff, 1993). A map unit serves as a basis for predicting soil behaviour (Dent & Young, 1981).

3.1.4.2 Kinds of map unit

Soils differ in size and shape of their areas, in degree of contrast with adjacent soils, and in geographic relationships. These determine the types of maps units that can be indicated on a certain scale at certain survey intensity. Soil Survey Staff (1993) identified four kinds of map units. However Van Wambeke & Forbes (1986) indicate one more kind of map unit i.e. unassociated soils. Various of these kinds of map units are found on a specific map.

Van Wambeke & Forbes (1986) describe the different kinds of map units as follows:

Consociations: In a consociation, a single soil taxon and similar soils dominate the delineations of the mapping unit. As a rule at least one half of the pedons in each delineation of a soil consociation is of the same taxonomic unit and provides the name for the map unit. The total amount of dissimilar inclusions of other components in a map unit generally does not exceed about 15% if limiting and 25% non-limiting soils. With "non-limiting" is meant soils with both (a) the same potential and (b) the same management requirements for a specific land use as the dominant soil in the consociation.

Undifferentiated groups: An undifferentiated group is dominated by two or more named taxa that are not consistently associated geographically but that are included in the same map unit because their use and management are the same or very similar for common uses. Generally they are included together because their distribution is such that they cannot be separated at the given map scale and survey intensity.

Associations: In an association two or more taxa with (a) different potentials and/or (b) different management requirements for a specified land use dominate the delinations of the mapping unit and provide the name for the mapping unit. The taxa occur in known proportions and definable patterns.

Unassociated groups: These are map units that, like associations, are dominated by two or more kinds of soil that have different suitabilities for use, but unlike associations their distribution in the landscape is unknown. They are used commonly in soil maps at very small scales when areas of two contrasting soils with unknown proportions and patterns must be included in the same delineation (Van Wambeke & Forbes, 1986).

Complexes: These are geographically complicated mixtures, usually of soils and non-soil features. The most common are so-called " Rock-Lithosol" complexes, i.e. mixtures of rock and shallow soils that cannot be separated even at large scales on maps.

3.1.4.3 Taxonomic units versus map units

Soil taxonomic units and map units are two distinct and different entities. Taxonomic units define specific ranges of soil properties in relationship to the total range of properties measured in the soil. Soil map units and their individual map unit delineations define area in a landscape. Taxonomic names are used to identify the soil properties most prevalent within the pieces of landscape identified as a map unit. Almost every map unit has more than one taxonomic unit included (Van Wambeke & Forbes, 1986; Soil Survey Staff, 1993).

3.1.4.4 Criteria for establishing of mapping units

Dent & Young, (1981) stated that a mapping unit can be determined by certain principles and constraints:

I. The mapping unit should be as homogenous as possible. It does not necessarily have uniform characteristics but the variation within a mapping unit is kept within defined limits and the kind of variation should be consistent within all mapping units of the same kind.

II. The grouping should have practical value.

III. It must be possible to map the units consistently.

IV. The mapping must be accomplished in reasonable time.

V. Relatively stable soil properties such as texture and lithology, should be used to define taxonomic units rather than properties whish change rapidly according to management, such as structure or topsoil organic matter.

3.1.5 Post field operation

3.1.5.1 Laboratory analysis

Laboratory analysis of soil samples taken in the profile pits is an indispensable part of a soil survey because it gives physical and chemical characterization of soil units and determines essential characteristics for the purpose of classification, to obtain essential data that will permit the use of the soil map for land management and reclamation and to study problems of soil formation (Olson, 1981; Breimer *et al.*, 1986).

Laboratory analyses can be sub-divided into a basic programme of routine analysis, performed on all samples from all profiles, and special analyses carried out for the purpose of studying specific characteristics and in-depth studies for the evaluation of soil-plant relationships (Breimer *et al.*, 1986).

In general routine analyses include determination of texture, cation exchange capacity, exchangeable bases and include acidity, pH, organic matter, total N, P, $CaCO_3$ and soluble salts. Special analyses include determination of bulk density, water retention, infiltration rate, aggregate stability, clay mineralogy, primary minerals and micromorphology (Breimer *et al.*, 1986).

3.1.5.2 Preparation of the survey report

The survey report is an essential part of the survey. It should contain a synthesis of all basic information, a description of methods and materials used, a synthetic description of the soils, standardized description of all mapping units and possibly a general evaluation of specific aspects of the soils (Breimer *et al.*, 1986).

Dent & Young (1981) stated that the aims of a soil survey report should be to tell the potential user what information is there, to emphasize the practical importance of the information and to help the user find the information he/she needs and enable him/her to understand it. The people who are users of the report have different backgrounds and special interests. Therefore the potential users of the final product must be identified and the report directed to them.

The arrangement of a typical report is as follows (Dent & Young, 1981):

The Summary: This part of the report must be self-explanatory and it must be illustrated whenever required by photographs, diagrams and small-scale maps. It should be written in plain language, without technical jargon. Areas mentioned in the text should be clearly marked on the accompanying map.

The main report: This part explains methods, findings and interpretation of the survey. It shows how to use the report. It indicates how to locate a farm or field on the maps and how to find the soils present from the map legend. It should contain an abstract, table of contents, background and aim of the survey, location of the survey area, brief description of physical environment, present land use, and socio-economic background of the area. In this part methods of survey should be described. Types of survey, level of scale, density of observation, kind of field method used in the survey, information about sampling method and laboratory analyses should also described.

Soils: In the report soil should described in non- technical terms, the soil classification employed and how the soil types have been grouped into mapping units and soils are related to land use. An extended map legend and description of soil mapping units should always form the part of the report and not be given as an appendix since it is essentially an extension of the map itself.

Land evaluation: To make the soil map applicable a land evaluation exercise should be carried out for one or more specific types of land use that are most relevant to the area surveyed (Breimer *et al.*, 1986). This part should include a description of principles, methods, criteria of land evaluation are to employed, land capability classification, land suitability classifications for rainfed cropping, irrigation, or for extensive grazing use (Dent & Young, 1981). The soil survey report must include soil and land management recommendations, suitability rating for of crops, soil fertility management, land preparation, erosion control and finally drainage and irrigation application.

Finally the report must contain technical appendices, explanation of technical terms, detailed description of individual soil units, representative profile description, analytical data and classification and other kinds of information (Dent & Young, 1981).

3.1.5.3 Maps

Laker (1978) stated that there are three main characteristics of the final soil maps which affect the quality and usefulness of the map. These are boundary and location accuracy, printing efficiency and quality and map legibility.

During the field investigation for semi-detailed to reconnaissance surveys soil boundary locations are usually drawn directly on the aerial photographs (Breimer *et al.*, 1986). But when the lines are transferred from the field sheets to the final map errors may be made (Laker 1978). This will affect boundary and location accuracy of the map.

Any printed information such as line symbols or text should have sharp edges with no blurring or running of ink on the paper. Soil boundaries should have uniform width and darkness (Forbes *et al.*, 1986).

Map legibility: Legibility means "how easy to read something" (Laker, 1978). Too many small delineations are considered illegible for two reasons: There is not enough room inside the delineation to legibly write the map symbol in the delineation and it has to be arrowed in from an adjoining bigger delineation, causing confusion. The proportion of the delineation covered by the bounding lines also becomes significant (Forbes *et al.*, 1986).

The minimum legible area is the smallest land area that can be legibly represented on the map at a given scale and is thus the land area represented by the minimum legible delineation (Forbes et *al.*, 1986). The legibility of soil map is determined by delineation size and amount of ground control information.

3.1.5.3.1 Map legend

There are three types of map legends, which may in practice be combined. An identified legend lists the symbols by which the map units are identified on the map, along with the corresponding map unit name (Forbes *et al.*, 1986). A descriptive legend gives information, in either narrative or tabular form, about each map unit such as proportions, landscape patterns and attributes of the soil bodies and non-soil areas making up the map units. An interpretive legend gives information about each map unit in terms of specific land use or management systems (Forbes *et al.*, 1986).

The purpose of a map legend is to provide a concise, clear, explanation of the map and to serve as a link between the map and its accompanying report (Dent & Young, 1981). A soil survey legend must be self explanatory, comprehensive and informative (Laker, 1978)

Laker (1978) stated that the mapping unit must be arranged in the form of a number of groups in the legend. The legend should be arranged in a logical way i.e. mapping units should be given in numerical and/or alphabetic order, and groupings should not be purely pedagogical because such groups will only be valuable to soil specialists and not to most soil map users. On the other hand groupings also should not be made purely according to interpretations of suitability.

3.1.6 Soil survey aids

3.1.6.1 Aerial photography

Aerial photography, a technique of taking various kinds of photographs with a camera mounted in airplane, is the most important one used in soil survey (Breimer *et al.*, 1986). The aerial photographs normally used for soil survey have in most cases been obtained originally from photogrammetric mapping (White, 1977). Photogrammetry, which is used to produce large proportions of the topographic mapping requirements in the world, is based on stereoscopic principles. Stereoscopic analysis of aerial photographs enables observation of aspects such as topographical features, rocky or eroded areas, etc (White, 1977).

Contact aerial photographs are photographs which are printed at scales at which they have been flown. Enlarged aerial photographs are photographic enlargements of these to larger scales (Laker, 1994). Contact aerial photographs are used as base maps where the basic topographic mapping has never been carried out, where the available maps are substantially out of date or where large tracts of land have very few features of the kind that are normally plotted on the conventional maps (White, 1977; Dent & Young, 1981).

Panchromatic aerial photographs give information on the relief, surface texture, and patterns and the relationships of objects and surfaces to each other. Colour and false-colour photographs give the relative spectral values of the different components of the scene (White, 1977).

Dent & Young (1981) stated that aerial photographs are not planimetrically correct, that is, it does not have constant scale across the print. Variation in scale is caused firstly by projection, scales being accurate only close to the center of the photographs; secondly objects closer to the camera appear at larger scale while those far from the camera, such as valleys, appear at smaller scale and thirdly by aircraft tilt.

Laker (1994) stated that orthophotomaps look similar to enlarged aerial photographs. However, orthophotomaps show contour lines unlike enlarged aerial photographs. Orthophotomaps have a very high degree of accuracy in regard to scale and planimetry and they indicate closely spaced contours, which make it much more accurate to identify soil boundaries which are related to topographical changes. However they are expensive.

3.1.6.2 Side looking airborne radar

Side-looking radar is used to produce permanent image records of the ground analogous to aerial photography (White, 1977). Like all radar systems it emits its own radiation and records the signals reflected back from the ground target. It works by directing a narrow beam of pulsed microwave energy from an aerial on the aircraft at a right angle to the line of flight. This illuminates successive strips of the ground to make up a continuous swath of coverage. The radar echoes from each strip or line is received by the same aerial and the variations in the strength of the signals reflected from different segments of the line are used to construct an image of terrain (White, 1977).

The strength of the reflected signals depend on the direction in which slopes face and the roughness of the ground surfaces. The images are palest where slope face the flight path, whilst slopes with opposite aspect produce black areas. Irregular or rough surfaces, including vegetation, contain elements which face the emitter, reflect the signal back and so appear lighter than smooth surfaces like water (Dent & Young, 1981). Its resolution is low and it gives a clumsy form of imagery for soil survey. However, it is a useful substitute for aerial photographs in regions of prevailing bad weather where medium-scale cover of large areas is required, because of its ability to obtain image through clouds (White, 1977).

3.1.6.3 Line scanners

Line scanners provide one approach to the problem of producing images from parts of the spectrum that cannot be recorded directly on photographic films. There are broadly speaking three kinds of scanner (White, 1977): (1) Single or dual channel thermal infrared, (2) microwave scanners, and (3) multispectral scanners operating in the ultra violet to near-infrared atmospheric window, which includes the full visible spectrum.

Multispectral scanning is a technique based upon rapid scanning of the ground by rotating mirrors, the signal from which is reflected onto the a detector, recorded electrically as a continuous signal and stored on a tape (Dent & Young, 1981). There are three ways of interpreting the stored data. The first is automatic data processing, where the recorded data are fed directly into the computer, without conversion into visible image. The second possibility is to interpret the black and white prints visually, just as if they were photographs. The third method is to combine the signals from various bands into a single colour image, which they can be interpreted by eye (Dent & Young, 1981).

White (1977) stated that single or dual channel thermal infrared scanners have fewer applications to conventional soil survey than multispectral scanners.

3.1.6.4 Ground- penetrating radar (GPR)

GPR is a broad band, impulse radar that has been specifically designed to penetrate earthen materials. Relatively high frequency, short duration pulses of energy are transmitted into the ground from a coupled antenna. The receiving unit samples and amplifies the reflected energy and converts it into a similarly shaped waveform in the audio frequency range. The processed reflected signals are displayed on the graphic recorder or are recorded and stored on magnetic tape (Dolittle, 1987).

GPR cannot be used to do soil classification and soil surveying as such because it cannot distinguish between different soils. GPR indicates the depth to abrupt transitions between sharply contrasting layers in the soil profile (Paterson, 1998). It is,

therefore, extremely useful to identify the depth at which a limiting layer such as a dense clay pan, hard rock or water table occurs in the soil. Its advantage over traditional methods like auguring or profile pits in this regard is that it gives a continuous picture of depths to limiting layers over the whole transect (Paterson, 1998). It will, for example, pick up a hidden rock reef below the surfaces, which may block drainage and lead to water logging upslope from it, which might have been missed with conventional methods (Figure 3.1). This is important in detailed surveys for irrigation planning, for example. It is important to note that GPR surveys must be supported by normal field surveys to check the nature of the layers indicated by the GPR images and for soil classification.

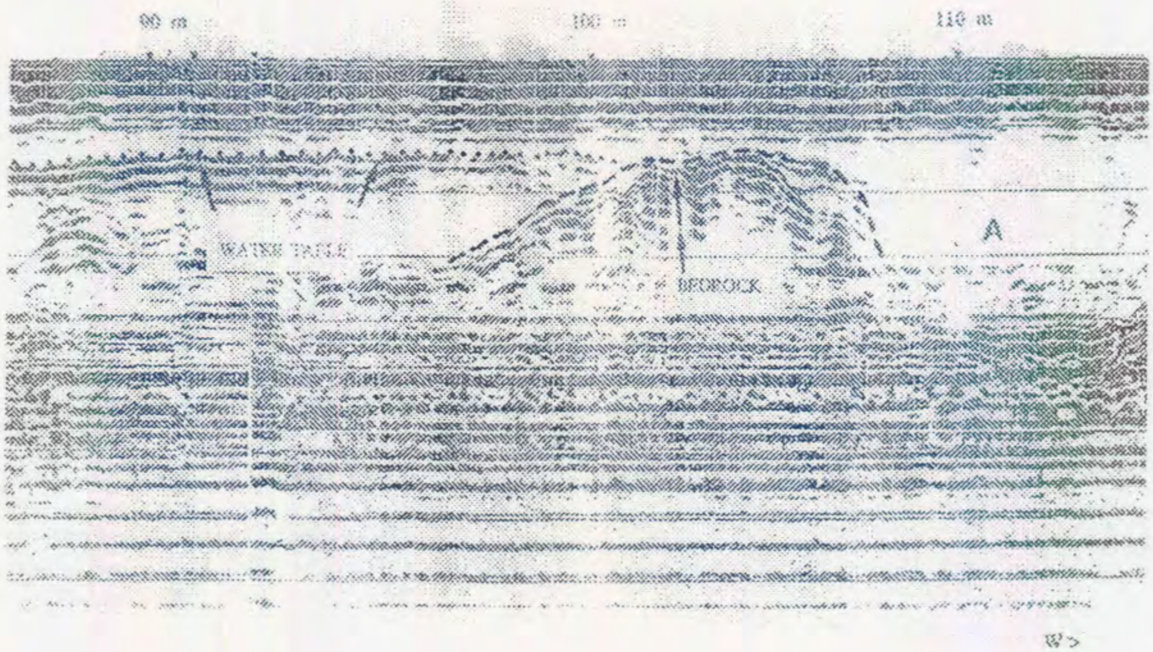

Fig 3.1 GPR bedrock profile and water table (From Paterson, 1998)

3.1.6.5 Global positioning system (GPS)

"GPS are space-based radio positioning systems that provide 24 hour three-dimensional position, velocity and time information to suitably equipped users anywhere on or near the surface of the Earth" (Beadles,1997). The system is composed of three major components: a user segment, a control segment and a space segment (Beadles, 1997).

The user segment is the user and a GPS receiver. A GPS receiver is a specialized radio receiver. It is designed to listen to the radio signals being transmitted from the satellites and calculate a position based on that information. The control segment is composed of all the ground-based facilities that are used to monitor and control the satellites. This segment is usually unseen by the user, but is a vital part of system. The space segment is composed of the GPS satellites that are transmitting time and position to the users (Beadles, 1997).

The most important features of GPS include its positional accuracy and velocity determination in three dimensions, global coverage, all weather capability, availability to an unlimited numbers of users, accurate timing capability and ability to meet the needs of a broad spectrum of users (Leick, 1990). However Leick (1990) also indicated that the USA Department of Defence specified the GPS accuracy at 100m level for non-Defense Department users. It also specified that the precise positioning services yielding high accuracy remains restricted to the USA and allied military and to highly selective, specialized US nonmilitary uses that can be shown to be in the national interest. GPS therefore was not a good tool for improving the accuracy of the siting of profile pits or delineation boundaries on a soil map, especially not on detailed maps. These restrictions have now been lifted. Features like big trees and other shade can reduce GPS accuracy. Therefore it is often still more accurate and affordable to use old tool and methods for detailed survey (Laker, Personal communication).

3.1.6.6 Remote sensing from satellites

Remote sensing from satellite becomes an important tool in resource survey. Although conventional surveying techniques are necessary in resource survey, satellite has become an important technique whereby data over wide areas can be collected and processed within a short time. They can help to speed up and improve fieldwork, but cannot replace conventional surveying techniques.

Compared to mosaics of photographs taken at somewhat different times, the synoptic view from satellite altitudes has the advantage of almost constant illumination over the whole area of investigation (Szekielda, 1986). The coverage of large areas from space has certain limitations but on the other hand it is more economical.

Hill (1991) indicated that a series of satellites have been flown in orbit since 1972 i.e. Landsat-1, Landsat-2, Landsat-3, Landsat-4 and Landsat-5. However the spatial resolution of most Landsat images are inadequate for semi-detailed or detailed survey.

These satellites are more useful for small-scale survey and identification of different land uses, highly eroded areas, etc; but even for these they have limitations.

In 1985 the French SPOT-1 (Systeme Probatoire de 1' observation de la Terre) was successfully launched from ESA's Kourou and an identical SPOT-2 satellite followed in 1990 (Hill, 1991). The satellites carry two identical pushbroom scanners called high-resolution visible instruments. These can be used to record either panchromatic or multi-spectral data (Hill, 1991). The SPOT satellites produce images of the earth's surfaces at 10m sampling intervals in the panchromatic mode, and at 20m sampling intervals in the multi spectral mode (Hill, 1991). In land resource inventory SPOT images have major advantages due to its high spatial resolution. Given the richness of textural and structural information contained in the simulated data, SPOT imagery would appear to be fairly comparable to small-scale aerial photography (Brachet, 1986). However SPOT images are very expensive.

Radar remote sensing is one of the techniques with potential for collecting natural resource data. Radars have a number unique measurement characteristics, their ability to acquire temporal data on a regular basis, their independence from solar illumination and their side looking geometry (Churchill & Sieber, 1991). These characteristics provide a number of potential advantages to resource survey. These are: the ability of radar sensors generating their own energy and by operating at relatively long wavelengths, can acquire data almost in any weather conditions. Radar is able to collect data at night. Such night time data acquisitions may be advantages in the assessment of moisture stress at day and night time. Data can be compared and the true moisture status of the vegetation can be determined (Churchill & Sieber, 1991). However this technique cannot employed in semi-detailed and detailed survey.

ERA (2000) indicated that Ikonos is the only commercial satellite to offer 1 meter resolution imagery. This satellite was launched in September 1999. The satellite circles the earth at an altitude of 681 kilometers, travelling at 7 kilometers per second and can record as much detail as small-to-medium aerial photography. Because the sensor can view sideways and has a long track, it is possible to obtain 1 meter resolution imagery for the same location every three days on average (ERA, 2000). However the cost of Ikonos images are too expensive to be afforded by developing countries. Satellites have major advantages over conventional surveying techniques. However they required expensive equipment and highly trained manpower.

3.2 Assessment of rangeland condition

3.2.1 What is range condition survey?

Range condition refers to the state of health of the range in terms of its ecological stability and its potential for producing forage for livestock production. Range condition survey will indicate the suitability of an area of land for livestock production, but it does not play a role in determining its land use capability (Trollope, 1986).

Range condition data can be used both for regional and farm planning. At the regional level the data are most useful in indicating the potential of an area for livestock production in terms of number and types of livestock. At farming level it is essential for the formulation of range management practices like stocking rate and stocking ratio (Trollope, 1986).

For range condition to be rated "good" it must comply with two criteria: Firstly it must be highly productive and palatable in order to achieve maximum financial benefit in the short term. Secondly, it must be stable and protected from unacceptable rates of soil erosion or vegetative degradation so as to sustain the resource for the future generations (Teaque & Danckwerts, 1989).

3.2.2 The need of rangeland surveys for Africa

In the overstocked grazing land of the more arid parts of Africa, the role of the rangeland surveyor is to make ecologically sound recommendations (Hemming, 1975). Rangeland survey is an important tool in the rangeland and pastoral development. Although investment has been in general very limited in the range sector, some countries have made a great effort to finance rangeland studies and surveys, which have not always resulted in tangible benefits (Hemming, 1975). On the other hand many countries, which have a substantial part of their total land surface composed of rangeland have only fragmentary surveys, or do not have any at all, apart from botanical collections (Risopoulos, 1975).

In the higher rainfall rangelands of Africa, with a mean annual rainfall above 400-500mm, the problem is often how to manage the grazing in such way that it can support the maximum amount of stock compatible with the maintenance of the basic natural resources, that is the vegetation. It is essential that the productivity of the rangelands be preserved in order to support future generations of man and his stock. In this area the aim of rangeland survey may be to classify the land into different ecological zones, each requiring different systems of grazing and browsing management (Hemming, 1975). In drier areas of Africa the situation is often quite different, the basic problem being how best to manage the land which is at present carrying more stock than it is able to support, without causing undesirable changes in the vegetation (Risopoulos, 1975). In general, as Stuart-Hill (1989) indicates, there are three main reasons why we conduct rangeland surveys. These are: for inventory purposes, to serve as reference points for prediction and to monitor vegetation change.

3.2.3 Techniques of assessing range conditions

The condition of range is assessed recognising that the forage base of range can comprise both grass and bush (Trollope, 1987). Quantitative features of vegetation that can be measured or observed mostly are: number of individuals, cover or area occupied, height, and frequency. Measurement of these characteristics makes it possible to assess vegetation composition (NRC, 1962). Separate techniques are used to assess the condition of these components of the vegetation (Trollope, 1986).

3.2.3.1 Grass Sward

The techniques used for assessing the condition of the grass sward are based on that development by Foran, Tainton & Booysen, (1978). The assessment of the condition of the herbaceous layer is based on the botanical composition and basal cover of the grass sward. It involves comparing the condition of the range in a sample site with that of a relevant benchmark site (Trollope, 1986). It is important to give much emphasis to the botanical composition of the grass sward. Danckwerts (1989) found that the carrying capacity is highly positively correlated with botanical composition. Measuring botanical composition is both rapid and accurate (Trollope, 1986). However the measurement of basal cover is very laborious and the subjective estimation of this parameter is adequate for indicating the resistance of range to soil erosion.

Rangeland condition assessment using grass sward techniques follow certain procedures, of which the first is the identification of benchmark sites. A benchmark site is an area of range that is in optimum condition for sustained livestock production (Trollope, 1986). A benchmark will not necessarily be the climax vegetation for an area and is in fact usually some form of sub-climax (Danckwerts, 1989).

As Trollope (1986) indicated, a point quadrate survey is conducted to determine the botanical composition and basal cover of the grass sward in a benchmark site, using the following procedure:

1. An area 50m x 100m is demarcated.
2. The relative frequencies of the different herbaceous plants and the basal cover are recorded using 1000 randomly placed points. This involves recording the nearest rooted plant to each point and the number of strikes of living rooted material.

The botanical composition of the sample site is expressed as the percentage frequency of the plants recorded during the survey. The basal cover is expressed as a percentage of the number of strikes in relation to the total number of points recorded (Trollope, 1986).

3.2.3.2 Assessment of sample sites

In selecting a sample site, the site must be representative of the range being analysed, and should not cover atypical areas such as watercourses, drinking points, etc. (Danckwerts, 1989). A point quadrate survey of 100 random points is conducted to determine the botanical composition of the grass sward. Two rows of 50 points are located down the center of each half of the sample site and the nearest point to each is recorded. The results are expressed as percentage relative frequency of each species occurring in the sample site (Trollope, 1987).

According to Danckwerts (1989) the basal cover of the grass sward is subjectively ranked according to the following five classes:

- class 1 - very poor cover - extremely erodible
- class 2 - poor cover - highly erodible
- class 3 - fair cover - moderately erodible
- class 4 - good cover - slightly erodible
- class 5 - excellent cover - non- erodible

3.2.3.3 Bush

The assessment of the condition of the bush component of the vegetation is not as well developed as that for the grass sward (Trollope, 1987). Teaque & Danckwerts (1989) indicate that sampling of the woody component is carried out as follows: A chain 100m long is laid out straight in the area of range representative of the area. The center of a 2m long rod is then moved up the chain at 90 degree. Each woody plant falling within this 2m width along the length of the chain has the following recorded:

- plant species
- plant height
- height of canopy bottom from the ground level
- horizontal canopy radius

- whether palatable or not

The data which are recorded, must be analyzed. Trollope (1987) indicates that the procedure for analysing bush survey data are as follows:

I. Botanical composition: It shows species composition and density per hectare.

II. Physiographic structure: It determines the number of acceptable and unacceptable bushes in 0.5m height classes.

III. Current browsing units: These represent the number of acceptable and available bushes that are less than 1.5m high or have browse within the 0 -1.5m stratum. The browsing units are calculated by multiplying the number of bushes in each height class by the median of each height class up to a height of 1.5m. Thereafter the number of bushes are multiplied by a factor = 1.5m for the remainder of the height class. The sum of the products is divided by 1.5m to convert it to browsing units and expressed per hectare using the area of the survey transact.

IV. Potential browsing units are equivalent to the sum of the available and unavailable acceptable bushes where it is assumed that the unavailable bush is reduced to a height of 1.5m.

3.3 Agro-climatic survey

Agro-climatic survey is a kind of land resource survey which is used to collect a variety of climatic information that is particularly relevant to agriculture. Although climatic information may be available, it may not always be readily accessible in a form that is suited to the needs of agriculture (Chetner, 1996).

A major problem in developing countries is that they have very few weather stations, which are very sparsely distributed. Extremely few of these are comprehensive weather stations that measure more than just rainfall or rainfall and temperature. Consequently the climates of large areas have to be interpolated and interpreted (or "guesstimated") from the data of these sparsely distributed weather stations (Laker, Personal communication). To aggravate matters, data are often available for short terms only - often less than 10 years. All these make the evaluation of the climate for specific land uses very uncertain and inaccurate. This is specially the case in mountainous and hilly areas where huge climatic differences can occur over very short distances. Sensible climatic modelling can help to improve interpretations in these situations. Most importantly use can be made of indirect methods to improve climatic interpretations such as studying the natural vegetation and leaching status of the soil, as well as learning from the observations and practical experience of local farmers (Laker, Personal communication).

The main objective of making a climatic survey is to describe and classify the climate in such a way that the agriculturist can put this information to use (Janick, 1981). The importance of climatic characteristics in influencing land use potential requires no emphasis. Climatic data are obtained from meteorological stations. Spatial interpolation is then necessary in order to produce maps of individual variables. When the need is to characterise areas in terms of a number of climatic attributes, then use has to be made of a climatic classification (Davidson, 1992).

There are numerous possible classifications of climate. Classification is a product of human ingenuity rather than natural phenomena. The value of a systematic arrangement of climates is determined largely by the purpose for which it is intended; a system that suit one purpose is not necessarily useful for another (Critchfield, 1983). The climatic data of the greatest agricultural value are those which are based upon interactions of temperature and rainfall (Janick, 1981).

3.3.1 The Köppen classification of climates

The most widely known system was devised by Köppen on the basis of climate and natural vegetation. His first climatic classification, as published in 1900, was largely based on vegetation zones, but a revised one in 1918 incorporated temperature, rainfall, as well as seasonal characteristics (Vink, 1975; Janick, 1981; Critchfield, 1983; Henderson-Sellers & Robinson, 1986).

Janick (1981) indicated that the Köppen system included five major categories, which are designated by capital letters as follows:

A. Tropical forest climates; hot all seasons
B. Dry climates
C. Warm temperature rainy climates, mild winters
D. Cold forest climates; sever winters
E. Polar climates.

In order to represent the main climatic types additional symbols are added. Except in the dry climates the second letter refers to rainfall regime, the third to temperature characteristics, and the fourth to special features to the climate (Critchfield, 1983). For example:

Af Tropical rain forest, hot; rainy in all seasons
Bsh Tropical steppe, semiarid hot
Cfa Humid subtropical, mild winter; moist all seasons. Long and hot summer.

The Köppen system has a limitation in its applications, however, the system has gained widespread recognition and use. Its simplicity and general adherence to vegetation zones has formed a basis for many revisions and other classifications (Janick, 1981).

3.3.2 The Thornthwaite classification of climate

The climatologist C.W Thornthwaite criticised the Köppen system for not being based on the temperature and precipitation measured in relation to plant requirements (Davidson, 1992). Thornthwaite differs from Köppen's largely qualitative classification in that two new concepts, Temperature Efficiency and Precipitation Efficiency are employed (Janick, 1981).

The effectiveness of precipitation is regarded as a function of precipitation and evaporation and is calculated by dividing the monthly precipitation by the monthly evaporation to find the P/E ratio. The sum of twelve monthly P/E ratio becomes the P-E index (Critchfield, 1983). There are five humidity provinces designated by capital letters, each associated with a particular vegetation type (Janick, 1981):

Letter	Humidity Province	Vegetation	P-E index
A	Wet	Rainforest	>127
B	Humid	Forest	64 - 127
C	Subhumid	Grassland	32 - 63
D	Semiarid	Steppe	16 - 31
E	Arid	Desert	< 16

The humidity provinces are subdivided into subtypes designated by lower-case letters on the basis of seasonal distribution (Janick, 1981):

Letter	Distribution of precipitation
R	Abundant in all season
S	Sparse in summer
W	Sparse in winter
D	Sparse in all seasons

The temperature efficiency (T-E) index is obtained by summing the monthly mean temperature above 0 degree Celsius (Davidson, 1992). There are six temperature provinces, each designated by a capital letter marked with prime (Janick, 1981)

Letter	Temperature provinces	T-E index
A’	Tropical	>128
B’	Mesothermal	64 – 128
C'	Microthermal	32 – 64
D’	Taiga	16 – 32
E’	Tundra	0 – 16
F’	Perpetual frost	< 0

Thornthwaite also introduced the concept of potential evapotranspiration (PE), which is the amount of water that would be evaporated from soil and transpired by plants. This potential evapotranspiration index can be calculated from either measuring the evaporation from an area of short stemmed green crop of uniform height with moisture being maintained by irrigation, or from using formulae as provided by Thornthwaite. PE is calculated on a monthly basis using temperature data with adjustments being made for the number of daylight hours. This done as follows (Davidson, 1992):

$$PEm = 16Nm\ (10tm/I)^{a}$$

where PE = Potential evapotranspiration

m = months 1,2,3.......12

Nm = monthly adjustment factor related to hours of daylight.

I = annual heat index

tm = monthly mean temperature

$a = 0.49 + 1.791 * 10^{-2} I - 7.71 * 10^{-5} I^{2} {}^{*}6.75*10\text{-}^{7}I^{3}$

This approach to calculate potential evapotranspiration is entirely empirical. It is not based on knowledge of the component processes associated with evapotranspiration (Davidson, 1992). The Thornthwaite approach enables the calculation of so-called “ water budget “, indicating when water surpluses or deficits can be expected and what the intensities of the deficits will be. Graphic presentations of these clearly indicate problem of favourable periods. Marais (1978) compiled Thornthwaite water budgets for a number of places in the former Ciskei (now central Eastern Cape province) in South Africa.

Figure 3.2 gives water budgets for two of these places. For Blaney the huge water deficit for the biggest part of summer (November, December, and January) indicates a big problem, because this is the rain season and maize is the main crop in the area. In contrast the situation for Amabele is much more favourable. The advantage of having this type of information for land use planning is clear.

Among the world classifications of climate many have been general and qualitative. They have tended to emphasise one or two climatic elements, especially temperature and precipitation (Janick, 1981). More recent efforts have been far more specific in that the aim has been to characterise climatic attributes of direct relevance to crops (Davidson,1992). The Köppen and Thornthwaite classifications are important on a broad national or regional scale. But it is not adequate for land evaluation and land use planning. Therefore it is important to include the following aspects:

I. The statistical probabilities of rainfall/moisture situation.
II. Seasonal rainfall distribution, water budgets and a midsummer droughts (In determining midsummer drought decad 10 day interval average recording of rainfall are important than monthly average).
III. Micro-climates
IV. Relative humidity and
V. Frost, hail, etc.

For more information on climatic requirements of crops refer to Weldegiorgis (2000).

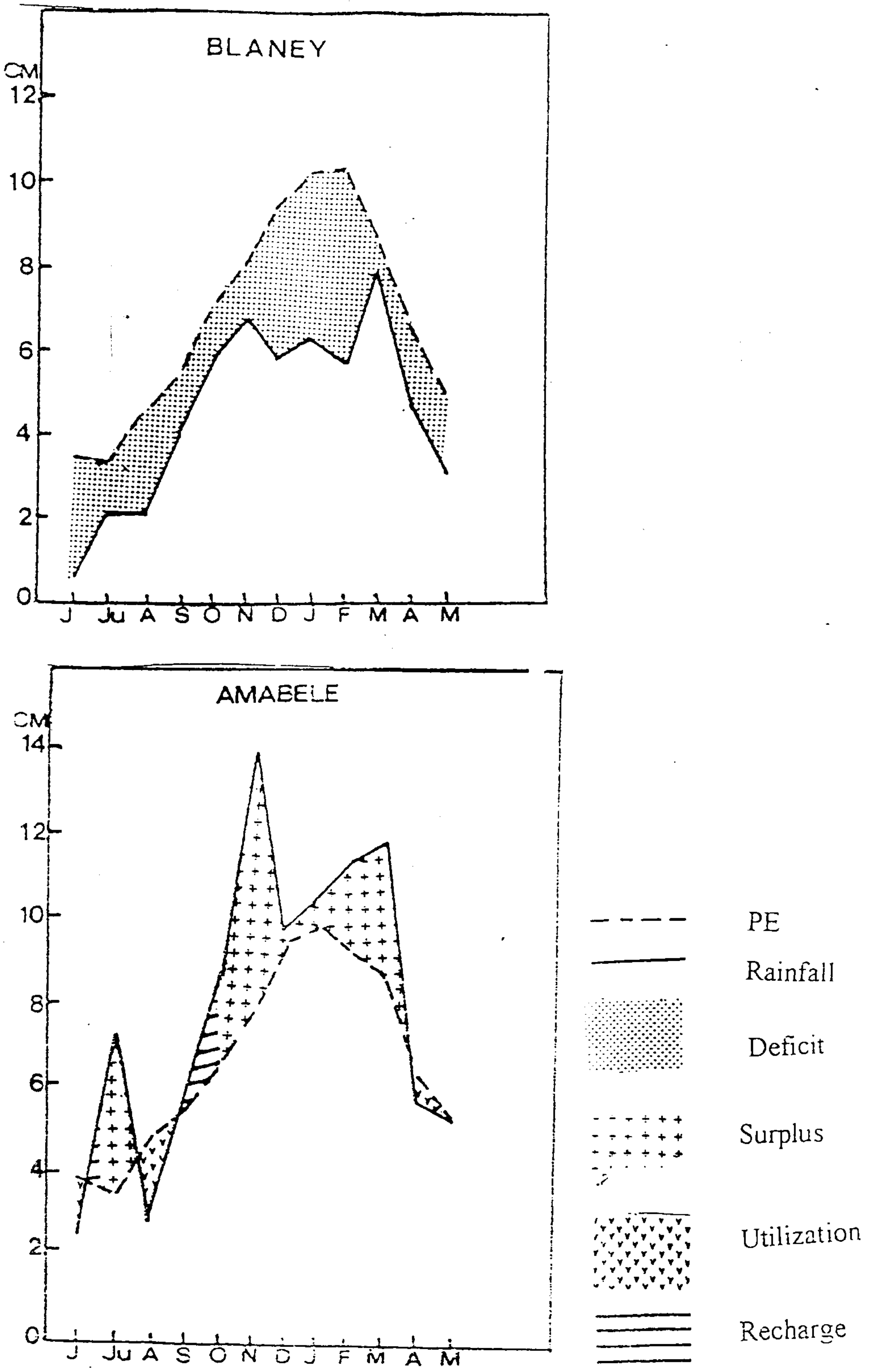

Fig 3.2 Thornthwaite water budgets for Blaney and Amabele (Marais, 1978).

3.4 Conclusion

In a land development programme the first and foremost reason for carrying out a soil survey is to avoid serious mistakes which it will be highly expensive, or impossible to rectify. The basic stages in soil survey are description and identification of soil types, classification and mapping. Methods of soil description and classification differs from country to country. Even though there are guidelines for description and classification prepared by FAO, most developed countries have their own systems of classification.

There are two kinds of soil survey, general purpose and special-purpose soil surveys. General-purpose surveys are very important for developing countries, where little or nothing is known about the physical environment and about the potential land use. Special-purpose soil surveys are carried out where the purpose is known and specific (Dent & Young, 1981). The objectives of soil surveys are not only to identify good and bad soil but also for monitoring soil changes such as soil degradation.

Surveys of the condition of the rangelands, showing how they are responding to grazing and browsing pressure, are of practical significance. Even though there is a problem of overstocking of grazing land of most arid parts of Africa, systematic surveys of rangelands are not regularly carried out. The pasture specialists do not appear to regard range survey as a useful management tool. The absence of an appropriate national organisation with this responsibility is limiting factor in many countries

Basic climatological data come from national meteorological services and by comparison with other environmental factors are good. Climatic classifications have been available since 1930s (Young, 1998). The Köppen and Thornwaite climatic classification systems are the most useful methods for agro-climatic description purposes.

CHAPTER FOUR

GEOGRAPHIC INFORMATION SYSTEMS IN LAND RESOURCE SURVEYING

4.1.Geographic Information System

GIS is the acronym derived from Geographic Information Systems (Hanna & Culpepper, 1995). The first GIS were developed in the middle 1960s by governmental agencies as a response to a new awareness and urgency in dealing with complex environmental and natural resource issues (Peuquent & Marble, 1990). According to Martin (1996) GIS showed a rapid development in early 1980s and it has become a commonly used term in our daily life.

GIS has different definitions Croukamp (1996) defines GIS as follows: "A GIS system produces a dynamic map which can be analyzed and restructured by entering search and display criteria. In other word, GIS software contains the raw data from which the drawing is derived. This derivation, the map, is a subset of the original database filtered through a query or model, **which you have defined**. The database is the map and a vice versa. The key is that the map is a by-product of an analysis of the original data." The last statement shows us GIS is not only map-making tool but a system to analyse and interpret data to resolve problems (Croukamp, 1996).

GIS currently available fall into two basic categories based on the manner in which the data are stored, i.e. vector based and raster based. In the latter the data are arranged in the form of a grid or a matrix where each storage location in the grid corresponds to a regular area on the ground. In the former, data are organized on the basis of geographic entities (Peuquant & Marble, 1990). Vector data structures provide efficient storage of data and also provide the most acceptable results in terms of digital cartography. Operations such as map overlay or processing of spatially referenced data are easier using raster data

(Davidson, 1992). Many modern GIS have the capability to operate in both vector and raster models, thus the advantage of both approaches can be obtained (Davidson, 1992).

4.1.1 Components of GIS

Martin (1996) indicted four major components in GIS (Figure 4.1) these are as follows:

1. Collection, input and correction are the operations concerned with receiving data into the system, including manual digitizing, scanning, key board entry of attribute information, and online retrieval from other database systems. It is at this stage that a digital map is first constructed (Martin, 1996). The digital representation can never be of higher accuracy than the input data, although the mechanism for its handling will frequently be capable of greater precision than the achieved during data collection (Clarke, 1999). **I.e. GIS cannot improve the quality of inherently poor quality or incorrect data.**

2. Storage and retrieval mechanisms include the control of physical storage of the data in memory, disk or tape. This data storage may be physically remote form the rest of the system and may meet the database requirements of other, non-geographic, data processing systems.

3. Manipulation and analysis represents the whole spectrum of techniques available for the transformation of the digital model by mathematical means (Martin, 1996). Data manipulation is a key area of GIS functionality since it allows data disparate sources to be converted to a common format for analysis (Maguire, Goodchild & Rhind, 1991).

4. Output and reporting involves the export of data from the system in computer or human readable form. It is at this stage that the user of a digital map database is able to selectively create a new analog map product (Aronoff, 1989; Martin, 1996).

were realised by the use of scanning techniques for digitizing, the automated classification of satellite data to produce land use maps and the use of satellites to precisely identify ground control points instead of using traditional surveying techniques. Automated methods are able to collect information more quickly and at lower cost than by using manual techniques. Therefore GIS can be applied to produce outputs that were previously too costly or not feasible for collection of natural resource data (Aronoff, 1989).

The applicability of GIS to land resource inventories can be by a range of processing capabilities: map input, editing, polygon processing, output, digital terrain model, thiessen polygons and interpolation (Davidson, 1992).

4.2.1 Map input, editing polygon processing and output

Information on maps exists in the form of point, line, area and text data. These data can be input to GIS by digitizing features on a digitizing table and captured through automated scanning of the original maps or through the purchase of data in digital form as provided by the Ordnance survey. At present most data capture is by digitizing, a time consuming and tedious task. A critical test for any digitizing module in GIS is the ease with which errors can be identified and corrected (Davidson, 1992).

With soil mapping data in the form of polygons, tremendous flexibility exist in terms of selecting polygons according to one or more attribute to generate as many maps as required. Data on such polygons can be stored in the form of attribute codes associated with the perimeter, lines, as seed point or in an integrated database system. It is the flexibility of map presentation, which is the outstanding character of GIS. Such flexibility is particularly important in land resource mapping and land evaluation (Davidson, 1992).

4.2.2 Digital terrain model

Digital terrain data are sets of elevation measurements for locations distributed over the land surface. They are used to analyse the topography of the area (Aronoff, 1989, Davidson, 1992). The methods used to capture and store elevation data can be grouped into four basic approaches: a regular grid, contours, profiles and a triangular irregular network (TIN). TIN is used in vector based systems. In a TIN, GIS generates a network of triangular facets, from a set of elevation sample points that can be irregularly distributed. These facets can then be manipulated as polygons and elevation, slope aspect and other parameters can be assigned to the facets as polygon attributes (Aronoff, 1989). DTMs data are generated from existing contour maps, by photogrammetric analysis of stereo aerial photographs, or by automated analysis of stereo aerial photographs, or by automated analysis of stereo satellite data (Davidson, 1992).

4.2.3 Thiessen polygon

Thiessen polygons define individual areas of influence around each point. Data from rain gauges are commonly analysed in this way. It is an approach to extending point information which assumes that the best information for locations with no observation is the value at the closet point with a known value (Aronoff, 1989).

Thiessen polygons are constructed around a set of points in such a way that the polygon boundaries are equidistant from the neighbouring points. It used to predict the values of surrounding points from a single point of observation. The method has a number of limitations. The division of a region into Thiessen polygons is completely dependent on the location of the observation points. This can produce polygons with shapes that are quite unrelated to the phenomenon being mapped (Aronoff, 1989).

4.2.4 Interpolation

With the possible exception of remote sensing, it is not usually possible to measure a geographic phenomenon at all points in space (Martin, 1996). Interpolation is the procedure of predicting unknown values using the known value at neighbouring locations. The neighbouring points may be regularly or irregularly spaced. A simple linear function, derived by analysing the known points, has been used to generate the missing values. Interpolation programmes employ a range of methods to predict unknown values (Aronoff, 1989).

The quality of the interpolation results depend on the accuracy, number and distribution of the known points used in the calculation and on how well the mathematical function correctly models the phenomenon. Interpolation assumes that the phenomenon being predicted is closely approximated by the mathematical function used. The unknown values are calculated according to this function. The choice of an appropriate model is therefore essential in order to obtain reasonable results (Aronoff, 1989).

4.3 GIS in developing countries

In developing nations, special attention must be given to the relevance of the products of any GIS to the understanding, analysis and solution of socio-economic development. If the immediate relevance of GIS is not apparent, it is unlikely that the technology will be adopted. If GIS is useful and effective, then it must be introduced by indigenous scientists who understand both the technological and socio-economic context in which the systems are to operate (Taylor, 1991).

4.4 Conclusion

A Geographic Information System is a computer-assisted system for the acquisition, storage, analysis and display of geographic data. Today a variety of software tools are available to assist this activity. There are two kinds of GIS vector and raster based GIS.

Both have their own advantage and disadvantage but modern GIS have the capability to operate in both vector and raster models.

One of the major functions of GIS is its use to capture data and this function is essential in basic land resources surveys. Since primary data collections in traditional survey techniques are very expensive and time consuming, GIS can be applied for this purpose relatively cheap and within short period of time. GIS can be applied in areas which have yet to be mapped, and for updating existing digital databases. GIS can be also employed for land suitability classification, for monitoring vegetation condition, weather data gathering and for land degradation assessment.

It must be emphasized the GIS is an excellent tool for handling resource data, but it cannot improve inherently poor quality data. Eg. it cannot correct field errors, it may NEVER be used to scale up small scale resource maps, etc. It also cannot MAKE interpretations. The scientist must still derive interpretation criteria. The GIS system can only apply these criteria to the available data.

CHAPTER FIVE

PROPOSED METHODS AND TECHNIQUES FOR RESOURCE SURVEYING FOR ERITREA

5.1 Soil survey

5.1.1 Objectives of soil surveys

Prior to any soil survey the objective of the survey must be specified very clearly, because it determines the scale of the survey and the survey techniques, as well as the amount of funds, manpower and time required to conduct it. It also determines the types of base maps, equipment, etc. required.

In Eritrea no systematic soil survey has been carried out. Without such surveys no meaningful regional planning or sustainable development planning can be done. The FAO published a soil map of Eritrea at a scale of 1:5 000 000, but this is far too small to be useful for regional planning in a small country like Eritrea.

In a country where no systematic soil survey has been carried out, the first objective of soil surveying should be for preliminary identification of areas having either high development potential or serious development problems. In addition to this the objectives could be for compiling soil resource inventories, for soil monitoring, assessment of land degradation and/or for proper land use. Since soil surveying in Eritrea is new and not well developed the survey strategy to achieve the objective of a survey must be based on the availability of funds, manpower and equipment, required for the soil survey. Smyth (1981) indicated that developing countries should undertake soil surveys in a systematic sequence of surveys of increasing intensity. The logic of this approach is a means of ensuring that limited specialized manpower, funds and facilities should be concentrated in the most promising areas. After compilation of the broad-scale soil surveys, detailed soil surveying in high potential areas should be given priority. For example the new collective farming system in selected areas of Eritrea, will require that detailed soil surveys must be conducted to identify areas that are suitable for the introduction of new farming systems which are more productive and appropriate in those areas and to identify management requirements.

5.1.2 Soil classification system

In order to achieve consistency during soil surveys and avoid confusion it is absolutely essential that a well-developed taxonomic soil classification system must be used during soil surveys. This is even more important for achieving efficient technology transfer between different regions or within regions in the country.

The development of a classification system is a very long process, which may take decades to complete. It also requires leadership from highly experienced pedologists, types of scientists which are presently not available in Eritrea. For various reasons Eritrea has not developed a national soil classification system. In view of the urgency for conducting soil surveys to achieve sustainable land use planning and development in Eritrea, there is simply not enough time to wait until a special unique soil classification system has been developed for the country.

It is recommended that Eritrea should adopt one of the "standard" international soil classification systems, which will best suit the needs of the country. The two main internationally used soil classification systems are the USA's Soil Taxonomy (Soil Survey Staff, 1975, 1999; Young, 1998) and the FAO-UNESCO system which was initially developed to serve as basis for the soil map of the world (FAO, 1974,1990; Driessen & Dudal, 1991). The latter has been intensively revised by the World Reference Base for Soil Resources (WRB), Working Group of the International Union of Soil Sciences (IUSS) (ISSS Working Group RB, 1998b). **It is recommended that the WRB (revised FAO) soil classification be adopted as basis for soil classification in Eritrea.** The most important reasons for this recommendation are:

I. The WRB system is less complicated than the USDA's Soil Taxonomy (Young, 1998)

II. At the 1998 World Congress of the IUSS in Montpellier, France, a resolution was adopted that all countries be requested to adopt the WRB system as reference soil classification system, in order to promote effective communication on soils between countries.

III. Most countries in East Africa are using the FAO system as basis for soil classification. These include at least some of Eritrea's neighbours, eg. Ethiopia. Some have already changed to the revised FAO, i.e. WRB, system. By using this system Eritrea will be able to benefit from effective communication on soils with these countries, especially regarding aspects such as land suitability evaluation and technology transfer.

IV. The USDA's Soil Taxonomy has major weaknesses in regard to the classification of some important soils of Southern and East Africa. The FAO system also had some weakness in this regard, but most of these have been eliminated in the WRB system. An example is the excellent definitions of Nitisols and their key horizon, the Nitic horizon, in the WRB system. The Nitisols are throughout East Africa recognized as very important soils for agricultural potential because of (i) their high potential and (ii) their exceptional stability against erosion. Nitisols are also important in Eritrea.

V. Apart from the formal classification system (ISSS Working Group RB, 1998b), there is also a more general outline of the system, "World Reference Base for Soil Resources: Introduction"(ISSS Working Group RB, 1998a). The latter adds several advantages, including that (i) it gives a description of where a certain soil can be expected on different geologies in different landscapes and the linkages between different soils and (ii) it gives broad outlines of the uses of different soils and the main advantages and/or limitations of the different soils. In addition Driessen & Dudal (1991) also give indications of the potential uses of different soil groups in the FAO system. These are valuable for junior soil scientists and land use planners and other non-pedologists that will use soil maps and soil survey reports.

It must be kept in mind that the WRB soil classification system is a global system, essentially for classification in the higher categories. It will, therefore, in Eritrea also be necessary over time to develop classification for the country in the lower categories, eg. at series level, for detailed surveys. But this should be done according to the principles and within framework of the WRB. Right from the start Eritrean soil surveyors must be alert for soil features which are important for land use in Eritrea, which are not well catered for in the WRB system. These must not be forced into the WRB system, but special provision must be made for them and defined during a soil survey.

Detailed soil surveys will also require the use of soil phases in the definition of mapping units. Good guidelines for phase criteria are given by Van Wambeke & Forbes (1987).

With a view to conducting soil surveys that will ensure sustainable land use planning and efficient technology transfer, it is essential that soils must be classified correctly. It is therefore strongly recommended that an expert on the WRB system be contracted to do initial training of Eritrean soil surveyors in the system by means of a short course in **Eritrea**. Such expert can be a senior member of the WRB Working Group and/or someone from another East African country with experience in the use of the WRB system.

5.1.3 Soil survey scale and level of intensity

The scale of a soil map should be decided by the purpose for which it is intended. One cannot determine the scale of soil survey without consideration of the objective of the survey and the country's economical and technical situation. By taking these factors into account, for a small country like Eritrea two levels of scale should be given priority: For broad scale a 1: 250, 000 survey should be best and detailed survey should be at a large scale (1: 5000 or 1: 6000).

Soil survey at a scale of 1: 250,000 is conducted for the purpose of soil resource inventories, identification of high potential areas and determining the country's agricultural potential. A good example is the South African land type surveys, which were conducted at a scale of 1: 250,000 to determine the agricultural potential of the country. The identification of promising areas can provide the necessary information for further detailed soil surveys. After identifying promising or high potential areas, it is essential to conduct surveys at a large scale of 1:5000 or 1:6000 for these areas. This can only be applied for selected areas, such as high potential areas, irrigation projects and to agricultural experimental stations. It requires very high cost per unit area, but for the above selected areas conducting detailed survey at this scale is essential. For example the new collective farming system has been carried out without detailed surveys, but the introduction of new farming systems may cause serious soil degradation in the long run. Therefore it is recommended to conduct soil surveys at a scale of 1:5000 or 1:6000 in these selected areas very urgently.

5.1.4 Methods and aids of soil survey

5.1.4.1 Aerial photographs

Aerial photographs are one of the best aids of soil survey in regard to:

(i) They can be used for stereoscopic analysis in terms of slope, identification of rocky areas, waterlogged areas, etc. Identification of these areas prior to field survey substantially reduces the cost and time required for the survey.

(ii) Using them as base maps, for planning routes and for recording the location of field observations and soil boundaries.

Laker (1994) indicated that enlarged aerial photographs are useful base maps for detailed soil surveys. Therefore it is recommended that contact aerial photographs are used to aid in the conducting of semi-detailed and small-scale surveys and that enlarged aerial photographs are used as base maps for detailed survey. The cost of aerial photographs for the whole country could be high, but by giving priority to selected areas it should be feasible to produce aerial photographs for these selected areas.

Aerial photographs should not be used to actually identify soil types, but rather to locate changes in the land surface patterns that may be related to different soil properties. They do not tell the interpreter directly what the soils are in detail and therefore fieldwork is always necessary. Laker (Personal communication) indicated that excessive reliance on aerial photographs (instead of using aerial photographs just as aid) has led to **BIG** mistakes even when done by experienced people. Furthermore, only experienced people can really use aerial photographic interpretation. It is unlikely that such kind of person is presently available in Eritrea. Therefore it must kept in mind that aerial photographs are a supplement to but not a substitute for field soil survey.

5.1.4.2 Ground Penetrating Radar (GPR)

GPR has great advantages over conventional methods of surveys, as mentioned in the previous chapter. GPR is an important tool for depth investigation, providing information along transects and being able to investigate a wide range of features. It is important however, to note that GPR surveys must be supported by normal field surveys to check the nature of the layers indicated by the GPR images and for soil classification. Even though GPR has certain advantages in soil survey, it requires special equipment and specially trained staff, however. It is highly unlikely to have such equipment and trained staff in Eritrea. For example, Laker (Personal communication) indicated that in South Africa there is only one soil scientist who is specialized in GPR operation. Therefore the application of GPR in Eritrea soil survey programme in the current condition is not recommended.

5.1.4.3 Global Positioning System (GPS)

The accuracy of GPS ranges from as good as a few millimeters to somewhere around 100meters depending on equipment and procedures applied to the process of data collection (Kennedy, 1996). However for civilian use the accuracy of GPS is between

30meters and 100meters. According to Laker (personal communication) the generally available GPS is about 30 meters out, which is totally unacceptable for a detailed soil survey Using GPS for locating one's position is easy and fairly accurate only in open field. In wooded areas and even areas with sparsely distributed trees its accuracy is reduced dramatically, however. It also requires expensive high-resolution GPS for locating your position with high accuracy. It is therefore not recommended for detailed soil survey in Eritrea.

In 1999 the author and another Eritrean colleague (B.W. Weldegiorgis) were a part of a team of honours students from the University of Pretoria who conducted a detailed soil survey in a very difficult area in Swaziland. The area had a very dense bush cover and the soil pattern was very complex. Traditional soil survey techniques were used, with orthophotos as base map. Engineers who then did the lay-out of irrigation plots in the area used highly sophisticated GPS with an accuracy of 0.5 metre. It was found that the GPS confirmed that the soil maps made without GPS, but with good field techniques were absolutely spot-on! (The area surveyed was the "host" area for a group of farmers who had to be relocated because their present area would be inundated by a new dam.)

5.1.4.4 Satellite imagery

There are different kinds of satellite imagery, with different spatial resolutions but most of them have low spatial resolution. Satellite imagery is useful for small-scale survey and for land cover studies such as indicating eroded areas, geology and land use. Eritrea already has a small-scale AEZ map. A small-scale satellite derived map cannot improve the existing AEZ map. In addition to low spatial resolution satellite imagery requires special equipment and trained manpower for image analysis. These equipment and manpower are not available in Eritrea currently. Therefore the application of satellite imagery for soil survey is not recommended.

5.1.4.5 Pedosystems

One of the objectives of soil survey in Eritrea was proposed for identification of high potential areas. The South Africa Pedosystems approach was successful in determining the agricultural potential of the country at a scale of 1:250 000. This system can be appropriate and effective in Eritrea soil survey programme because:

(i) The inter-relationship between soils and landform is a good system for relating soils to the landscape position in which they occur. The terrain type provides a suitable framework (Land Type Survey Staff, 1984).

(ii) The terrain types are convenient parts of land whereby the soils of the whole country can be systematically surveyed, inventoried and presented (Land Type Survey Staff, 1984). Pedosystem surveys can be done within a reasonable period of time and cost, since each terrain type can be traversed systematically by motor vehicle, using augering, exposures and occasionally soil pits. It also speeds up the survey by paying attention to genetic principles such as topomorphism and the effect of geology (Land Type Survey Staff, 1984).

(iii) In pedosystems the terrain types are delineated first and then the soils in each terrain type are identified. A separate map showing the distribution of climatic zones can be done overlaid on pedosystems. This can be done either manually or by GIS. In Eritrea meteorological stations are few and record only few climatic parameters. Thus there will be much more uncertainty about the climatic data than about the soil and terrain form data and it will not be wise to integrate climatic data with terrain and soil data into land type maps at this stage.

It must be kept in mind that the pedosystems approach can be applied in broad scale soil survey only, but not for detailed soil survey.

5.1.4.6 Field survey

As indicated earlier, the field surveys for detailed mapping can be conducted according to one of three approaches. However based on present conditions a fixed grid approach is recommended for Eritrea for detailed surveys at a scale of 1:5000 or 1:6000. A fixed grid approach is recommended because:

i. Eritrea lacks adequate aerial photographs and topographical maps. In a fixed grid approach the use of aerial photographic interpretation is limited and the surveyor can locate him/herself across the grid by measuring distances.

ii. Most Eritrean soil survey staff are relatively less experienced. A fixed grid approach requires less experience than other approaches, since the subjective selection of observation points is very limited.

It must be kept in mind that a fixed grid approach has disadvantages, i.e. it is inherently wasteful and a significant proportion of sites are unrepresentative, including for example settlements or near landscape boundaries where the soil class is indeterminate (Laker, 1994). However, if the site selection is done with a little bit of flexibility approach the above- mentioned disadvantages can be avoided.

5.1.4.7 Field description

Most developed countries have their own soil profile description system similar to that of the (USDA Soil Survey Staff, 1951). In most cases the USDA criteria have been adapted or modified slightly. However with slight modification, the USDA Soil Survey Staff have published a new version of Soil Survey Manual. This soil survey manual (Soil Survey Staff,1993) can be good guideline for soil profile description. Therefore it is recommended as base for Eritrea's soil survey programme.

5.1.4.8 Supporting services

In soil survey chemical and physical analysis must be carried out on representative profiles for the purpose of soil classification. Most developed countries have their own national laboratories and developed standard laboratory methods. In Eritrea, however, there is no national soil laboratory or any developed standard laboratory method. The development of laboratory methods requires years and experienced soil scientists. Therefore, it is not possible for Eritrea to develop methods of soil analysis for the country. It is recommended to adopt and adapt some of the international methods of soil analysis. The Soil Survey Staff of USA developed methods, which consist of procedures for collecting soil samples and methods of analysis for soil survey. It is therefore recommended to use Soil Survey Laboratory Methods Manual (Soil Survey Staff, 1996) as guide for soil analysis. It also equally important to establish a well-equipped soil laboratory and man it with trained staff.

Dent & Young (1981) indicated that the requirement for laboratory studies must be established at the planning stage because they are expensive and time-consuming relative to field observation. Therefore it is essential to take into account the required laboratory equipment and manpower prior to any soil survey programme in the country.

Compilation of the final soil map and soil survey report is a critically important phase of soil survey (Laker, 1994). Most soil survey programmes allocate inadequate funds and time for the compilation of the final report and map. However, this phase is as important as the rest of the phases of soil survey. Therefore it is essential to allocate enough time and funds for it.

In addition to these a well-equipped and well-staffed map drawing section is important. If the final report and map is not good enough for users, all hard work in the field or laboratory will be wasted time and money. All the necessary materials and human power must be prepared at the planning stage of soil survey. In map preparation GIS can be a good tool, but alternatively it can be based on conventional methodologies. Even though GIS requires trained manpower, it is a wonderful system for map drawing, because it needs less time and gives higher accuracy than conventional methodologies. Therefore both GIS and conventional methodologies for map preparation are recommended for Eritrea.

5.2 Rangeland Survey

5.2.1 Objective of rangeland survey

Rangeland survey must be designed to assist development planning or project implementation on rangelands. Rangeland survey can be complex and costly. It is therefore important that surveys should be concentrated where they can do most good. Prior to this, however, it is important to broadly assess the current status of rangeland resources in the country. The objectives of rangeland surveys should be:

(i) In Eritrea, which does not have a basic inventory of rangeland resources, a quick survey of the major ecological units may help to identify areas with high potential for pastoral development. This survey can be conducted at a scale of 1: 250, 000 or smaller. The survey should be able to identify the major ecological areas such as broad types of rangeland, forest, water resources, nomadic and transhumance patterns. It is important for development programmes and national policy making.

(ii) After identification of priority areas, survey at project level should be conducted at scale of 1:10000 or 1:25 000. This survey can be useful to determine the carrying capacity of rangeland and rangeland management systems.

5.2.2 Procedures for rangeland resources inventory at national level

As Trollope (1986) indicated, assessing the condition of an area will depend upon what is known about both land use capability and suitability of the area under consideration. In situations where only the land use capability is known, then the range condition survey should be conducted in both arable and rangeland classes of land. Conversely if the land use suitability is known, then range condition surveys should be restricted to the areas classified as rangeland. In Eritrea it is only the land capability which is known, therefore it is important to conduct range surveys in both arable and rangeland classes of land.

The first step in assessing range condition at national level is to classify areas into agroecological zones (AEZ) and into agroecological units (AEU). Even though the present AZE classification system is not detailed, it can be employed for assessing range condition at national level.

In step 2, appropriate categories of present land use should be identified, for example arable land or grazing land. The present land use categories should be mapped from available data sources, such as interpretation of satellite imagery or aerial photographs. The boundaries should superimposed onto the AEUs and AEZs to calculate the areas of each land use within each ecological unit (Sweet, 1996). Therefore this can lead one to identify the total area available for grazing and/or browsing. However, at this stage it is difficult to determine the potential of the area for grazing or browsing due to the fact that there are areas which are thick bush, riverine forest and steep slopes which are not suitable for these purposes.

The present AEZ classification of the country should be used as starting point for mapping and vegetation description but additional fieldwork, and possibly interpretation of aerial photographs, are likely to be necessary. Then appropriate classification systems should be selected and all AEUs characterized accordingly, so that equivalent AEUs sharing the same vegetation unit (VU) will be grouped together (Sweet, 1996). The VUs should be grouped based on their inherent grazing potential rather than botanical composition only. After identifying all VUs, the total areas of each unit and their percentages should be calculated from air photos or satellite imagery. However, sub-dividing VUs requires large-scale aerial photographs. Therefore this should take place at project or farm level. It must be noted that the degree to which VU sub-divisions are made will depend upon the size of the survey area and the degree of the heterogeneity in the vegetation. Once the VUs have been delineated on an aerial photograph and verified in the field an assessment is made of the condition of the rangeland in each VU. The overall condition of the rangeland in the survey area is calculated using the proportional contribution of each VU of the total area.

5.2.3 Methods of rangeland condition assessment at farm level

Rangelands in Eritrea are managed under traditional systems of communal tenure and pastoralism. Farm planning in these systems may not be practical, since rangeland condition assessment at farm level is used for formulation of rangeland management practices like stocking rate and ratio. However, the condition of rangeland in Eritrea is degrading from time to time due to population pressure and drought. It is therefore essential to assess the condition of rangeland at project or village level.

There are different kinds of rangeland condition assessment methods and techniques which are applied at farm level. Developing methods and techniques of rangeland condition assessment for a specific country could take years and requires experienced experts and substantial funds. In Eritrea, however, neither the manpower nor the funds are available. It is essential therefore to adopt techniques from other international methods. Separate techniques for rangeland condition assessment based on grass and bush were developed in South Africa by Foran *et al.* (1978). These techniques were applied and adapted successfully in Eastern Cape (Trollope, 1986). These techniques can be applied to Eritrea because of:

(i) They require less expensive equipment. The procedure can be applied easily. It is is easier and more manageable than other methods.

(ii) The grass sward assessment puts more emphasis on the botanical composition of the grass. I.e. botanical composition is more appropriate to determine grazing capacity of rangeland. In addition to this it is a reliable index of the productivity of the range. These make these techniques both accurate and rapid.

5.2.4 The application of remote sensing in rangeland survey

The application of small-scale aerial photographs in rangeland survey can provide information about rangeland. However, delineating different vegetation boundaries for the purpose of rangeland condition assessment is difficult or not possible. Aerial photographs at large scale (1: 5000) is applicable to sub-divide the area into homogeneous vegetation units. These homogeneous vegetation units are similar in climate, soil aspects and vegetation type. Aerial photographs at scale 1:30 000 - 1: 50 000 can give a synoptic view of a large area which facilitates the recognition and delineation between the communities. Aerial photograph at a scale 1: 40 000 for regional or national survey and 1: 5000 scale for farm or project planning surveys are therefore recommended for Eritrea. The production cost of aerial photographs at these scales can be high, but aerial photographs are very important for proper rangeland survey. In addition they can also be used for soil surveys.

For accurate description and monitoring of vegetation infra-red colour films are particularly valuable in the assessment of herbaceous vegetation. However, the cost per unit area is higher than black and white aerial photographs. Therefore, the application of colour aerial photographs in rangeland survey is not recommended for Eritrea, since it is not economically feasible for a country like Eritrea.

Satellite imagery can provide information on seasonal changes of vegetation. The imagery obtained during wet and dry seasons can show seasonal vegetation changes. However, it is unlikely that information from satellites could be used in the immediate management of rangeland resources. Satellite imagery is therefore not applicable for medium or large scale of rangeland survey.

5.3 Agro-climatic survey

Gathering 30-years of climatic data can assess the inventory of climatic resources. In Eritrea however the availability climatic data are only for few places, in addition to this the data are not reliable and accurate. The objective of making a climatic survey is to describe and classify the climate in such a way that the agriculturist can put this information to use. This paper therefore puts more emphasis on precipitation, temperature and evapotranspiration which are the most determining factors in agricultural production. In addition to this, it is also important to evaluate climatic hazards such as frost, hail and storm.

5.3.1 Precipitation measurement

Rainfall can be expressed as average annual, average monthly rainfall and daily rainfall. However it must be kept in mind that annual mean rainfall and average monthly rainfall data are not the best methods for land suitability assessment. In Eritrea rainfall is erratic, unevenly distributed and inter-annual variation is a common occurrence. It is therefore important to obtain rainfall figures for decads, i.e. 10-day periods of each month. FAO (1984) recommends that if monthly average rainfall data are available, these could be disaggregated into 10-day periods. This approach cannot be recommended because it will obscure critical drought periods which over the long term may be associated with a certain part of the month. This is very clearly illustrated in the study of Mbatani (2000). Applying 10-day periods is important in determining the so-called mid-summer drought. For example Mbatani (2000) indicated that mid-summer drought in her study area usually occurs during the most critical periods of the crop's development. It is therefore essential to determine mid-summer drought occurrence, when land suitability evaluation is done. For further information refer to Weldegiorgis (2000).

The rain gauge is the most familiar and widely used meteorological apparatus to measure rainfall. In Eritrea there are about 88 rain gauges. These are far from enough for recording complete rainfall data. In addition to this most of rain gauges are manually operated and the standard of installing rain gauges is not up to standard. Due to this data of rainfall are less accurate and reliable. The number of rain gauges required for the whole country can be large due to the extreme variability in geographic distribution of precipitation. The ideal number of rain gauges for accurate measurement can be so large, that it may not be realistic to install across the country. Using interpolation techniques can reduce the number, by taking into account elevation and topographical influences. Rainfall can be very strongly enhanced over the windward side of high ground and reduced in its lee (McIlveen, 1992). Since such pattern can affect the quantity of rainfall, it is vital to take into consideration this effect during interpolation.

The efficiency of collection and the accuracy of a gauge are quite sensitive to the way in which the collecting mouth is exposed. Until recently gauge mouths were always raised above the surrounding surfaces to avoid flooding or splash-in. However according to McIlveen (1992) this deforms the flow of air over the gauge and may significantly reduce the amounts collected, especially in the higher winds, which often accompany substantial rainfalls Therefore it is recommended for Eritrea ,the gauge mouth should be placed about 30 cm above the land surface.

The total rainfall is obviously the first statistic to be looked at. However annual figures have little meaning unless they are interpreted in the light of other factors which determine rainfall effectiveness. As Janick (1981) indicated the effectiveness of rainfall is determined by the seasonal distribution, duration, quantity, reliability and intensity of rainfall. Most of rainfall records in the country only show the quantity of rainfall, but this not enough for land evaluation purposes. It is recommended to use automatic rain gauges, which can provide all the necessary information. Automatic rain gauges can provide information like duration, quantity and intensity of rainfall. Automatic rain gauges are more expensive than manual ones but more effective and accurate. It is not simple to acquire automatic rain gauges in large part of the country. However by taking the geographic distribution of rainfall into consideration. Rain gauges can be installed in most representative sites of the country.

Even though the ideal way of collecting data is from meteorological stations, it is also important to use local knowledge for collecting data. One can always gather a lot of useful information through participatory rural appraisal (PRA) or informal interviews with local farmers. Local knowledge may not give the exact figures, which are required by the experts, however it can provide information which can be interpreted and analysed. Arnold (2000) states that one should " listen, and heed, the counsel of many other specialists. Some specialists (are) the indigenous people who have thunder books hidden away in their memory banks........" He describes a " thunder book" as " a collection of statements..........that provide quick, handy information when you want to answer a particular question." In addition to local knowledge rainfall can be assessed by observing type and condition of vegetation, leaching status of soil, fertility and salinity of soil which all can give a good indication of the water balance of the area.

5.3.2 Temperature measurement

The oldest and most common instrument for measuring temperature is the mercury-in-glass thermometer. This instrument is widely used throughout the world. In Eritrea also it widely applied in meteorological stations. However, only few meteorological stations have standard shields for the thermometers. It is essential to use and apply standard methods of shielding for reliable and accurate data. McIlveen (1992) indicated that care is necessary because a thermometer is sensitive to solar and terrestrial radiation, from which it must be shielded to isolate the effect of air temperature. The shield must allow sufficient ventilation for the temperature of the air outside the shield. Therefore the familiar Stevenson Screen is recommended for thermometer shielding for Eritrea. The use of Stevenson Screen is vital to obtain reliable and accurate data.

In land evaluation temperature can be important factor in determining the suitability of an area. According to FAO (1984) for land evaluation mean monthly temperature during the growing season, day-degrees during the growing season, temperature for the coldest and hottest months during the growing season are the most diagnostic factors which should be considered. Weldegiorgis (2000) indicated all the important factors in land evaluation. The ideal way of obtaining the necessary temperature data is through meteorological station records. However, when data are not available in the area, it is also important to use local knowledge.

5.3.3 Methods of Estimation of Evapotranspiration

There are various methods developed to estimate evapotranspiration from different climatic variables. There is no need for a country like Eritrea to develop its own method of estimating evapotranspiration. It is however important to adopt the most accurate, appropriate and least expensive method of estimating evapotranspiration.

FAO (1998) indicated that a large number of more or less empirical methods have been developed over the last 50 years by numerous scientists and specialists worldwide to estimate evapotranspiration from different climatic variables. Testing the accuracy of the methods under a new set of conditions is laborious, time-consuming and costly. Evapotranspiration data are important for project planning or irrigation scheduling design. To meet this need, guidelines were developed and published in the FAO Irrigation and Drainage Paper No. 24 ' Crop water requirements'. The publication presented four methods to calculate evapotranspiration: the Blaney-Criddle, radiation, modified Penman and pan evaporation methods. For detail information about these methods of estimating evapotranspiration refer to Weldegioregis (2000).

These methods each have their own advantages and disadvantages for different locations. However FAO recommended the Penman-Monteith method as the sole method for determining reference evapotranspiration (FAO, 1998). It is therefore recommended for Eritrea because:

(i) It is a method with high accuracy of predicting evapotranspiration in a wide range of locations and climates.

(ii) It has provision for application in data-short situations. Since in Eritrea meteorological stations record only few climatic data, the flexibility of this method allows to calculate evapotranspiration with incomplete data. According to FAO (1998) even where the data set contains only maximum and minimum air temperature it is still possible to obtain reasonable estimates of 10-day or monthly evapotranspiration with the FAO Penman-Monteith equation. FAO (1998) indicated that unanimous agreement was reached in the consultation to recommend the Penman-Monteith approach as the presently best performing combination equation for estimating evapotranspiration.

Class A pan is widely used for measuring evaporation. However FAO (1998) indicated the great sensitivity of the daily evaporation of the water in the pan, influenced by a range of environmental conditions such as wind, soil-heat flux, vegetation cover around the pan, painting and maintenance conditions, etc. Therefore the use of pan evaporation method for estimating evapotranspiration should be recommended only if instrumentation and the site are properly calibrated and managed (FAO, 1998).

5.3.4 Growing period

A quantitative assessment of the growing period was applied in the AEZ classification of Eritrea to determine the length of growing period of each AEZ. This method was successful in agro-climatic classification. FAO (1984) recommended that, where the area covered by an evaluation included important climatic differences of agricultural significance, these should be treated initially in terms of broader mapping units namely major climate, growing period and agro-climatic zones. Assessing growing period therefore could be an appropriate method for land evaluation purposes for Eritrea. This method can be the best method to assess suitability of an area because :

(i) According to FAO (1984) growing period is a major determinant of land suitability for crops and cultivators. In addition in country like Eritrea with a wide range of rainfall, growing period could be a good method for classification of crop suitabilities.

(ii) Calculations are based on mean daily temperature, precipitation and potential evapotranspiration. Data used for calculations are 10-day periods. This can be useful to determine the climatic variability within a month. For example this approach could help to identify the so-called mid-summer drought. Most of the time land use planners make BIG mistakes taking only annual mean and monthly mean climatic data for land evaluation purposes. Annual mean and monthly means climatic data do not show the climatic variability of the area. This climatic variability could be detrimental for crop growth.

(iii) The growing period assessment requires extended records of rainfall, maximum and minimum temperature, vapour pressure, wind speed and sunshine duration (FAO, 1978). When data are incomplete however it can be carried out by interpolation form other observed or estimated climatic elements from neighbouring stations.

5.3.5 Agro-climatic hazard assessment

In land evaluation the assessment of agro-climatic constraints such as frost, hail, drought and wind hazard are important characteristics in determining the suitability of a certain area for agriculture purposes. For detailed information about agro-climatic constraints refer to Woldegiorgis (2000).

5.3.5.1 Drought hazard assessment

Drought is a common occurrence in Eritrea. Therefore it is important to take into consideration drought hazard in any land evaluation programme. Drought can be predicted from a year by year moisture balance by modeling (FAO, 1984). Drought can be assessed by total amount of rainfall but this can mislead because the total annual rainfall can be good enough for minimum crop requirement. But the distribution may not be good throughout the growing season. Therefore total rainfall cannot separately applied for drought assessment. It is important to determine the crop water requirement of each crop and the difference tolerance of crops to period without moisture. It is therefore recommended for Eritrea to follow FAO (1984) Guidelines land evaluation for rainfed agriculture, the guidelines gave appropriate procedure for assessing drought hazard.

5.3.5.2 Frost, Storm and Flooding hazard assessment

Many evaluations do not take into consideration frost, storm and flooding hazard. However these factors could be an important limiting factors in certain areas of Eritrea. Frost may not be critical in lowland of Eritrea. However in the highlands frost could be an important limiting factor, e.g. in tomato production.

The assessment of frost can be done through local knowledge or climatic records. The ideal way of assessing frost is through climatic records such as air temperature of below -3^0 c for more than 6 hours during fruiting or during the growing season. Such kinds of quantitative data may not be possible to obtain from local knowledge. However farmers have an intimate knowledge of the frequency of frost and its severity in their area. Therefore if data are not available from meteorological stations, it is possible to express it qualitatively as nil, slight, moderate, severe or very severe.

Storm hazard could be caused by high winds, high intensity rainfall, hail or a combination of these (FAO, 1978). Storm hazard, like frost, could be an important limiting factor in certain parts of Eritrea. It is therefore important to take storm hazard into consideration in land evaluation. Storm hazard, like frost, can be assessed through local knowledge or climatic records.

Flood hazard could be an important limiting factor in certain part of Eritrea. Therefore it is vital to assess flood hazard in land evaluation. It is difficult to obtain quantitative data of flood hazard from hydrological data in Eritrea. It is however possible to assess it using qualitative methods. PRA and similar methods can be used for qualitative assessment, since farmers have an intimate knowledge of their area. It is therefore recommended for Eritrean land evaluation, by using local knowledge to apply the FAO (1984) classification of frequency of damaging floods:

- Very rare or never: Less than 1 year in 20 or never known to occur.
- Rare: Less than 1 year in 5.
- Infrequent: Between 1 year in 5 and once per year.

- Frequent: Between 1 and 5 times per year.
- Very frequent: More than 5 times per year.

Even if this classification is not good enough to predict flood hazards. It can indicate whether flood hazard is a problem or not in particular area. It must be kept in mind that such kind of assessment can only be done at farm or project level.

5.4 Conclusion

In collection of basic land resource data the application of international units of classification, such as the Köppen climatic classification, the agro-ecological methodology and the FAO/UNESCO soil classification systems are very important. In a country like Eritrea, which lacks most require resources for developing its own classification systems. It is only possible to adapt or adopt these international classification systems in a view of the urgency for conducting resource surveys to achieve sustainable land use planning and development programme in Eritrea. But it does not mean developing its own classification system is not important for the country.

Methods and techniques of land resource survey have been used for a long time. Their effectiveness, however, differs from country to country due to socio-economic and physical environment differences. The problem of most developing countries is transferring of technology directly from developed countries. Even though the capacity of developing their own methods and techniques is very limited, it is very important to select appropriate and cost-effective methods for the country.

CHAPTER SIX

RECOMMENDATIONS AND CONCLUSION

6.1 Aerial photograph production

In a country where land is a major natural resource and agriculture is the backbone of the economy, the assessment of natural resources is vital for any land development programme. The failure of most development programmes in most developing countries is due to lack of proper natural resource surveys or assessment. Even if the country gives priority to food security, it is not possible to achieve this goal without proper resource assessment. Therefore proper and efficient land resource survey is needed and the use of aerial photographs in land resource survey is essential. At small-scale survey satellite imagery may substitute aerial photographs. However, in detailed and intensive survey the application of aerial photographs could be vital.

The Eritrean economy is not strong enough to afford the cost of production of aerial photographs for the whole country. However with the help of NGOs and international organizations such as FAO, it is not impossible to produce aerial photographs at a scale of 1: 25,000 for the whole country. Aerial photographs at a scale of 1: 25,000 can be used as base map in areas which have not been mapped previously and empty or sparsely settled areas which lack roads, houses, field boundaries and other features shown on topographic maps. Even though priority must be given for the production of aerial photographs at a scale of 1: 25,000 it is also important to produce enlarged photographs at a scale of 1:5000 for the purpose of detailed surveys for project or farm planning in selected areas. In addition to this, the production of topographic maps at scale of 1: 50,000 are required to supplement the existing topographical maps. Besides these photographs orthophoto maps are also necessary. The application of these maps can substantially decrease the cost of field observations.

6.2 Application of GIS

There is no question about the importance of GIS in land resource survey. GIS is a powerful tool, which can be applied for data capturing, storing, analysis and retrieval. For the application of GIS in Eritrea special attention must be given to the country's socio-economic development. The establishment of GIS in the country may need high cost, qualified experts and technology. At present the country lacks the above mentioned factors and therefore there are two possible approaches to introduce GIS in to the country's resource survey system. The first approach is to depend on foreign donors, expatriates or foreign firms, which may not understand the socio-economic condition of the country. This approach alone is less likely to be successful. In contrast by using local resources and experts, a better understanding of socio-economic conditions in the country will be gained. This approach is likely to be successful. However there is lack of experienced local experts and lack of resources in the country. Therefore the combination of these two approaches can be more useful than using them separately. It is recommended to combine both approaches, first to gain experience from expatriate experts who are more acquainted and familiar with the technology and local experts' help to understand the socio-economic condition of the country. Eritreans who recently have had training in GIS should be drafted into the process so that they can eventually, after gaining experience take over the roles of the expatriates.

6.3 Training and education

At present a problem of the country is lack of qualified experts. The government of Eritrea has a praiseworthy, active programme of human resource development, but there are only a few trainees on the field of resource survey and land use planning. The Ministry of Land, Water and Environment (MLWE) and Ministry of Agriculture (MOA) should give high priority to training experts in these fields of specialization. Resource survey needs various kinds of experts in fields such as soil, rangeland, forestry and climatology.

Currently there are only few experts in the above-mentioned fields of specialization in the country, therefore there is an urgent need for increased training in these fields of specialization. In-service training for officers is also essential to update them with new technologies and ideas. Improvement in human capital is not only to increase this ability to define and deal with problems, but also increase the ability of experts to apply technology to local conditions. Knowledge is not only acquired from formal training but also from indigenous knowledge. Settled farmers have an intimate knowledge of variations in soil and water availability field by field, in far more detail and depth than itinerant soil surveyor is likely to acquire. Nomadic pastoralists known where good grazing resources are available at different seasons and adapt movement of livestock to the vagaries of weather. Therefore it is also important to train resource surveyors and land use planners in skills to optimally exploit indigenous knowledge.

The accumulation of new technology is depending on human capital accumulation. The government of Eritrea therefore should continue with its programme of human resource development. The programme however does not emphasise involving trainees in local research while they are studying. It must be noted that as far as possible the research of trainees should be conducted in Eritrea. This helps the trainee to acquire intimate knowledge about his/her home country's land resources and to develop his/her own ideas and technologies that are appropriate to the country condition.

6.4 Equipment and materials

Currently in Eritrea, equipment and materials, which are required for resource surveys, are not available. The Ministries and institutions which are responsible for land resource surveys, must acquire the necessary equipment, which is mentioned in the previous chapters. The attitude that resource surveys are a luxury which can not be afforded when development funds are scarce, is still encountered. This seems correct by taking into consideration current condition of the country. It is inevitable, however, to spend certain amounts of money for this purpose, since the country needs to have land resource data for development programmes. It is recommended therefore to allocate funds for acquiring the necessary equipment for various resource surveys. This being the case, great care must be taken in selecting suitable and appropriate technologies for the country socio-economic condition.

6.5 Policy

The policies of MLWE and MOA do not give high priority for natural resource surveying. In their policies both ministries emphasise proper land use planning, but without the necessary land resources data, the implementation of these policies are less likely to be successful.

The ministries should have a well-defined and planned operational policy concerning these activities in the country. Land reform, whether to have large intensive projects and/or small farmers' settlement, irrigation scheme and/or dry land farms, production potential priorities in the different agro-ecological areas, are a few examples of issues which need to be resolved. All these activities require good land resource data.

The country may not be able to resolve these problems within short periods of time, but a well defined and planned policy is one of the a key point for these problems. MLWE and MOA should develop policies at national and zonal level for various activities of land resources surveys.

6.6 Conclusion

Resource surveying methods and techniques cannot easily be recommended or prescribed to specific country. Each method and technique differs in its appropriateness from country to country. Therefore it is very important before adopting any methods and techniques to take into account the country's socio-economic and technical condition. This paper attempts to recommend different kinds of methods and techniques of resource surveying which are considered suitable for Eritrea. These methods are internationally accepted and recommended. However these methods are not there entirely to replace local methods and techniques. Currently in the Eritrean condition it is not an easy task to develop its own methods and techniques of resource surveying due various reasons. Therefore it is only possible to adopt suitable and appropriate methods and techniques for the country.

Agricultural development planning that is done without proper resource surveys and inputs from resource experts invariably lead economic, agricultural, environmental and socio-economic disasters (Laker & D'Huyvetter, 1988; Laker, 2000).

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