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DEVELOPMENT OF A STRATEGY AND STRUCTURE FOR LAND SUITABILITY EVALUATION FOR ERITREA

By

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December 2000

Mini-dissertation submitted in partial fulfillment of the requirements for the degree of Magister Institutionis Agrariae in Land Use Planning in the Faculty of Natural and Agricultural Sciences at the University of Pretoria.

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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..

ACKNOWLEDGEMENTS

Collecting data, especially about Eritrea, was the difficult part and many people have participated to make this dissertation a reality and I am grateful to all that were involved directly or indirectly. Generally my appreciation goes to the following persons and institutions for their support and encouragement.

* Professor M. C. Laker for his wonderful encouragement, advice and leadership from the beginning to the completion of this work.

* My wife Elsa and other members of my family and friends for their patience and encouragement all the way from my undergraduate studies till the completion of this work.

* Postgraduate school of Agriculture, University of Pretoria, for their partial coverage of my bursary.

* Members of the Embassy of Eritrea in Pretoria, South Africa, for understanding my situation and helping me with their full capacity to solve the problem.

* Members of the Department of Plant Production and Soil Sciences, especially Mr. R. W. Gilfillan, for his assistance with computer and related materials.

* The cartographic unit in the Department of Geography, for helping me with maps of Eritrea.

ABSTRACT

Different evaluation systems of land have been used around the world. Basically these systems can be categorised into two main systems i.e. the USDA (initiated and started in the USA around 1930th) and the FAO Framework for Land Evaluation (developed in 1976 to answer some of the questions developing countries had with the USDA). The former deals with land capability classification where soil survey is done first and the use of the land is decided in general way from class I (best land for arable farming) to class VIII (worst land for arable farming). This type of classification is a narrow approach where economic analysis and comparison of different uses were not considered and it favours for arable use only. The later system takes the survey of land resources and producing of mapping units with homogenous characteristics at the same time defining the major kind of use and describing the land use types in detail. Comparison of the two will follow putting all factors i.e. physical, social, economic and environmental into consideration. Through the process of iteration different actions could be taken to bring both into harmony. This includes from land improvement (minor or major) to the complete change of the general objective of the evaluation.

Suitability evaluation is more flexible and can give more room for application in developing countries like Eritrea. The process is long and it is multi-disciplinary where different scientists from different field of studies work for the achievement of common goal. This help in the exchange of data for the future planning.

To initiate the evaluation exercise, two cereal crops i.e. wheat and sorghum were taken as a major kind of land use and their requirements and limitations were described in detail. On the other hand the major land qualities for rainfed agriculture in Eritrea i.e. moisture availability, nutrient availability, rooting condition and erosion hazard were chosen and their significance were discussed and ways for their assessment were proposed. Different factors that need to be considered during comparison of the requirements of the land use type and the qualities of the land were discussed. For determining the suitability, different systems are discussed and the appropriate one is proposed for Eritrea. The final result of suitability evaluation is different maps showing the suitability rate and written report that indicate all the data, assumptions used during the evaluation process. At last more crops that grow in Eritrea were chosen and their requirements and limitations were identified and a check list for evaluating land qualities for irrigated agriculture and extensive grazing are described at the appendix.

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CHAPTER ONE

1.1 General

Eritrea is a country that emerged as a nation after a long fierce fighting for independence against Ethiopia. Its natural resources are not abundant and like all other sectors, including the infrastructure, have suffered serious damage during the long lasting war, thus negatively affecting its productive capacity. The territory used to be one of the most developed areas in terms of agriculture and light industry. But because of wrong policies of the Ethiopian government the capacity had been reduced to below subsistence i.e. most people depends on food aid for their survival (CIA, 1999).

The FAO (1994a) report on Eritrea suggested there is reason for optimism, however. In the first place the Eritrean people are a hard working and resourceful and secondly, it is the human factor that counts more than the abundance of resource endowment, as the history of many nations demonstrates. The later is true but it doesn't mean that natural resources are not important. In fact natural resources, like human resources, are very important to a country like Eritrea where more than 70% of the population is dependent on agriculture. So in order to use natural resources appropriately without degrading them, proper evaluation of natural resources is very important for planners and other policy makers to decide on proper land use.

1.2 Research initiatives

Natural resources are the basis for the existence of human beings. Their distribution differs from one region to the other and from one country to another. Eritrea, like most sub-Saharan African countries, has limited natural resources especially rainfall. Its erratic nature and uneven distribution seriously limits successful rain-fed agriculture. In addition soil erosion (water and wind) increases the danger of reducing the fertility and sustainability of these natural resources (especially soils).

People have every right to use the existing natural resources for their benefit, but only without jeopardising the ability of future generations to use these resources

(Norgaard, 1994). This is the essence of sustainable use of natural resources, but this is only possible when the nature and qualities of the existing natural resources are known and policies and strategies for their optimal use and conservation are in place. Land is the core of all natural resources whether it is used for agriculture or otherwise. The initiative for this project emerged from the fact that evaluating the land and utilising it to its maximum capacity without endangering the environment is the best way to ensure sustainable use of land. I believe there is a shortage in terms of a suitable strategy and system of land evaluation for the Eritrean situation. It is hoped that this dissertation will contribute to the sustainable use of the natural resources of Eritrea without negatively affecting the social and economic livelihood of the present communities. That is it aims to promote "inter-generation equity" in terms of land use by looking at **both** present and future generations, and **not only** at future generations, as is often implied (Laker, personal communication).

1.3 Objectives of the study

The general objective of the study was to develop an appropriate strategy and system of land suitability evaluation for Eritrean situation. The specific objectives are:

I To examine the strategy and system of land evaluation currently used in Eritrea.

II To compare major land capability and suitability schemes/systems available in different parts of the world.

III To look at the advantages and disadvantages of these different land evaluation systems in relation to the Eritrean situation.

IV To design a step by step strategy and system of land suitability evaluation for Eritrea.

1.4 Research methodology

The study consisted of three main parts viz.:

A. Collection and analyses of data on the present situation regarding land evaluation in Eritrea. This was done by consulting bodies like NGOs, working with in the country, the FAO and the Eritrean ministries of Agriculture and Land, Water and Environment.

B. In-depth studies of various land evaluation systems developed and used in different parts of the world. From these principles, concepts and approaches, which could be useful to incorporate in a land evaluation strategy and system for Eritrea, were identified.

C. Synthesis of a proposed land evaluation strategy and system for Eritrea.

1.5 Information about Eritrea

1.5.1 History of Eritrea

On first January 1890, Italy set the boundaries of Eritrea and ruled it as a colony until 1941. After the British defeated the Italians in Africa, the British then took over the administration of Eritrea. Following a decision by the United Nations, Eritrea was federated to Ethiopia in 1952, with a certain amount of autonomy.

However, during the federation with Ethiopia, Emperor Haile Selassie's government systematically violated the rights granted by the UN. The oppression intensified with the dissolution of the Eritrean parliament and the annexation of Eritrea as Ethiopia's fourteenth province in 1962.

In 1961, an armed struggle for independence began. Thirty years of fighting ended in May 1991, when the Eritrean people's liberation front (EPLF) liberated Asmara and established the provincial government of Eritrea (PGE). In an internationally supervised referendum in April 1993, 99.8% of the Eritreans voted for independence, which was officially declared on 24th of May 1993 (Esterhuysen, 1998).

1.5.2 Location and size of Eritrea

Eritrea is located in the Northeast of Africa and its geographic co-ordinates are 1500N and 3900E (CIA, 1999) and it is located between 12 and 18 degrees N and between 36 and 44 degrees E. The total area of the country is 121,320 sq. km. It is bordering Sudan in the west and northwest, Red Sea in the north and northeast, Djibouti in the southeast and Ethiopia in the south (Esterhuysen, 1998) (Figure 1.1). Figure 1.2 shows the position of Eritrea in relation to some East and North African countries.

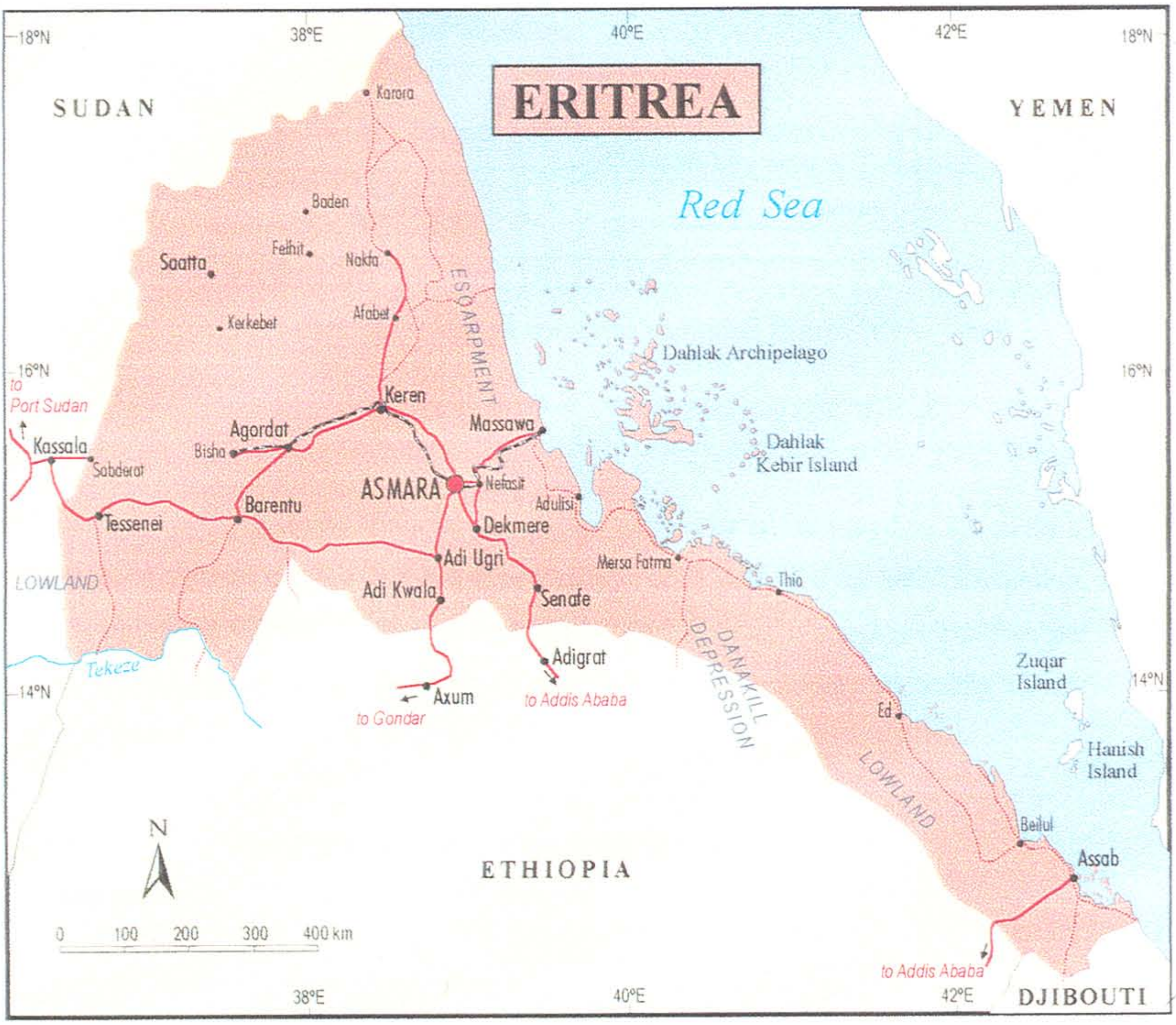


Fig. 1.1: Geographic location of Eritrea (From Esterhuysen, 1998)

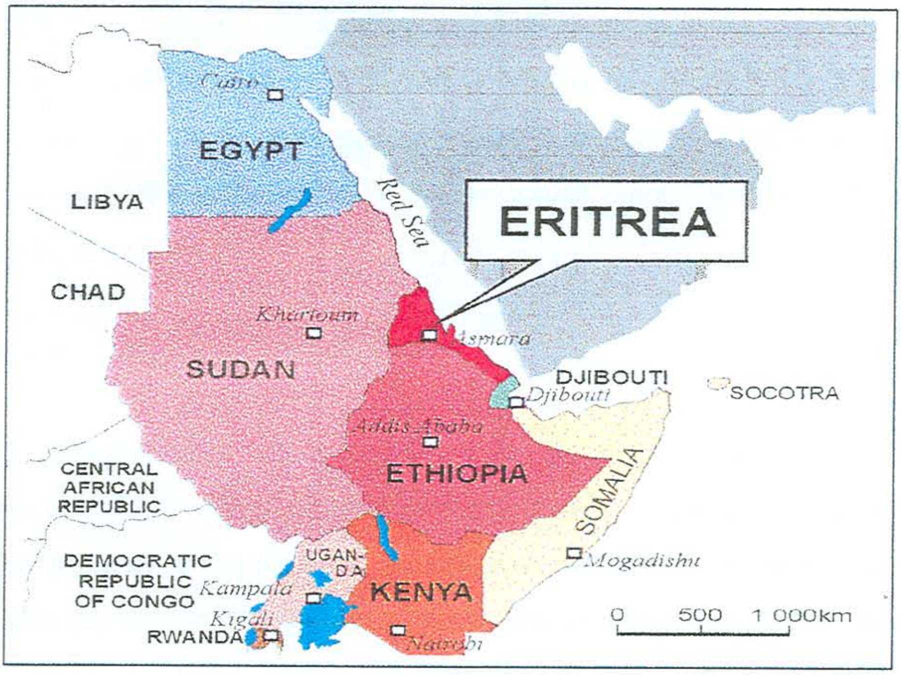


Fig. 2: Map of East and North African countries including Eritrea (CIA, 1999)

1.5.3 Population

According to CIA (1999), the total population of Eritrea is estimated to 3,9 million. Population growth is 3.9% and life expectancy is 55,7 years for the total population, 53,6 years for males and 57,9 years for women. Fertility rate is about six children per women. The age structure, percentage, male and female numbers according to age group are as follows:

Table1.1: Number of people in relation to age groups (CIA, 1999)

Age group	%	Male	Female
0-14	43	859,899	852.329
15-65	54	1,061,921	1,078,102
>65	3	67,969	64,503

1.5.4 Natural resources

Natural resources are here discussed in relation to agricultural production capacity. It is impossible to try to discuss all the natural resources of Eritrea and it will be out of the scope of this project. In this section climate, soils, topography and water resources will be discussed.

1.5.4.1 Climate

Eritrea is a country with a complex series of landscape and climatic features, which give to a wide variety of agro-ecological zones. Climate in Eritrea range from hot arid, adjacent to the Red Sea, to temperate sub-humid in isolated micro-catchments within the eastern escarpment of the highlands (Figure 3). According to temperature, around 72% of the country is classified as very hot or hot (with mean annual temperature exceeding 24°C) while not more than 14% is classified as mild or cool (with mean annual temperature below 21.5°C) (Table, 1.2).

Table1.2 Temperature regimes of Eritrea (Source FAO, 1994a)

Temperature Regime	Mean annual Temperature (°C)	Elevation range (m)	Area	
			Sq.km.	% of country
Very hot	29-26,5	<0-500	40,705	33.4
Hot	26,5-24	500-1000	47,454	38.9
Warm	24-21,5	1000-1500	16,982	13.9
Mild	21,5-19	1500-2000	11,623	9.5
Cool	<19	>2000	5,073	4

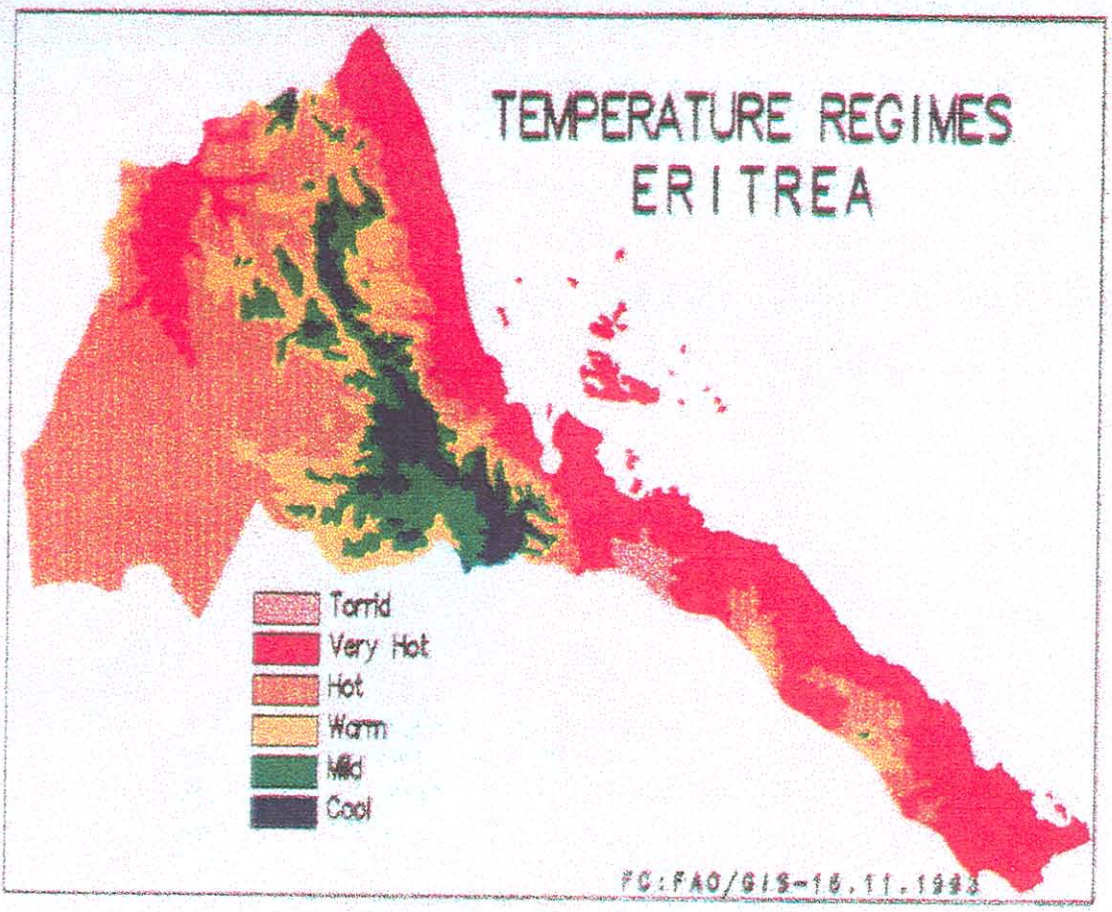


Fig. 1.3: Temperature regime of Eritrea (from FAO, 1994)

Like other Sahelian African countries, Eritrea receives its rainfall from the south-west monsoon in the summer months, from April to October. "Small rain" fall in April and May, and the "main rain" 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 (November through March) that is borne by north and north-east continental air-streams that carry little moisture until affected by the Red sea where they pick up moisture (FAO, 1994a).

Generally, total annual rainfall tends to increase from north to south; from less than 200 mm at the northern border with Sudan to over 700 mm in a restricted area on the southern border with Ethiopia. A small region, known as the "green belt", on average receives over 900 mm (Figure 1.4).

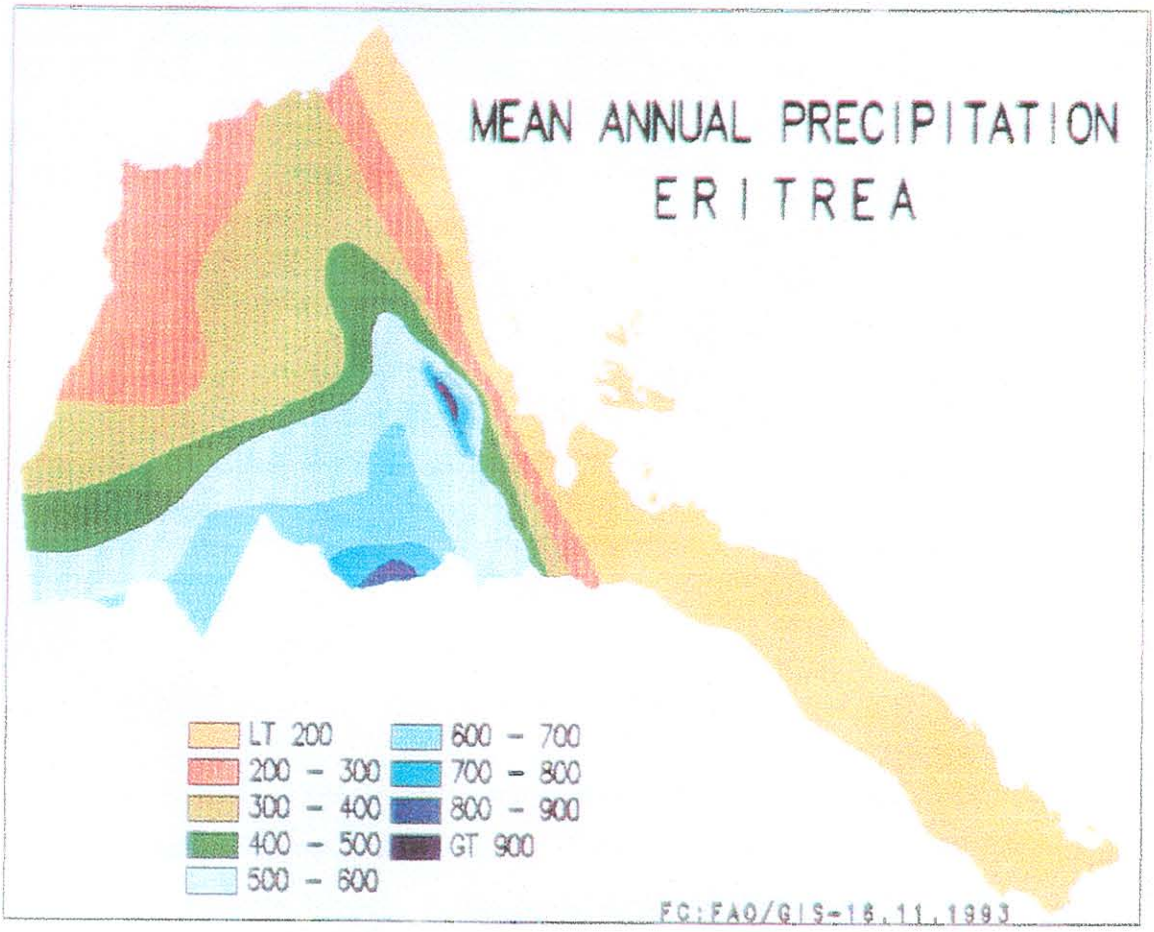


Fig.1. 4: Map showing distribution of rainfall in Eritrea (FAO, 1994a)

The problem of inadequate total rainfall over much of the country is compounded by the high variability of both total annual rainfall and its intra-annual distribution. All existing and potentially important crop production areas are to varying degrees drought-prone by international standards, with the exception of the small "green belt" mentioned above.

Table 1.3 shows the distribution of rainfall in Eritrea for the past eight years for some representative stations. From this one can understand how skewed the distribution is and how small the total amount of rainfall is. This is to show the nature of rainfall but data for thirty years should be analysed. The information in Table 1.3 was obtained from the ministry of Agriculture.

Table 1.3 Mean annual rainfall of representative stations of Eritrea (MOA, 2000)

Station	Asab	Massawa	Tessenei	Keren	Agordat	Ghinda	Barentu	Nakfa	Asmara	Adikeyih
Years	1992 1999	1995-1999	1993-1999	1992-1999	1992-1999	1992-1999	1992-1999	1992-1999	1992-1999	1992-1999
Jan.	15.5	22.2	0	0	0	60.7	0	5.5	4.7	1.3
Feb.	8.2	6.8	0	0	0	24.6	0	0.8	0	2
Mar.	9.9	5.8	0	7.4	3.6	40.2	0.7	16.7	9.7	17.4
Apr.	4.5	11.1	2.9	16.3	8.3	53.3	4.1	48.2	17.8	37.4
May	0	5.6	20.6	29.6	26.9	19.5	34.5	48.9	61	41
June	2	0	32.8	61.9	20.9	7	40.9	27.6	13.8	24.3
July	1.1	1	105.9	123.7	117	73.8	151.4	91.8	158.8	135.5
Aug.	18.2	9.4	167.2	177.5	144.5	53.9	156.5	158.9	153.1	71.4
Sep.	1.1	0	65.7	39.7	44.7	16.6	47.8	47.9	23.6	3.8
Oct.	1	35.1	11.2	14.4	11.3	78.3	8.8	42	38.5	20.5
Nov.	1.3	52.4	3.4	2.1	0.8	93	5.6	26	9	10
Dec.	3	41.6	0	0	0	127.2	0	1.4	0	0
Total	113.5	191	409.7	472.6	378	648.1	457.5	515.7	577.3	364.6

1.5.4.2 Soils

According to FAO (1994a), twelve major soil units were identified in Eritrea, these are Arenosols, Solonchaks, Leptosols, Calcisols, Lixisols, Luvisols, Gypsisols, Cambisols, Fluvisols, Nitisols, Vertisols and Regosols. Their distribution is shown on Figure 1.5, and it can be seen that, much of the area is dominated by Leptosols, which are weakly developed shallow soils (FAO-UNESCO, 1990). Some of the most important characteristics of each soil unit are explained as follows and the general description of the soil and the origins of the name are presented in Appendix 1.

Arenosols: Connotative of weakly developed coarse textured soils (FAO-UNESCO, 1990). These soils can be found in different environments and the possibilities to use them for agriculture vary accordingly. All Arenosols have certain features in common i.e. their texture is coarse, which is accountable for their high permeability and low water holding capacity (FAO-UNSCO, 1991). Arenosols of arid area, with annual rainfall of <300 mm, are mostly used for extensive (nomadic) grazing. If the rainfall is >300 mm, dry farming could be possible. Good yields of small grains, pulses, melons and fodder crops have been obtained on irrigated Arenosols but high percolation

Arenosols but high percolation losses often make surface irrigation impossible. The low coherence, low nutrient storage capacity and high sensitivity to erosion (especially wind erosion) are further limitations of Arenosols in the dry zone (Driessen and Dudal, 1991). Eritrea has <1% of the total area covered by Arenosols.

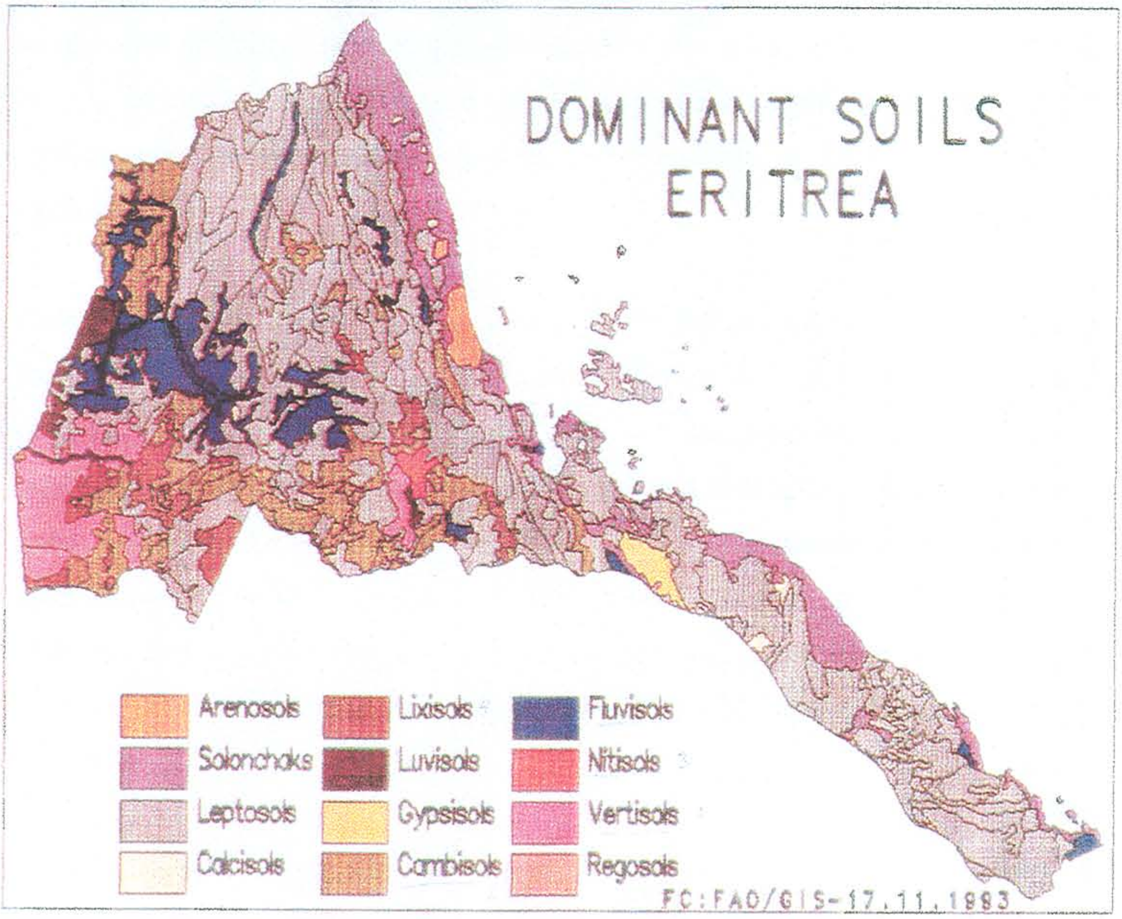


Fig. 1.5: Dominant soil units of Eritrea (FAO, 1994a)

Solonchaks: Saline soils (soils with high accumulation of salts) (Landon, 1991). According to Driessen and Dudal (1991) the accumulation of salts can affect plant growth in two ways. That is directly, by inducing physiological drought as a result of high osmotic pressure of the soil moisture and indirectly, by skewing the composition of the soil solution which disturb the availability of plant nutrients. These soils can not be used for normal cropping. It needs more water for leaching and normal irrigation is not adequate for desalinisation. Sometimes the opposite could happen, i.e. that salt contained in the irrigation water remains behind in the soil and the salt level builds up. In Eritrea Solonchaks are found in the coastal areas of the Red Sea.

Leptosols: these are very shallow, freely drained soils, with no glayic or stagnic properties at shallow depth and they are free from high level of soluble salts. Their shallowness or stoniness affects their water holding capacity. The chemical soil fertility of Leptosols is often higher on hill than on level land. Crops can grow on these soils, but at the high risk of soil erosion. Terracing and removal of stones by hand could transform steep slope with shallow and stony soils into cultivable land (FAO-UNESCO 1990). Because of their extreme shallowness they are not recommended for cultivation. Almost 50% of Eritrean land is dominated by Leptosols.

Calcisols: soils with high amount of lime (FAO-UNESCO, 1990). They can be used for extensive grazing. Wheat or sunflower might do well under rainfed conditions, preferably after a few fallow years, but with well managed irrigation, they can give good result. Fodder crops such as Rhodes grass and alfalfa can tolerate high calcium level. Cotton can be grown with the addition of nitrogen, phosphorous fertilizers and trace elements (Fe, Zn). Furrow irrigation is better than basin irrigation because it reduces seedling mortality due to surface crusting; pulses are very vulnerable, especially during seedling stage (FAO-UNSCO, 1990). Calsisols occupy <1 % of Eritrea.

Lixisols: Soils with high accumulation of clay and strong weathering (Landon, 1991). The low aggregate stability in the surface horizon(s) of Lixisols is conducive to slaking and/or erosion if the topsoil is exposed to the direct impact of raindrops. Heavy machinery or tillage of wet soils can cause structure deterioration and compaction of the surface soil and interfere with the rooting of crops. Minimum tillage and erosion control measures such as terracing, contour ploughing, mulching and the use of cover crops help to conserve the soil. Perennial crops are better than annual crops especially on sloping land. Erosion and soil deterioration can be enhanced through cultivation of tuber crops (groundnut) so it must be avoided. Many Lixisols are best used for extensive grazing or forestry (FAO-UNESCO, 1990).

Luvisols: soils of high base status and accumulation of clay content in lower horizons (Landon, 1991 and FAO-UNESCO, 1990). Luvisols are fertile soils suitable for a wide range of agricultural uses. Structure could be deteriorated with high silt content, if the soil is tilted in wet condition and/or with heavy machinery. Luvisols on steep slopes require erosion control measures (FAO-UNESCO, 1990). Around 3% of Eritrean soils are Luvisols.

Gypsisols: Soils with high accumulation of calcium sulphate (FAO-UNESCO, 1990). In the lower B-horizon or slightly deeper, it is possible to find from a soft, powdery and highly porous mixture of gypsum, lime and clay, to a hard and massive layer of almost pure, coarse gypsum crystals. Gypsisols with few percent of gypsum in the upper 30 cm layer (60 cm if irrigated) can be used for the production of small grains, cotton, alfalfa etc. Dry farming on Gypsisols needs fallow years and other water harvesting methods but it is not profitable. Generally, dry farming with more than 25% Gypsum cannot be recommended (Dreissen and Dudal, 1991). 2% of Eritrea is covered by Gypsisols.

Cambisols: A cambic B-horizon is the main feature of Cambisols. According to FAO-UNESCO (1990) most Cambisols can be categorised into four main criteria:

I. Most Cambisols occur in areas with high precipitation but with good position of discharge of surplus water.
II. Most Cambisols are medium textured and have a good structural stability, a high porosity, good internal drainage and a good water holding capacity.
III. Most Cambisols contain, at least, some weatherable minerals in the silt and sand fractions.
IV. Most Cambisols have a neutral to weakly acid soil reaction, a satisfactory chemical fertility and an active soil fauna.

These, therefore, makes them soils of good agricultural quality and are mostly intensively used. Such soil types contribute 15-20% of the total area of Eritrea.

Fluvisols: Soils of alluvial deposits (FAO-UNESCO, 1990) and they are depositional rather than pedogenetic profiles (Landon, 1991). These are young soils with weak horizon differentiation. Some show structural development but only in parts of the profile. It is evident that their recent sedimentation and wetness dominate the characteristics of Fluvisols. The high natural fertility makes them favourable for the cultivation of a wide range of dry land crops on river levees and on higher parts in marine landscapes. For example, in tropical lowlands with a year round supply of fresh water, three crops per year are possible (FAO-UNESCO, 1990). 8-10% of Eritrean soils is Fluvisols.

Nitisols: Tropical soils with prominent shiny clay skin, which are usually formed on basic rocks (Landon, 1991). They are well-drained soils with deeply developed nitic horizon. Nitisols are one of the most productive soils of the humid tropics, their deep and porous solum permits deep rooting. They are, therefore, less susceptible to erosion than many other soils. They have good internal drainage, water holding capacity and workability. These make them suitable for most tropical crops (FAO-UNESCO, 1990). Unfortunately such soils are very scarce in Eritrea and their percentage is less than one.

Vertisols: According to FAO-UNESCO (1990) these are soils with swelling and cracking characteristics when they are wet and dry and they are suited to large-scale mechanized forms of agriculture but are less suited to low-technology farming on account of their poor workability. They are susceptible to erosion so cultivation should be discouraged on slopes more than 5 degrees. Some measures (contour cultivation and contour banding) can improve infiltration and helps to make better use of available water but care should be taken to protect water stagnating against bands and this can be done through graded bands. Vertisols make around 10% of Eritrean soil.

Regosols: Soils with low moisture holding capacity and susceptible to erosion problems. In tropical areas, they are mainly used for extensive grazing and many are not used at all (FAO-UNESCO, 1990). In Eritrea the area covered by these soils is very insignificant (<0.5%).

1.5.4.3 Topography

Eritrea has a wide range of altitudes; the lowest being 10m above sea level in the port of Massawa and the highest is 2490m above sea level in Adikeyih in the south of Eritrea near the border with Ethiopia (Figure 1.6). In addition to these there are two extremes of elevation, where the lowest point near Kulul within the Denakil depression which is -130m (one of the hottest places in the world) and the highest point, Soira 3018m above sea level (Esterhuysen, 1998). The wide variation in elevation has an effect on potential evapo-transpiration and temperature and their relation can be seen in Table 1.4 (Ministry of Land, Water and Environment, 1997).

Eritrea is divided into six major agro-ecological zones depending on climate, landform, soils, etc. The topography of Eritrea includes mountains, hills, rolling plains and flatland. Table 1.5 shows the type of the landform, percentage area covered, and dominant crops for each agro-ecological zone. Each zone will be discussed fully in Section1.6.

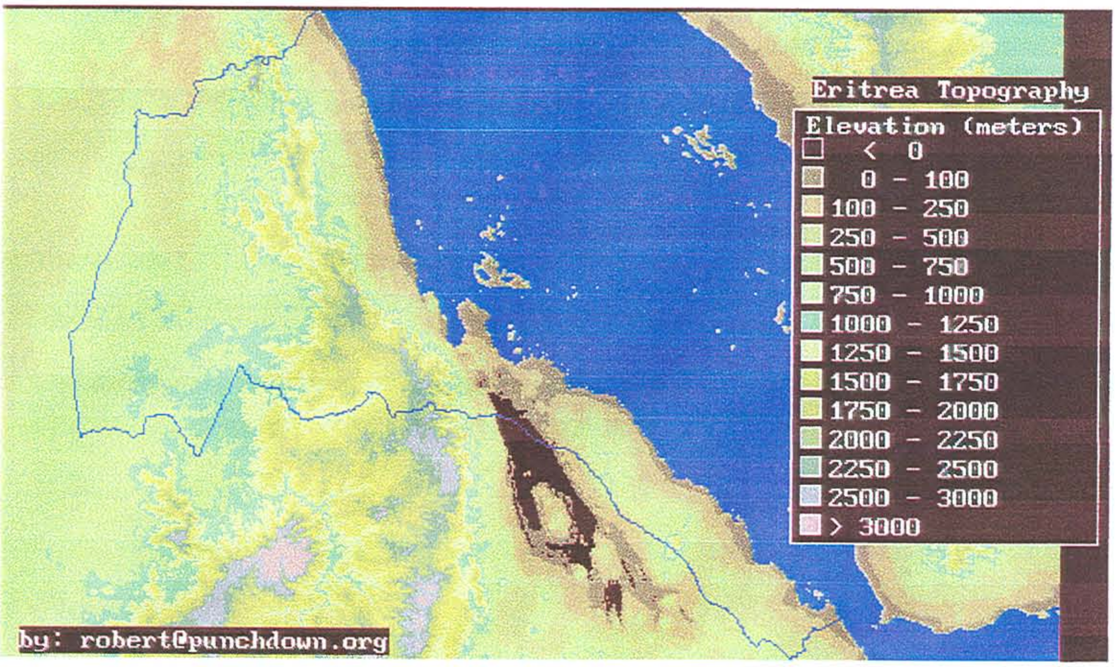


Fig. 1.6: Topographical map of Eritrea (from Van Buskirk, 1999)

Table1.4: Altitude co-relations with PET and temperature (Ministry of Land Water and Environment, 1997)

Station	Altitude (m)	Annual PET (mm)	Average rainfall(mm)	Mean max.(°c)	Mean min.(°c)	Mean (°c)
Massawa	10	2033	191	32.9	26.8	29.8
Aseb	11	2341	113.5	35	25.3	30.15
Tesenay	585	1928	409.7	36.1	21.1	28.6
Agordat	626	2031	378	36.4	21.6	29
Ghinda	962	1655	648.1	29.1	20.1	24
Barentu	980	2044	457.5	33.5	16.9	25.1
Keren	1460	1808	472.6	30.8	15.3	23.05
Nakfa	1676	1595	515.7	25.2	12.7	18.95
Asmara	2325	1585	577.3	23.2	10.1	16.65
Adikeyih	2490	1624	364.6	24.7	10.9	17.8

Table 1.5 Agro-ecological zones and their landforms (adapted from Ministry of Land, Water and Environment, 1997)

Agr-ecological zone	Dominant crops	Land form	Area %
Moist highland	Barley, wheat, teff, sorghum, maize, finger millet, pulses	Undulating to rolling plateau, partly dissected, with hills, valleys, ridges and escarpments.	7,4
Arid highland	Sorghum, pearl millet, barley	Steep escarpments and mountains, with dissected plateau and rolling hills	2,5
Moist lowland	Sorghum, sesame, cotton, finger millet, pearl millet, maize	Undulating to rolling plains with outlying hills: lower part of western escarpment with ridges and valleys.	16,2
Arid lowland	Sorghum, pearl millet	Flat to rolling plains with outlying hills and mountains.	34,3
Sub-humid escarpment	Maize, sorghum, coffee, barley	Steep escarpment with mountains and valleys.	0,8
Semi-desert zone	Sorghum and maize under spate irrigation	Flat to rolling plains with outlying hills and mountains, islands, volcanic calderas, dunefields, and evaporite basin.	38,8

1.5.4.4 Vegetation

Vegetation of Eritrea is very sparsely scattered. According to Van Buskirk (1999) Eritrean vegetation is divided into two major categories viz. highland and lowland vegetation, depending on the type and density. The soil types, land use, and the climate determine the vegetation of an area. In general, the dominant vegetation types includes Acacia bushland and shrubland, Savanna woodland, some disturbed forests with *Juniperus procera* and *Olea africana*, scattered woodland (*Hyphenae palm* along major rivers), sparse scrub, grass and halophytic communities (*Acacia mellifera)*, bare lava or sand (Ministry of Land, Water and Environment, 1997).

1.5.5 Surface water resources

According to FAO (1994a), Eritrea falls into three drainage basins. The Mereb-Gash and Tekeze-Setit rivers drain into 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 south-eastern border drains in to the closed Denkel basin.

The Tekeze-Setit river basin has a catchment area of 68,751 km^2, of which the major part is in 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. The Setit is a major tributary of the Atbara river (Sudan), which itself joins the Nile below Khartoum.

The Mereb-Gash is a narrow, westward-oriented basin covering 24,000 km^2 of Eritrea from the southern part of the central highlands to the Sudanese border. Much of the upper basin has a high erosion hazard, which has resulted in the deposition of wide areas of colluvial sands and gravel along the main river valleys.

Both the Barka and Anseba rivers arise on the north-western slopes of the central highlands to the Sudan border in the extreme north-west of Eritrea. The area of the basin is 41,700 km^2 but annual rainfall is low, ranging from 500mm in highlands to less than 200mm in the northern lowlands. The Red Sea drainage basin also comprises numerous small rivers originating from the eastern escarpment. Only a very small area of the country lies in the Denkel basin which, due to its closed topography and arid climate, is characterised by highly saline soils and has little agricultural potential.

Some of the rivers could have some good potential for irrigation and at the same time could be a cause of major conflict between countries like the Sudan which depends on irrigation from water comes from Eritrea through some rivers like the Gash river.

Around ten countries of the region are discussing the fare use of some major rivers like Nile and this is a good hope, which can avoid unnecessary conflict in future.

1.6 Agro-ecological zones

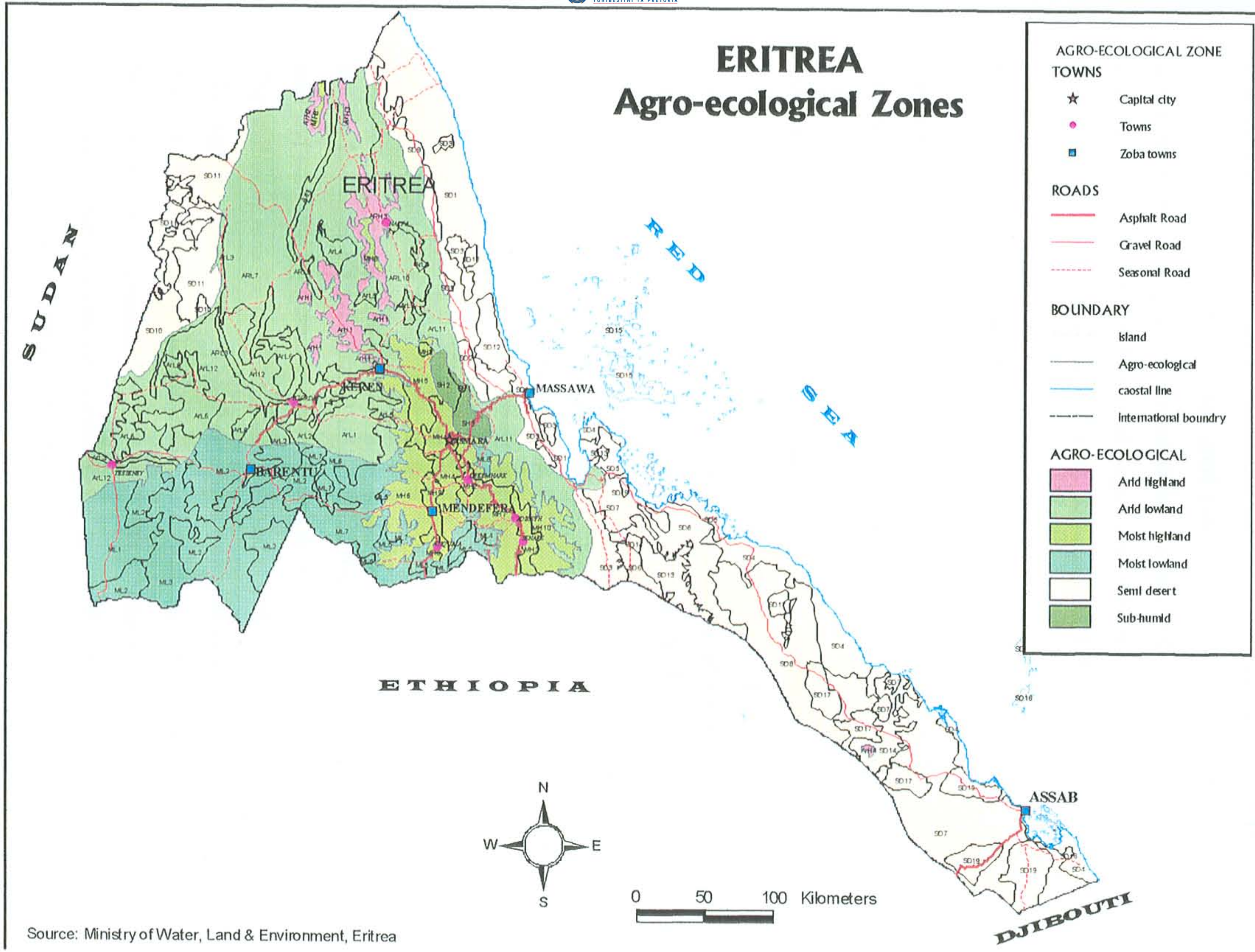
Agro-ecological zone (AEZ) refers to any method for classifying the earth's surface into more-or-less homogeneous areas with respect to the physical factors that are most important to crop (or other plant) production (Rossiter, 1994). It provides the geographical basis for national agricultural planning, and a number of applications have been developed for research, extension, project identification, and regulation of land use (Ministry of Land, Water and Environment, 1997). FAO (1994a) and Ministry of Land, Water and Environment (1997) classified Eritrea into six major agro-ecological zones depending on agro-climate and soil parameters (Fig. 1.7). Each agro-ecological zone is divided into agro-ecological units and in Eritrea there are 55 agro-ecological units. The main six zones are summarized as follows:

1.6.1 Arid highland zone

It is found in the northern highlands of Eritrea. The climate of this zone is arid with annual precipitation of 200-500 mm. On the other hand, evapo-transpiration ranges from 1600-1800 mm. The topography of this zone includes steep escarpments and mountains with dissected plateau and rolling hills. The dominant crops include sorghum, pearl millet and barley. Livestock like cattle, sheep, goat and camel are common to the area. Vegetation is sparse shrubland with scattered bushland and woodland. Soils like Lithosols, Cambisols, Leptosols, and some bare rocks are dominant in this zone. The area covered by this zone is only 2,5 % of Eritrea (Ministry of Land, Water and Environment, 1997).

1.6.2 Arid lowland zone

This zone is found in northern Eritrea, excluding coastal strips, extreme northwest and lower part of eastern escarpment. It has flat to rolling plains with outlying hills and mountains with annual precipitation range of 200-500 mm and evapo-



Source: Ministry of Water, Land & Environment, Eritrea

Fig.17 Agro-ecological map of Eritrea

transpiration of 1800-2000 mm. Natural vegetation are in the form of shrubland and bushland (scattered woodland). Cambisols, Leptosols and Fluvisols are the dominant soil units of the zone. The area has good potential for grazing or browsing and the dominant crops are sorghum and pearl millet. Camel, cattle goats and sheep are well adapted to the zone. This is the second largest zone with around 34,3% contribution to the total area (Ministry of Land, Water and Environment, 1997).

1.6.3 Moist highland zone

This zone is found in central and southern highlands of Eritrea with warm to cool semi-arid climate (FAO, 1994a). The annual precipitation ranges from 500-700 mm with potential evapo-transpiration of 1600-1800mm. The landforms include undulating to rolling plateau, hills, valleys, ridges and escarpments with the highest altitude of 3018 meter above sea level. Dominant vegetation of the zone is in the form of derived bushland and shrubland with remnant *Juniperus procera* and *Olea africana* and the common soil unit includes Cambisols, Luvisols, Lithosols, Regosols and Vertisols. Barley, wheat, teff, sorghum, maize, finger millet and some pulses are the main crops with sheep, goat and cattle as the major livestock of the zone. This zone covers about 7,4% of the total area of Eritrea (Ministry of Land, Water and Environment, 1997).

1.6.4 Moist lowland zone

This is known as the breadbasket of Eritrea (irrigation potential, important grazing area and wildlife). It is found in the southwest of the country and upper Mereb valley. The landforms include undulating to rolling plains with outlying hills and the annual precipitation ranges from 500-800 mm with potential evapo-transpiration of 1800-2000. The altitude range is 500-1600 meter with savanna woodland and derived bushland as natural vegetation of the zone. Cotton, sesame, sorghum, pearl millet and maize are dominant crops with cattle, sheep, goat and camel as important livestock. Soils like Cambisols, Vertisols, Fluvisols, Lithosols, Regosols are common and the area covered by this zone is about 16,2% (Ministry of Land, Water and Environment, 1997).

1.6.5 Semi-desert

This is the largest zone (38.8%) and includes coastal areas, islands and the area of northwest of Barka-Sawa river. Landforms include flat to rolling plains, with hills and mountains, volcanic calderas. The precipitation is usually less than 200 mm but the evapo-transpiration ranges from 1800-2100 mm. Sparse scrub, grass and halophytic communities' bare lava or sand dominate the vegetation of the area. Soils like Solonchaks, Lithosols, Cambisols are common. Sorghum and maize are grown only under spate irrigation. Generally, it can be said that the productivity of this zone is very low (Ministry of Land, Water and Environment, 1997).

1.6.6 Sub-humid zone

This is the smallest (0,8%) and unique zone and sometimes called the green belt zone (FAO, 1994a). It is found in the central escarpment with annual precipitation range from 700-1100 mm and evapo-transpiration of 1600-2000 mm. The landforms are steep escarpment with mountains and valleys. The vegetation is in the form of disturbed forest with *Juniperus procera* and *Olea africana.* Crops like maize, sorghum, coffee and livestock like cattle, sheep and goats are adapted to this zone. Lithosols, Cambisols, and Fluvisols are the major soil units of the zone (Ministry of Land Water and Environment, 1997).

1.7 Present land use

According to the FAO Production yearbook (FAO, 1997) the estimated present land uses of Eritrea are presented in Table 1.6. These data is subjected to some errors because they are estimated data not the exact count on the available land use. The possible meanings of the land use categories, which were used by FAO during the preparation of the book, are given below.

Table1.6 Land use of Eritrea (FAO, 1997)

Land use	**Area(1000ha)**
Arable and permanent crop	520F
Arable land	440F
Permanent crop	80F
Non arable and permanent	9580F
Irrigation	28F
Land area	10100
Total area	11760

F= FAO estimate

Arable land- includes land under temporary crops (double-cropped areas are counted only once) temporary meadows for mowing or pasture, land under market and kitchen gardens and land temporarily fallow (<5 years). The abandoned land resulting from shifting cultivation is not included in this category. Arable land is not meant to indicate the amount of land that is potentially cultivable.

Land under permanent crop- land cultivated with crops that occupy the land for long periods and need not be replanted after each harvest such as coffee, vines, citrus etc. but excluding land under trees grown for wood and timber.

Non-arable and permanent- any other land not specifically listed under item " arable and permanent crop" e.g. permanent meadows and pastures, forest and woodland, built-on areas, roads, barren land etc. (FAO, 1997).

The dominant cereal crops are sorghum, maize, wheat, pearl millet and barley. Sesame and cotton are grown for commercial purposes. Different fruit (Oranges, mangos, Banana etc.) and vegetables enjoy the weather of Eritrea, and Eritrea was one of the fruit and vegetable exporting countries to Europe and the Middle East in the 1960 and early 1970th (FAO, 1994a). Cattle, sheep, goats and camel are among the important livestock resources of the country.

1.8 Infrastructure

Roads are the main component of infrastructure for successful agricultural production. Most main roads of Eritrea were damaged during the war for independence and also the railway, which used to link the port of Massawa and Agordat via Asmara. After independence, the government put transportation facilities in a priority list and started the rehabilitation programme immediately. Since then, as far as road construction and maintenance is concerned, a lot has been achieved and still continues. Currently the road construction works are in an advanced stage and they have reached the town of Barentu (western low land). The railway construction is in progress and it is left with only some 25km to reach the capital. This shows the determination of the government, but a lot needs to be done to change the situation to normal.

Other secondary roads have also given much emphasis like Dekemhare-Mai Aini, which was identified as one of the potential irrigation area (Hazemo plains and Tseroena). Generally it can be said that, development of infrastructure facilities are very important for quick delivery of inputs to farms and outputs to markets. In addition to roads, improving the market situation for local and international trade is very important and Eritrea is a country with two seaports and these can play important roles in developing the agricultural situation in the country.

1.9 Land tenure system

After independence Eritrean land policy was based on three basic framework legislation, Proclamation n. 58/1994 of 24th August 1994, Proclamation n. 95/1997 of 19th May 1997 and Legal notice n. 31/1997 of 19th May 1997. The general features of this framework legislation can be summarised as follows:

* All land is owned by the state; therefore, every legal right on land must be granted by the Eritrean government.
* The law recognises three main types of land rights: usufruct on land in farm, housing land in rural areas and leasehold.

* Rights can not be transferred, except where expressly provided for by law. Illegal transactions are null, void and punishable as a crime.
* The Land Commission through its local branch, the Land Administration Body (LAB), will grant all rights on land. The Land Commission was originally intended to be an independent authority but was eventually incorporated into the Ministry of Land, Water and Environment.

Expropriation can be ordered only for proposes of development and capital investment projects aimed at national reconstruction or other similar purposes. Compensation for expropriated land is to be paid in cash or in kind after the two parties have agreed on the amount (Castellani, 2000).

1.10 Conclusion

Eritrea is a country that came into existence after 30 years of war against Ethiopia and it was officially declared a nation on the 24th of May 1993. It is a young country with 3.9 million people. The country's natural resources, like many other sub-Saharan countries, are not abundant, especially its rainfall. Generally it can be said that, the total annual rainfall tends to increase from north to south; from less than 200 mm at the north to over 700 mm in restricted areas on the southern border. Because of this, Eritrea is one of the countries categorized as a drought prone nation according to the UN.

The only existing soil map is in a small scale of the FAO and this doesn't tell much concerning the conditions of soils in Eritrea. Eritrea is divided into six agro-ecological zones depending on climate, landscape, soils and vegetation cover. This classification is important in directing a detailed resource survey that can help in the identification of suitable areas of land for a particular purpose.

From the available reports of the FAO, Ministry of agriculture and Ministry of Land, Water and Environment there is not enough data to suggest that proper resource surveys and land evaluation specifically for Eritrea have been conducted. To elaborate this the agro-ecological report of the Ministry of Land, Water and Environment

(1997) states that " It is important to recognize that the agro-ecological zone map has been compiled on the basis of existing data, with relatively limited field checks. Some of these data, particularly that related to soils, is of questionable accuracy, and there remains a clear need for systematic surveys of soils and other natural resources to be carried out". From this statement one can understand the shortages of data for proper planning and this project is to highlight the need for such resource surveys for evaluating the land according its capacity to be used with out eroding and degrading the environment. In the next chapters the importance of land evaluation, suitability and capability classifications and their differences, major land capability and suitability classifications of the world and finally a land suitability classification strategy for Eritrean situation will be proposed.

CHAPTER TWO: LAND EVALUATION

2.1 Introduction

Decisions on land use have always been part of the evolution of human society. In the past, land use changes often come about by gradual evolution, as the result of many separate decisions taken by individuals based on past experience (Mather, 1986). On the other hand, in the over populated and complex world of today, they are resulted from the process of land use planning. This practice of planning takes place in both the developed and developing countries. It can be said that, the essence of planning is to put environmental resources to new kind of productive use. The FAO Framework for Land Evaluation (FAO, 1976) stated that; the function of land use planning is to guide decisions on land use so that natural resources are put to the most beneficial use for present, whilst at the same time conserving those resources for the future use.

Land resources are gifts of nature, and they are described in strictly scientific terms; they give no indication on how they should be used. Land qualities, are used as a means for showing the direct link between the land as an ecological complex and the biological and technological activities of land use. Land qualities may, therefore, be used as diagnostic criteria for land suitability, but they do not themselves indicate suitability. Land qualities are very important in indicating how a land, with given natural (resource) characteristics could be used for a given land utilization type. They do not, however, indicate if one land utilization type would be better on a particular kind of land than another. They can also indicate improvement needs, but they do not show suitable improvements to execute for future land utilization type. Therefore, a systematic land evaluation is necessary for the purpose of judging 'land suitability' both for land use and for land improvement (Vink, 1975,). But what is land evaluation?

2.2 What is Land Evaluation?

Vink (1975), citing Brinkman and Smith (1973), defines land evaluation as "the process of collating and interpreting basic inventories of soil, vegetation, climate and other aspects of land in order to identify and make a first comparison of promising land use alternatives in simple socio-economic terms". Dent and Young (1981) said that land evaluation is the process of estimating the potential of land for alternative kinds of use. These include productive uses, such as arable farming, livestock production and forestry, together with uses that provide services or other benefits, such as water catchment areas, recreation, tourism and wild life conservation. As FAO (1976) stated it, sometimes land evaluation may be concerned with present use of the land but most frequently it deals with change and its effects in the future i.e. with change in the use of land and in some cases change in the land it self.

Almost every activity of man uses land and, as the population number increased and activities multiplied, land has become a scarce resource. Decisions to change the use of land could have advantages and disadvantaged, (e.g. economic or environmental). Decision making about land use could also result in political unrest, often raising strong emotions and mostly determined by the social and economic situation of the people (McRae and Burnham, 1981). It is obvious that crop production, grazing by livestock, forestry and recreation call for different qualities of land, but their requirements are not the same (i.e. one require more than the other). As Young (1998) suggested, the general essence of land evaluation is to compare kinds of land use with types of land. It answers questions of two kinds:

1. Here is an area of land; what is the best use to which it can be put?
2. If one want to expand the existing uses, where are the best areas on which to do it?

Questions of the first kind arise when the planning objective is to improve the living standard of a region as a whole, by any kind of development which is found to be most appropriate. It can also be used at national level planning to identify priority areas for different kinds of development. Questions of the second kind apply where the objectives are to find areas for development of specified kinds of land use, such as small scale coffee cultivation, irrigation projects or poultry farms. In these circumstances, the need is to find which areas of land will support such uses, and those that can not support it.

According to Dent and Young (1981) land evaluation demands information from three sources: land, land use and economics. Data on land can be collected through natural resource surveys, including soil surveys. Information on the ecological and technical requirements of different kinds of land use is obtained from agronomy, forestry and other relevant disciplines. Depending on the objectives of the evaluation, economic data are required. For physical evaluation, the economic data needed are only concerned broad features of the economic and social context, e.g. general wage levels, the extent of mechanization, size of land holdings etc. But for economic evaluation, the data on specific costs and prices are needed (McRae and Burnham, 1981).

Evaluation procedures compare relevant kinds of land use and their requirements with land mapping units and their qualities (Dent, 1986). Davidson (1980) suggested that, in the process of evaluation, assessment of physical characteristics is not enough, but the exercise should be extended to the point where economic feasibility, social consequences and environmental impacts of the proposed use should also be analysed. In addition McRae and Burnham (1981) noted that land varies greatly in topography, climate, geology, soil and vegetation cover, so a clear knowledge of the opportunities and limitations presented by these relatively permanent factors of the environment is vital. Land evaluation concerned with these opportunities and limitations and tries to translate the information collected about land into a form usable by land users.

2.3 Definitions of important concepts

The following definitions of important concepts are adopted from FAO (1976) where it is taken from other source the reference is stated on the corresponding definition.

Land: is an area of the earth's surface: the characteristics of 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 underlying geology, the hydrology, the plant and animal populations, and the results of past and present human activity, to the extent that these attributes exert a significant influence on the present and future uses of land by man.

Soil: is a natural body consisting of layers or horizons of mineral and/or organic constituents of variable thickness, which differ from the parent material in their morphological, physical, chemical, and mineralogical properties and their biological characteristics (Davidson, 1980).

Land mapping unit: is a mapped area of land with specified characteristics. They are defined and mapped by natural resource survey, and form a basis for evaluation.

Major kind of land use: is one of the few major sub-divisions of rural land use, such as rainfed agriculture, irrigated agriculture, extensive grazing, forestry and recreation.

Land utilization type: is any use of the land defined in greater detail than a major kind of land use. It, for example, refers to a specific crop under a specific management system. Factors that should be considered during formulation of land utilization are presented in appendix 7.

Multiple land use: land use consists of more than one kind of uses simultaneously undertaken on the same land, e.g. livestock grazing within a tree-crop plantation.

Compound land use: land use consists of more than one kind of use undertaken on areas of land which are treated in the evaluation as a single unit, e.g. mixed arable-livestock farming.

Land quality: is a complex attribute of land which act in a manner clearly distinct from the actions of most other land qualities in its effluence on the suitability of land for a specific kind of land use.

Land characteristics: are those properties of land that can be measured or assessed without excessive effort e.g. topographical, meteorological and ecological information.

Land suitability: refers to the potential of a land for a defined use or practice, e.g. suitability for carrot growing.

Land capability: refers to the range of uses of a land e.g. for agriculture, forestry, recreational development etc.

Current suitability: refers to the suitability for a defined use of land in its present condition, without major improvements.

Potential suitability: refers to the suitability, for a defined use, of land units in their condition at some future date, after specified major improvements have been completed where necessary.

Minor land improvement: Improvements that have small effect, or less permanent, or do not require large capital investment.

Major land improvement: is one which involves a substantial and reasonably permanent improvement in the qualities of land, and which requires a large capital expenditure.

Prime farmland: is the land best suited for producing food, feed, forage, fibre and oil seed crops, and also available for these uses (the land could be crop land, pasture land, forest land or other land, but not urban built-up land or water).

Unique farmland: is land other than prime farmland that is used for the production of specific high-value food and fibre crops. It has the special combination of soil quality, location, growing season and moisture supply needed to produce sustained high quality and/or high yield of a specific crop when treated and managed according to modern farming methods e.g. citrus, olives and vegetables.

2.4 Functions of land

Land and people are the two most basic resources. But human beings are ever inclined to stress the importance of human resources, so it is important to acknowledge the essential roles land resources play in supporting our existence and our day-to-day activities (Barlowe, 1986). Lichfield and Drobkin (1980) noted the role of land resources by stating that it is common place for all which makes it unique, in the sense of being significantly different from all other aspects of economic, social and political life and it is a platform for all human activities. According to Young (1998) land comprises all elements of the physical environment to the extent that these influence potential for land use. Thus land not only refers to soil but also includes the relevant features of geology, landforms, climate and hydrology, the plant cover, fauna, including insects and micro fauna associated with diseases.

On the other hand Davidson (1992) indicated that physical results of past human activities, such as vegetation clearance and reclamation from the sea, are included within the concept of land. Unfavourable consequences from past use, such as eroded soils and degraded vegetation, must also be included. Economic and social features, however, whilst taken into account in evaluation procedures, are not part of land.

The first use of land which comes to mind is as a means of production for agricultural and forestry, together with urban settlement. But according to Young (1998) and FAO (1999), there are a number of functions which land can offer to human society, putting the production first, these functions are as follows:

I. Production based on plant growth: production of food, animal fodder, fibres, timber and fuel-wood, by means of agriculture, forestry and fresh water fisheries.
II. Regulating of the storage and flow of surface water and groundwater.
III. Conservation of bio-diversity and habitats: ecosystems, plant and animal species and genetic resources.
IV. Storage and ongoing supply of non-renewable resources: fuels, minerals and non-biotic raw materials.
V. Functions related to human activities: housing, industry, transport and recreation.
VI. Waste disposal: receiving, filtering and transforming the waste products of settlement.

VII. The heritage function: preserving natural sites of interest and beauty and evidence of cultural history

Some of these functions seem to be mutually exclusive, but even in apparently single-purpose uses, there is a degree of multiple function e.g. cereal crop production contribute to atmospheric and hydrological regulation, urban areas include appreciable areas of trees, grass and crop and animal production.

2.5 Principles of land evaluation

The objective of land evaluation is to judge the value of an area for defined purposes. For evaluation to be based on some common line it is necessary to develop a certain kind of guideline. To help this the FAO Framework (1976) established six main principles that should be followed during evaluation for a specific use. These are:

1. *Land suitability is assessed and classified in relation to a particular land use*. This principle recognises that land uses vary in their requirements so that a field highly suitable for one crop may be unsuitable for another.
2. *Evaluation requires a comparison of the input needed and output obtained on different types of land.* This could be done by comparing the costs of production with the economic returns of different types of land.
3. *A multidisciplinary approach is required.* Contributions from such specialists as crop ecologists, agronomist, pedologists, climatologists, economists and sociologists are vital in order to make a comprehensive and sound assessment of land suitability for a specified use.
4. *The evaluation is made with careful reference to the physical, economic and social context of the area under consideration.* It is fairly obvious that any land use proposal has to be realistic for an area. It is important to take into account such factors as cost of available labour and skills of the labour force and the environmental impact of any change and acceptability by the community.
5. *Suitability refers to use on a sustained basis*. The proposed use of land must not result in its degradation through processes such as wind erosion, water erosion or salinization.

6. *Evaluation involves comparison of more than a single kind of use*: The comparison could be between different land uses or between individual crops. Sometimes it includes comparing the existing practice with the proposed new land use. Evaluation is only effective if benefits and inputs from any given kind of use can be compared with a least one, and usually several different alternatives. This is because, if only one kind of use is considered, there is a problem that, whilst the land may be suitable for that use, some other and more important use may be ignored.

2.6 Purposes of land evaluation

According to Dent and Young (1981), the major purpose of land evaluation is to predict the consequences of change. For instances if a farmer is already growing maize or barley, he can simply assess the production from records of his own costs, yields and returns without formal evaluation procedures. Land evaluation becomes necessary where the change is contemplated. These may include change in kind of use, such as bringing into production land formerly under natural vegetation or establishing a recreational park; or it may be the introduction of new technology, such as supplementary sprinkler irrigation, the introduction of mechanized farming in areas of manual and animal labour. Prediction is needed of the suitability of the land for different forms of production, the inputs and management practices needed, the production or other benefits, and the consequences of such changes upon the environment. These include adverse consequences, such as the warning that certain land should not be cultivated owing to a severe hazard of soil erosion. McRae and Burnham (1981) cited the example of the United States where all soil survey reports present yield predictions for the crops commonly grown in each map unit.

2.7 Types of land evaluation

The results of land evaluation may be presented in terms of qualitative, quantitative physical, or economic.

2.7.1 *Qualitative land evaluation*

This is one way in which the result of land evaluation is expressed and according to Singer, Tanj and Snyder (1978), it results in the ranking of the land areas for specific use. The suitability of land for alternative purposes is expressed in qualitative terms only, such as highly suitable (S1), moderately suitable (S2) or marginally suitable (S3) or not suitable (N) for a specific use. Economic considerations are necessarily present as a background to differentiate the boundary. There are, however, no calculations based on specific costs and prices, although the boundary between land assessed as suitable and not suitable for a given purpose is set what is roughly estimated to be that between profit and loss.

Qualitative evaluation is used mainly in surveys at a reconnaissance scale, or as a preliminary to more detailed investigations and these help to indicate the general potential of the land for a specific use (Rossiter, 1994).

2.7.2 *A quantitative physical evaluation*

This is used to provide quantitative estimates of the production or other benefits to be expected, e.g. crop yield, beef or poultry production, rates of timber growth etc. To achieve this it is necessary to specify the inputs also in quantitative forms, e.g. tonnes of fertilizer, man-days of labour, pesticide treatments. Some approximate calculations of costs and prices are often made, in order to decide appropriate levels of inputs on which to base the estimates. Quantitative physical evaluation is most frequently carried out as the basis for economic evaluation. The shortcoming with this type of evaluation is that it does not normally supply a basis for comparison between different forms of production (Dent and Young, 1981).

2.7.3 *Economic evaluation*

This is purely economic which deals with profit and loss, for each specified enterprise on each kind of land. Specific money values are applied to data from quantitative physical evaluation, thereby obtaining the cost of inputs and value of production. It should be stressed, however, that an economic evaluation is by no means exclusively confined to considerations of profit and loss. Other consequences, e.g. environmental and social, are also set out among the results, to be combined with the economic data as a basis for taking decision (McRae and Burnham, 1981). Figure 2.1 can be used to explain the process of economic land evaluation in a very simple way.

Input/output prices have a direct effect over economic evaluation. E.g. the increase in costs of input (e.g. fertilizer) can make an area to be currently not suitable (N1). On the other hand the price increase of some inputs (e.g. coffee) can transfer currently not suitable (N1) land to marginally suitable (S3) land. This is because the boundary between S3/N1 is purely economic (Rossiter, 1994). Therefore, economic evaluation needs to be updated with the current input and output costs.

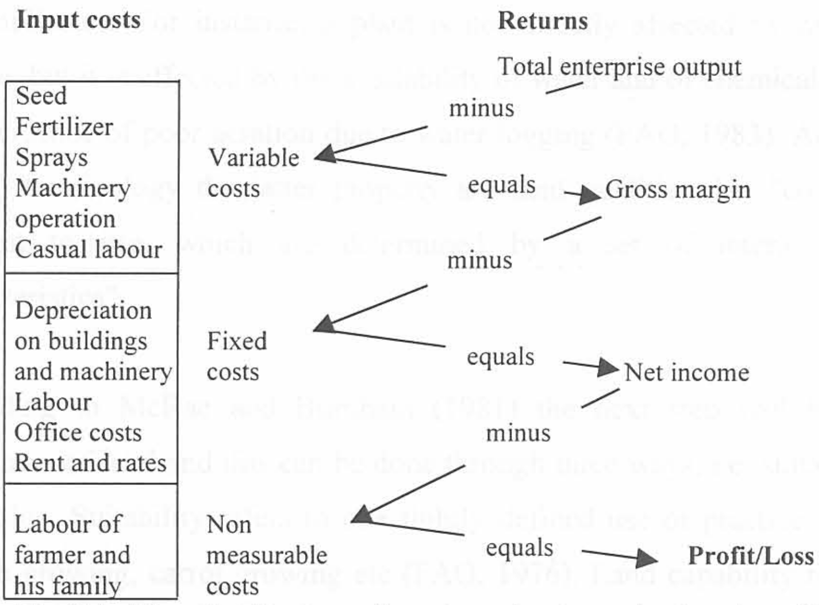


Fig 2.1: The distribution of costs and returns in farming (from McRae and Burnham, 1981)

2.8 Methods and strategy of land evaluation

2.8.1 Methods of land evaluation

Land may be evaluated **directly**, by trials i.e. by growing the crop and measuring the results. Strictly speaking, this type of evaluation is applicable only to the specific trial sites and for that particular use. Direct evaluation is of limited value unless the evaluator has the resources to collect a large amount of data. Most of the time existing data are always biased and tend to be inadequate and they are open to challenge. Thus most land evaluation systems are **indirect**, they assume that certain soil and site properties influence the success of a particular land use in a reasonably predictable manner, and that the quality of land can be deduced from observations of those properties (McRae and Burnham, 1981).

Indirect land evaluation has six steps, representing successive interpretative stages (Figure 2.2) (McRae and Burnham, 1981). The first interpretative stage must ascertain which land properties are likely to be relevant and can be measured or assessed without excessive effort, and then to measure or assess them, such properties are called land characteristics. Data concerning these are collected from soil surveys, including topographical, meteorological and ecological information.
The effect of these land characteristics on systems of land use is seldom direct and uncomplicated. For instance, a plant is not directly affected by rainfall or by soil texture, but it is affected by the availability of water and of chemical nutrients and by the incidence of poor aeration due to water logging (FAO, 1983). According to FAO (1976) terminology the latter property are land qualities, i.e. "complex attributes, relevant to use, which are determined by a set of interacting single land characteristics".

According to McRae and Burnham (1981) the next step will be to assess the usefulness of land and this can be done through three ways, i.e. suitability, capability and value. Suitability refers to one tightly defined use or practice, e.g. suitable for banana growing, carrot growing etc (FAO, 1976). Land capability refers to range of uses, e.g. for agricultural, forestry or recreational development (Davidson, 1981). The concept value involves a monetary or similar basis. The final step and the end product of indirect land evaluation is a decision on optimal land use, whether private "shall I plant an banana in this field?" or public "On which site shall we build this new factory"?

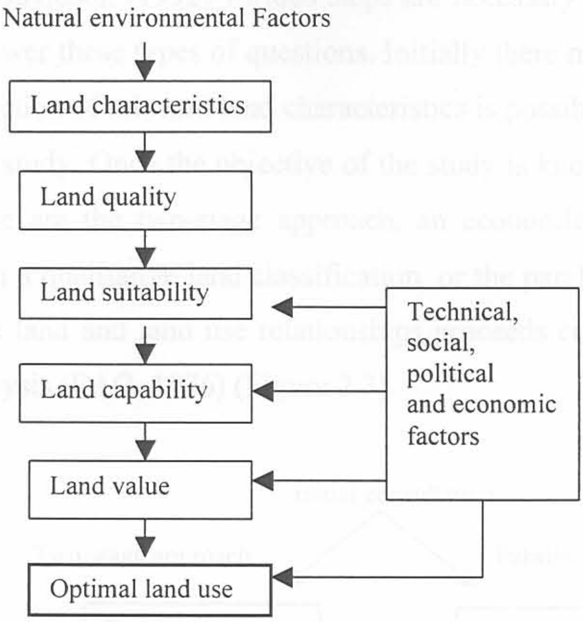


Fig 2.2 The stages in indirect land evaluation (from McRae and Burnham, 1981)

2.8.2 Approaches to land evaluation

FAO framework (1976) proposes that any land evaluation project should be able to answer questions of the following type:

1. How is the land presently managed, and what will happen if present practices do not change?
2. What improvements in management practices, within the present use, are possible?
3. What other uses of land are physically possible and economically and socially acceptable?
4. Which of these uses offer possibilities of sustained production or other benefits?
5. What negative effects i.e. physical, economic or social are associated with each use?
6. What kinds of inputs are necessary to bring about the desired production and reduce the adverse effects?
7. What are the benefits of each forms of land use?

According to Davidson (1992) various steps are necessary in order for an evaluation exercise to answer these types of questions. Initially there must be a clear objective of the study. Selection of relevant land characteristics is possible only with in the context of a particular study. Once the objective of the study is known, two approaches could be used. These are the two-stage approach, an economic and social analysis may follow on from a qualitative land classification, or the parallel approach, in which the analysis of the land and land use relationships proceeds concurrently with economic and social analysis (FAO, 1976) (Figure 2.3).

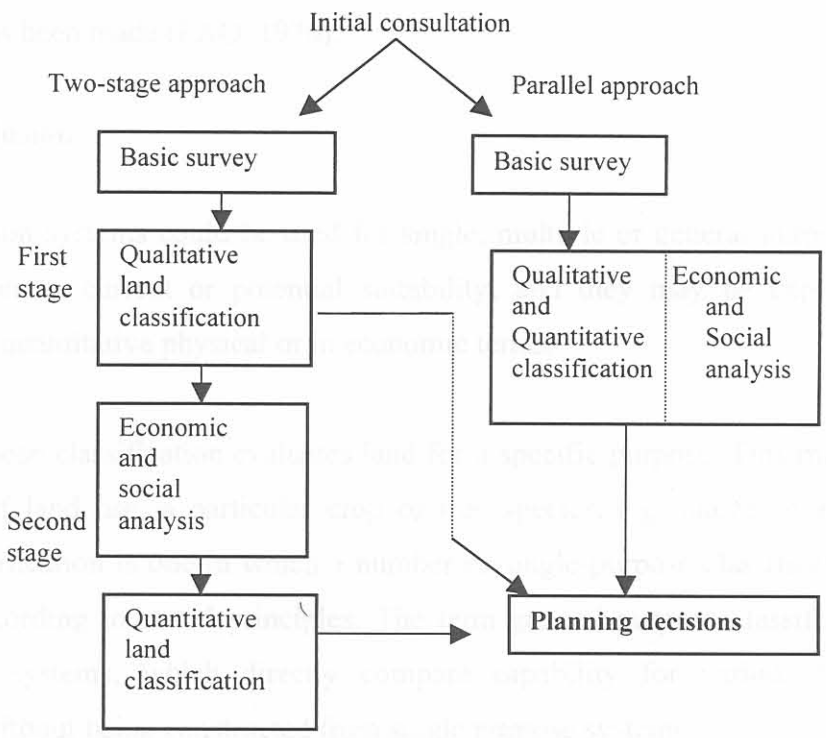


Fig 2.3 Two-stage and parallel approaches to land evaluation (from FAO, 1976)

2.8.3 Levels of intensity

Three levels of intensity are distinguished i.e. reconnaissance, semi-detailed and detailed. These are usually reflected in the scales of resulting maps (Young, 1976).

Reconnaissance surveys deals with broad inventory of resources and development possibilities at regional and national level (Dent and Young, 1981). Evaluation is qualitative with very general economic analysis. The result from this type of survey leads to selection of development areas and priorities at national scale.

Surveys at the semi-detailed, or intermediate, level are concerned with more specific aims such as feasibility studies of development projects (FAO, 1976). Land evaluation is mostly quantitative. This level provides information for decision on the selection of projects, or whether a particular development project or other change is to go ahead. On the other hand detailed level covers surveys for actual planning and design, or farm planning and advice, usually carried out after the decision to implement has been made (FAO, 1976).

2.9 Conclusion

Land evaluation systems could be used for single, multiple or general purpose; they may also refer to current or potential suitability; and they may be expressed in qualitative or quantitative physical or in economic terms.

A single-purpose classification evaluates land for a specific purpose. This might be a major kind of land use, a particular crop or tree species, e.g. maize. A multiple-purpose classification is one in which a number of single-purpose classifications are combined according to stated principles. The term general-purpose classification is reserved for systems, which directly compare capability for various land use alternatives without being constructed from single purpose systems.

Current land suitability is the potential of land in its present condition, with recurrent inputs (e.g. fertilizer) and minor land improvements (e.g. stone clearance) but without major improvements. Potential land suitability is the potential of the land at some future date that is after major improvements have been carried out.

Major land improvements are those which need a substantial non recurrent input of capital, which can rarely be financed or executed by an individual farmer, and which would cause a significant and reasonably permanent change to the land characteristics, e.g. drainage, reclamation, and irrigation. On the other hand, minor land improvements can be financed by the individual farmer from his own resource or short-term loans and cause no substantial permanent change e.g. bush clearance or simple soil conservation works.

Qualitative land evaluation systems give the suitability of land in general physical terms. It specifies the inputs and the production from the forms of land use under consideration; economic conditions are taken into account but as a general background only. Economic evaluation systems assess land suitability in terms of costs of inputs and value of production. In the next chapter attempt will be made to distinguish between suitability and capability classifications. The most important factors that need to be considered during the process of land evaluation will also be discussed.

CHAPTER THREE: LAND SUITABILITY AND LAND CAPABILITY CLASSIFICATIONS

3.1 Introduction

McRae and Burnham (1981) indicated that suitability and capability are not the same but they have often been confused or even regarded as identical. Suitability is always used for specific production e.g. onion production, while capability is used in a broader sense, such as agriculture or urban development. Thus suitability assessment has a sharp focus, looking for areas possessing the positive features associated with successful production or use, where as capability must be vaguer, and is often defined in terms of negative limitations which prevent some or all of the individual activities being considered.

In developing a suitability and capability classification, technical data from agronomy, forestry and others are used. Socio-economic factors are very important to consider. These, range from easily quantifiable geographical circumstances (position in relation to settlement, transportation, and other human activities) to political and administrative decisions like eligibility for planning permission and such unquantifiable factors such as the availability of managerial skill or the existence of religious constraints (Young, 1976; Dent and Young 1981).

3.2 Land suitability classification

Land suitability is the fitness of a certain area of land for a specific use (Vink 1975; Young 1976; Dent and Young 1981; Davidson 1992). According to Vink (1975) differences in the degree of suitability are determined by the relationship (actual or potential) between inputs required and outputs gained from a particular land used for a specific use. For the purpose of judging 'land suitability', both for land use and for land improvement, a systematic land evaluation is necessary. Land evaluation, therefore, links the gap between the physical, biological and technological means of land use and its social and economic purposes. Land evaluation is not economics, but neither is it a purely physical disciplines; it is the utilization of social and economic parameters in evaluating physical data. In its most quantitative form, land suitability is expressed in economic term of input and outputs, or in its result as net income.

Vink, (1975) stated that two main sets of assumptions about land conditions could be used to interpret land suitability from land resource maps. These are:

- The suitability of land unit for the use in question in its present condition, without major land improvement, i.e. *actual land suitability*.
- The suitability of land unit for the use in question at some future date after major land improvements have been effected where necessary, *potential land suitability*.

3.2.1 Structure of the classification

According to the FAO Framework (1976) there are four categories or levels of classification: land suitability orders, classes, sub-classes and units (Table 3.1). These suitability classes are assessed separately for each land-mapping unit in the survey area.

Table 3.1 structure of land suitability classification

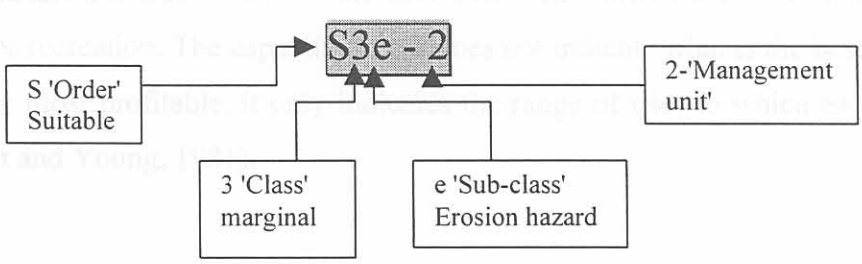
Order	Class	Sub-class	Unit
S (suitable)	S1 S2 S3 etc.	S2m S2e S2me etc.	S2e-1 S2e-2 etc.
Sc (conditionally suitable)		Sc2m	
N (not suitable)	N1 N2	N1m N1e etc.	

Suitability order: This separates land assessed as 'suitable' (S) from that which is 'not suitable' (N) for the use under consideration (FAO, 1976). According to Dent and Young (1981), there are three main reasons why land may be classified as not suitable. These are, the proposed use could be technically impracticable, e.g. cultivating very shallow or rocky soils; or is environmentally undesirable, e.g. would lead to severe soil erosion; or is economically unprofitable, the income from estimated production being less than the cost of the required inputs.

Suitability classes: These are divisions of *suitability orders* that indicate the *degree* of suitability i.e. highly suitable (S1), moderately suitable (S2), marginally suitable (S3), unsuitable for economic reasons but otherwise marginally suitable (N1), unsuitable for physical reasons (N2). N2 implies limitations that can not be corrected at any cost within the context of the land utilization type. In *physical* evaluations, S3 and N1 are combined into 'S3/N1' because the distinction between these is purely *economic* (cost/benefit of overcoming the limitation). The limits between S1 and S2, S2 and S3/N1 are arbitrary or based on single-factor yield reductions. In *economic* evaluations, the limits between S1 and S2, S2 and S3, and S3 and N1 are made on the basis of predicted economic value (Rossiter, 1994).

Suitability subclasses: These are divisions of suitability classes which indicate not only the degree of suitability (as in the suitability class) but also the nature of the limitations that make the land less than completely suitable. So, suitability class S1 has no subclasses. The subclass code consists of the suitability class code, followed by a suffix, which indicates the nature of the limitations. There is a suggested list of suffixes in some of the guidelines (FAO, 1976 and McRea and Burnham, 1981). E.g. 'S3e': marginally suitable (S3) because of erosion hazard (e), 'S3w': marginally suitable (S3) because of wetness ('w) etc.

Suitability units: These are divisions of suitability subclasses, designated by numbers within subclasses, e.g. 'S3e-3', which are meant to be managed similarly. These have different management requirements, but the same degree of limitation and the same general kind of limitation (because they are divisions of subclasses). E.g. 'moderate' fertility limitations, but one management unit may require extra K and another extra P. The hierarchical nature of the suitability classification can be presented as follows (Rossiter, 1994).



3.3 Land Capability Evaluation

Capability refers to general kinds of land use and used to allocate land rationally to the different kinds of land use required i.e. rotational arable, permanent grazing, woodland etc. The main product of land capability classification is a map in which areas of land are put into capability classes ranging from I (best) to VIII (worst) (Rossiter, 1994). It was first developed by Klengebiel and Montgomery (1961) in the USA and is mainly conservation oriented. The reason why an area is allocated to a given class is indicated by a letter suffix; thus sub-class IIe indicates an erosion hazard, IIw a problem of excess water. Each class of land has the potential, or capability, for use in a prescribed number of ways, or with specified management techniques. Thus class I land can be put to arable use without soil conservation measures whilst classes II to IV require increasingly costly conservation practices; classes VI to VIII should not be used for arable use (Dent and Young, 1981).

3.3.1 Concepts and assumptions

There are two concepts that are basic to the system. These are capability and limitations. The potential of the land for use in specified ways or with specified management practices is called capability (Davidson, 1992). There is a sequence of assumed uses built into the system. These are as follows: (a) arable use for any crops and without soil conservation practices; (b) arable use with restrictions on choice of crops/or with soil conservation practices; (c) grazing of improved pastures; (d) grazing of natural pasture or, at the same level, woodland; (e) and at the lowest level, recreation, wildlife conservation, water catchments and aesthetic purposes (Dent and Young, 1981).

Land that is allocated to any particular capability class has the potential for the use specified for that class and for all classes below it. Thus class I land, whilst excellent for arable use, can equally be put to any of other uses; class VI land is suited for improved pasture but also be any of the uses below it, whilst class VIII land can be used only for recreation. The capability class does not indicate what is the best use for land, nor the most profitable, it only indicates the range of uses to which each could be put (Dent and Young, 1981).

Limitations are land characteristics, which have an adverse effect on capability (McRae and Burnham, 1981). Permanent limitations are those which can not easily be corrected. Temporary limitations can be corrected, at least by minor land improvements. Land is classified mainly on the basis of permanent limitations (FAO, 1976). The general rule is that if any one limitation is of sufficient severity to lower the land to a given class it is allocated to that class, no matter how favourable all other characteristics might be. Thus it is use less to have level land, well drained and free from flooding, if it only has 10cm of soil which is too shallow to practice any crop production. Dent and Young (1981) indicated that this type of classification emphasizes the negative features of land, which are taken into account in assigning different types of land to capability classes. Soil erosion hazard, and hence conservation requirements, normally gets more attention.

3.3.2 Structure of the classification

Three categories are used i.e. capability classes, sub classes and units (Davidson, 1992). If the classification is based on soil survey, that is, not upon direct survey for capability, the capability units are themselves groupings of soil mapping units and most of the time the system is often applied without identifying capability units (Mather, 1986).

Capability class: a general degree of 'goodness' in the sense of 'possible intensity of use': I (best), VIII (worst). Roman numerals I, II, VIII are used to indicate the capability class and the restriction on kinds of land use and management needs increases from class I to class VIII (Rossiter, 1994) (Table 3.2).

Table 3.2 Structure of land capability classification (From: Davidson, 1992)

	Capability class	capability sub class	capability unit	mapping unit
	I	IIe-erosion	IIe-1	P-series
Arable	II	IIw-wet ness	IIe-2	Q-series
	III	IIs-soil	IIe-3	R-series
	IV	IIc-climate	etc	
	V	etc		
Non Arable	VI			
	VII			
	VIII			

The risk of soil erosion increases through class I to IV, progressively reducing the choice of crops and requiring more expensive conservation practices and more careful management (Dent and Young, 1981). Class I-IV can conveniently be thought of as "very good", "good", "moderate" and "marginal" arable land respectively. Class IV should only be used for arable purposes if very carefully managed. Class V is allotted to land rendered unsuitable for cultivation by reasons other than erosion hazard, e.g. wetness or excessive stoniness.

Classes VI-VIII are precluded from arable use by very severe permanent limitations (McRae and Burnham, 1981). For most part they have steeply sloping land. Class VI can be managed under improved pasture, class VII only under rough grazing or woodland, whilst class VIII cannot be used for commercial plant production of any kind, except recreation.

Capability subclass: indicates the major limitations, by the use of one or more letters. USDA subclasses: 'e' = erosion hazard, 'w' = excess water, 's' = soil limitations within the rooting zone (includes shallowness, stones, low native fertility difficult to correct, salinity), 'c' = climatic limitations (temperature or rainfall). Class 1 has no subclasses (Rossiter, 1994).

Capability unit: a division of the subclass that have nearly identical potential, limitation and management requirements (Davidson, 1986). The degree and general type of limitations are the same in a subclass, but there may be important management differences, for this reason, it should be separated on the capability map and in the recommendations table. For example, class IIIs could be due to excess gravel in the root zone or excess salts; one could assign these unit codes 'IIIs1' and 'IIIs2' respectively (Rossiter, 1994).

3.4 Information needed for Land Evaluation

The interaction of two sets of factors influences land uses. These are first, physical factors such as geology, relief features, climate, soil and vegetation, which limit the use of the land, and secondly socio-economic factors. Socio-economic factors represent the length of occupancy of the area, demographic and cultural conditions, institutional framework and the technological levels of the people which determine the extent to which the land can be utilized (Mandal, 1982).

Surveys of land resources i.e. climate, water, soils, landforms and vegetation are necessary to avoid costly mistakes and to improve efficiency of investment (Young, 1998). McRae and Burnham (1981) also suggested that, for indirect land evaluation to succeed information about soil and site properties are crucial. The first task of the land evaluator is to choose the system most appropriate to his/her conditions and needs to determine what kind of data he/she needs in order to implement it. The next step would be to investigate possible sources of data. Suitable data may:

1. Be derived from remote sensing; e.g. air photos or satellite imagery.
2. Existed as maps especially soil maps and topographic maps.
3. Exist as spatially located data, not in map form, e.g. climatic data.
4. Be directly acquired through field observations and measurements, interviews with farmers, etc (McRae and Burnham, 1981).

Finally the data has to be processed and used (Davidson, 1992). Sometimes the processing could be converting data on land characteristics to information on land qualities. The overall strategy of data use is more fundamental and is concerned both with the reliability of the data and ways of extrapolating point source or other spatially dependent data. There are many lists of useful soil and site attributes, but the most important, according Dent and Young, (1981) include:

(a) Soils
(b) Water
(c) Climate
(d) Topography/ Relief
(e) vegetation
(f) Socio-economic data

3.4.1 Soils

The role of soils in nature is complex, many sided and includes biospheric, hydrospheric, atmospheric and lithospheric facets. The properties and attributes of the whole soil body always determine the productivity of soils (with regard to their utilization) (Szabolcs, 1994). As Davidson (1980) puts it "Knowledge of soils is clearly integral to improving the management and output from the existing agricultural area as well as developing new localities". The planning of a new arable area, for example, requires information about the nutrient status of the soil, so that appropriate types and quantities of fertilizer can be proposed. Soil moisture regime in the rooting zone is also critical. Many soils suffer from too much or too little moisture at critical periods during farming season. As Singer *et al.* (1978) suggested it is neither practical nor necessary to expect to have all possible data on soils of an area before making planning decisions. Those characteristics that are most important for planning purpose depend, to some extent, on what use will be made of the land. McRae and Burnham (1981) added that conducting soil surveys and compiling soil maps is expensive, so a soil map should normally be planned to remain useful for several decades.

3.4.2 Water

Next to soil, water is by far the most important land resource which is simultaneously relatively stable, and can therefore provide relatively permanent supplies as well as permanent constrains. In the world fresh water is a scarce resource. Vink (1975) citing Water Resource Council (1970) noted that the use of water recourses and their planning is always closely related to the use of land resources. Water as a resource in land use may be said to be much scarcer than land. For agriculture in developing countries water is a major constraint. This constraint is most acute in arid and semi-arid areas, which constitute over one-third of the entire land surface of the earth (Wallace and Batchelor, 1998). As pointed out earlier, this is also a major constraint in Eritrea.

3.4.3 Climate

The following climatic features have a considerable effect on agricultural land use: (a) temperature, (b) precipitation (c) wind velocity, (d) evaporation and (e) various extremes and hazards.

Of these, the first three are basically independent factors, whereas evaporation is largely a function of the first three factors combined. Relative humidity (secondary factor) also affects agriculture. Evaporation and evapo-transpiration have a great impact on land use, and they must be considered as factors of primary importance. Calculated soil moisture deficits, i.e. the differences between precipitation and potential evapo-transpiration, are more useful than rainfall data alone (McRae and Burnham, 1981). Moisture deficiencies in the plant rise to moisture stress conditions, which could have great detrimental effect on production. Rainfall distribution over season enables the decision-maker to determine the best planting date and therefore allows averting the summer drought, which occur during the most critical period of the crop's development stage (Mbatani, 2000). There are some extreme climatic hazards such as frost, extreme wind velocity or hailstorms that are capable of damaging crops (Vink, 1975).

The amount of moisture needed for a successful crop production is determined from the difference between the total precipitation minus the amount of water evaporated from the surface of the soil and plants i.e. evapo-transpiration. Predicting the amount of evapo-transpiration rate is very important during planning specifically for irrigated agriculture. Because one could determine the amount of water needed to overcome the shortages.

Different methods are used for calculating the rate of evapo-transpiration, depending the climatic data available (Table3.3). Doorenbos and Pruitt (1992) suggested four main methods, these are (a) the Blaney-Criddle, (b) Radiation, (c) Penman and (d) Pan evaporation method. These methods have some accuracy problems, but the Penman method would give best results with minimum possible errors of plus or minus 10 percent in summer, and around 20 percent under low evaporative condition. The pan method is second best with errors of around 15 percent, depending on the location of the pan. The radiation method, sometimes, involves errors of around 20 percent during summer. The Blaney-Criddle method, on the other hand, should only be used for periods of one month or longer. This is because some 25 percent errors have been recorded in certain conditions with humid, windy, mid-latitude winter. For full procedures of each method, reference should be made to Doorenbos and Pruitt (1992). So, calculating the evapo-transpiration rate is very important in determining water deficit and this helps to find alternative solutions to supplement the water shortages.

Table3.3 Climatic data needed during applying different methods for calculating rate of evapo-transpiration (from Doorenbos and Pruitt, 1992).

Method	Temperature	Humidity	Wind	Sunshine	Radiation	Evaporation	Enviro.
Blaney-Criddle	*	0	0	0			0
Radiation	*	0	0	*	(*)		0
Penman	*	*	*	*	(*)		0
Pan		0	0			*	*

* Measured data; 0 Estimated data (*) If available, but not essential

Evapo-transpiration rate is normally expressed in millimeter (mm) per unit time. This indicates the amount of water lost from a cropped surface in units of water depth. The time could be in an hour, day, month or year. For example 10000 m^2 is equivalent to one hectare, and 1 mm is equal to 0,001 m, so a loss of 1 mm of water means a loss of 10m^3 water per hectare. Therefore, 1mm day^{-1} is equivalent to 10 m^3 ha^{-1} day^{-1}.

Energy is also involved in the process of evapo-transpiration. The energy or heat needed to vaporize free water is called latent heat of vaporization (λ) and it is a result of temperature. FAO (1998) gave an example to show the relation between energy needed and the depth of water evaporated. At 20°C, λ is about 2,45 MJ kg^{-1}. This means 2,45 MJ are needed to vaporize 1 kg or 0,001 m^3 of water. Thus an energy input of 2,45 MJ per m^2 is able to vaporize 0,001 m^3 or 1 mm of water, so 1 mm of water is equivalent to 2,45 MJ m^{-2}. The evaporation rate expressed in units of MJ m^{-2} day^{-1} is represented by λ ET (the latent heat flux). Table 3.4 shows the units used to express evapo-transpiration rate and the conversion factors.

Table 3.4 Conversion factors for evaporation (from FAO, 1998)

	Depth mm day^{-1}	Volume per unit area		Energy per unit area * MJm^{-2} day^{-1}
		M^3 ha^{-1} day^{-1}	l s^{-1} ha^{-1}	
1mm day-1	1	10	0,116	2,45
1m3 ha-1 day-1	0,1	1	0,012	0,245
1l s-1 ha-1	8,640	86,40	1	21,17
1MJ m-2 day-1	0,408	4,082	0,047	1

*For water with a density of 1000kg^{-3} and at 20°C

The following example could be used to show how to convert evaporation from one unit to another. E.g. in summer day, a net solar energy received at a dam reaches 20 MJ per square meter per day. If 75 % of the energy is used to vaporize water, how large could the depth of evaporation be?

Solution: From the table, 1MJm^{-2} day^{-1} is equivalent to 0,408mm day^{-1}. Therefore, 0,75*20MJm^{-2} day^{-1} is the same as 0,75*20*0,408 mm day^{-1}= 6,1 mm per day. The depth of water evaporated per day would be 6,1mm.

Climatic data are usually obtained from meteorological stations, maps and/or records of temperature, precipitation, and wind speed. A land evaluator could take his/her own records especially at meso and micro climate level e.g. windiness on sites which might have an exposure problem, or the frequency of frosts where sensitive crops are to be grown.

The relevant temperature regime of an area can be expressed in different ways. These include, the temperature of a period representative of the growing season, the length of frost-free period, or the length of the growing season which is usually taken as the period above a limiting temperature, e.g. 5.6°C or accumulated temperature. Temperature is not a limiting factor in tropical and sub-tropical areas.

3.4.4 Topography

The influence of relief on agricultural land use is massive, and it is one of the most important factors that affect agricultural land use. Its forms and dimensions are primarily associated to geological formations and with the climate, both past and present, which have either direct or indirect influence upon this formation. Agricultural land use is directly affected by the size and shape of the relief forms and with regard to size, relief can be divided in to three i.e. macro, meso and micro relief. As far as relief shape is concerned, as Vink (1975) stated, it can be classified into the following four forms:

(a) Straight, flat, convex and concave.

(b) Long, short (slopes) and aspect (slope direction).

(c) Regular, irregular (slope forms, surfaces).

(d) Narrow, wide (depression, valley).

Aspect (slope direction) influences the amount of radiation a certain area receives and the evapo-transpiration rate. In Eritrea, for example, the sun shines diagonally from the south (because the equator is south of Eritrea). Therefore, the amount of radiation is more on south facing slope than on north facing ones. As a result south facing slopes are warmer than north which result in higher evapo-transpiration rates, drier soils and sparse vegetation with less organic matter accumulation on south facing slopes. Such factors should be considered carefully during the process of suitability evaluation.

All of these factors have a direct impact on land management and may have a considerable significance for land improvement, and they may to a great extent determine whether certain land utilization types are feasible in certain area or not.

3.4.5 Vegetation

Climate is recognized as the major factor influencing the natural vegetation cover. Within each climatic zone, the types of soil and the natural vegetation communities associated with it are a function of the interactions between climate, the underlying geology (and thus the soils) and the indigenous flora. These interactions link vegetation, fauna, soils, hydrology and climate to form the ecosystems characteristic of each climatic zone. There are strong interrelationships between climate, soils and vegetation. These are:

I. Climate, both its nature and seasonality, will have a great influence on the potential erosion hazard to which the soils are subjected, as well as on the ability of vegetation to flourish.

II. Soils, together with the climate, will determine the nature of vegetation that can be supported and thereby also influence the extent to which they themselves can be protected against erosion. It also affects resilience (recovery potential).

III. The vegetation, in turn, provides the basic material with which to implement biological construction techniques to protect the *in situ* soils from the effects of extremes with in the prevailing climatic condition (Coppin and Stiles, 1995). So kinds of vegetation (height, density, distribution and use); orchards and groves (e.g. mango, guava, banana, lemon, papaya and others) should be clearly studied at farm level (Mandal, 1982).

IV. Climate, soil and slope (including aspect and slope position) affect the quality and quantity of the vegetative material produced for extensive grazing (Laker personal communication).

3.4.6 Socio-economic factors

These factors are very important to consider. After all, development without full participation of the local people is not sustainable. Social factors that should be studied include rules, believes, customs, religion, etc. of the people concerned. These give an indication for planners to introduce new practices, which can be compatible to the culture of the community. Otherwise it will not be sustainable.

The economic aspect is the basic indicator of what resources are used and produced in the area and this is the most important aspect of the material life and the way in which the people sustain themselves. Among others farm size, present land use, financial situation of the land user, sources of income, farming enterprises, implements and farm buildings and condition of labour are the most important factors for determining economic condition of land users (Williams, 1998). In the words of Young (1998): " In the final analysis it is people who manage land resources-farmers and local communities. If they do not do so sustainably, then no one else will". From this one can conclude that it is wise to consider socio-economic factors before any development plan is implemented.

3.5 Conclusion

Evaluation results can be presented in terms of land suitability or land capability. In the former, land is classified as suitable or not suitable for particular kind of use. During classification, actual land suitability and potential land suitability could be considered. In the former case, land is classified in its actual state i.e. without any major land improvements, but in the latter case, future land improvements are considered which can improve the condition of the land. This kind of classification can be categorized into order, class, sub-class and units. Where Order indicate the state of suitability (suitable or not suitable), Class indicate degree of suitability (highly, moderately and marginally), Sub-class shows limitations (erosion, moisture stress, climatic etc.) and Units indicate management needs of particular land for specific use.

Land capability classification which originates from the United States Department of Agriculture (USDA) is used to divide land broadly into eight classes, where Classes I-IV can be used for arable agriculture but with increasing limitations and conservation requirement increases from Class I-VIII. Class VIII land can only be used for recreation on the account of high limitation that can never be corrected by any means of improvement. This kind of classification has two concepts to be based on i.e. capability and limitations. Capability refers to the ability of land to be used in specified ways without erosion problems, while limitations are land characteristics which limit the utilization of land for a particular use or increase the cost of improving the condition of the land or conservation practices. This kind of classification has some divisions, i.e. class, sub-class and units. Classes indicate capability of the land, subclass shows the limitations within the land and units indicate the management and other conservation practices needed for that particular land.

Before one can implement the above two types of classification, there are important data that should be collected related to the specific area of land. These include climatic, soil, vegetation, topographic, water availability, and socio-economic data. It is only after these data are collected and analyzed carefully that one is able to classify any piece of land for particular kind of use.

The following chapter looks at the major land capability and suitability classification systems available in the world.

CHAPTER FOUR: MAJOR LAND CLASSIFICATION SYSTEMS OF THE WORLD

4.1 Introduction

It has been said that land is the basic natural resource. Over the span of human history, man has drawn most of his sustenance and much of his fuel, clothing and shelter from the land. Land has been man's habitat and living space. Land has been a matter of life and death, of survival or starvation. That the use of land should have been of major importance to man is, therefore, not surprising (Mather, 1986). Vink (1975) indicated that, as circumscribed by the earth, the area of what is considered to be land is finite and fixed in place. Land uses are subject to control by people, whose numbers are not fixed, who have many needs, and who move easily. According to Davis (1976) some areas of land have certain characteristics that makes it more useful than other land areas. These include **location** and **fitness** of a particular piece of land.

Vink (1975) defines land use as the ability of human being to manage their ecosystem in order to produce some of his needs. This indicates the ability of man to preserve or destroy land; i.e. man has a full control over land. As Spellerberg (1992) noted, large forest areas have been cleared for agriculture and most remaining forests have sadly been damaged in some way. The consequence was increasing erosion and degradation. In addition, in more developed western countries, because of industrialization, the invasion of prime agricultural land was eminent. These problems bring about the need for classification. Dent, (1986) citing Jacks (1946), defines land classification as "the way of grouping of land according to its suitability for producing plants of economic importance".

The foundation of land classification lies in land resource inventories, starting with major geological surveys during the nineteenth century. The development of land capability schemes during the 1930s in the USA marks the beginning of the second major development in the subject, but the widespread adoption of land capability schemes only began after 1960 (Davidson, 1992).

The American work during the 1930s was a response to the serious soil erosion problems which occurred then, especially in the mid-west. The major aim of the classification was to express the risk of erosion and to indicate sustainable land uses. The assessment of land capability involves an evaluation of the degree of limitation posed by permanent or semi-permanent attributes of land to one or more land uses. The US land capability scheme is essentially negative in approach, whereby the degree of limitation to land uses is assessed. This is a marked contrast to the central concept of the FAO Framework for land evaluation in which land units are assessed with reference to the requirements of specific land use (Davidson, 1980, 1992). Because of this negative approach and its lack of quantitative evaluation between different classes, Smyth (1977) suggested that, the land capability system of the US soil conservation service (and all its imitators) is a typical example of static land capability system, which is not suitable for developing areas. But for developed countries such system is good. For instance, Davidson (1992) noted that land capability assessment contributed in a gradual realization that good quality land is of limited and enables for measures to be taken to control it.

The loss of prime agricultural land around Canadian cities through the spread of urbanization and industrialization has been an issue of considerable concern. The preservation of such prime land for agricultural use is a stated objective in many countries (Davidson, 1980).

Different land capability classification systems, mostly imitations of the USDA system, are used in different parts of the world. In this Chapter major land classification systems of the world and the supporting mechanisms, like the FAO agro-ecological zones, crop modelling and application of GIS in suitability evaluation, will be discussed.

4.2 The American System (USDA)

The American system of land assessment goes back to the 1930s, but it come into effect only after 1961 when a comprehensive book was published (Klingebiel and Montgomery, 1961). The Soil Conservation Service of the US Department of

Agriculture evolved the technique and it will be referred to as the USDA method. Integral to the assessment procedure is an evaluation of soil erosion hazard, wetness, soil and climatic limitations. Land capability assessment is based on a broader range of characteristics than soil properties. Information on slope angle, climate, flood and erosion risk as well as on soil properties is required (Davidson, 1992).

According to Mather (1986) the USDA can be used in a number of possible subsidiary applications such as in the field of agricultural credit and the planning of new routes. However, the primary purpose was in the planning of soil conservation work on farms and ranches. The method was geared to producing farm-scale maps, which graded land on the basis of the intensity of soil disturbance that was "safe". For example, very intensive cultivation was a "safe" land use only on Class I land, and cultivation was "safe" on the top four land classes.

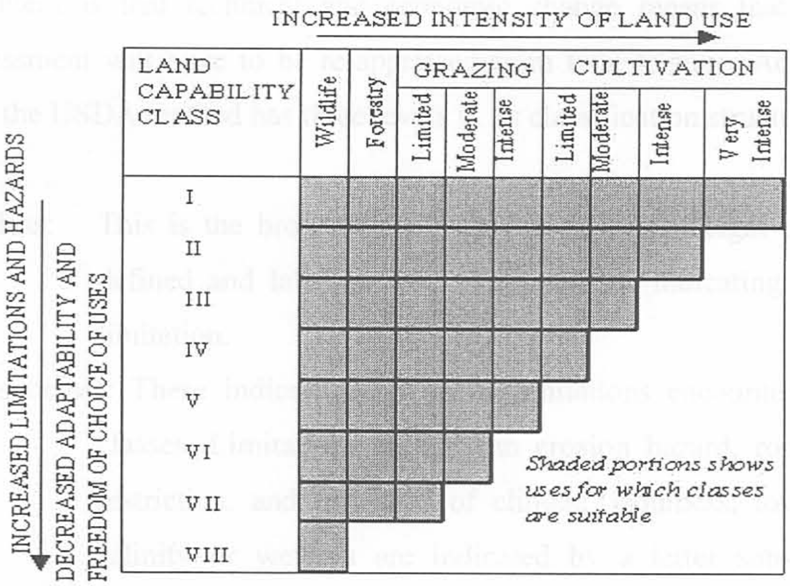


Fig. 4.1:the relation ship between USDA land capability classification Classes and intensity with which each class can be used safely (From: Davidson, 1992)

Davidson (1980, 1992) indicated that the main aim of the method is to assess the degree of limitation of land use or potential imposed by land characteristics on the basis of permanent properties. A scale of land capability grades can thus be envisaged with the degree of limitation and hazard defining the class. This concept is illustrated in Figure 4.1 with the eight classes of the USDA method. As the degree of limitation increases, the range of land use options decreases.

It is very important to comment on the nature of the limitations, i.e. whether it is permanent or temporary. This is mainly because some limitations could be easily corrected which increases the value of the land, while others cannot. For example, adding lime can change the pH of a soil. On the other hand, it is impossible or difficult to change limitations that are permanent, like limited soil depth, slope of land, soil texture, type of clay mineral, water holding capacity, etc. If it is not technically and economically feasible to tackle such problems as water lying on the surface of the soil, lack or excess of water in the soil, stones, presence of soluble salts or exchangeable sodium, then these limitations are considered to be permanent. This causes problems in deciding what is technically and economically feasible and an additional problem is that technical and economic change means that any land capability assessment will have to be re-appraised from time to time. According to Mather (1986) the USDA method has three levels in its classification structure:

1. Capability class: This is the broadest category and a total of eight classes are defined and labelled I to VIII inclusive indicating degree of limitation.
2. Capability subclass: These indicate the type of limitations encountered within classes. Limitations such as an erosion hazard, rooting zone restriction, and problems of climate, stoniness, low fertility, salinity or wetness are indicated by a letter subscript. For example, class V with limitations imposed by excess water and climatic characteristics is indicated as Vwc.
3 Capability unit: This is a subdivision of the sub-class. Land in one capability unit clearly includes many different soils but has little variation in degree and type of limitation to land use.

It is important to reiterate the underlying assumption that soils of different types may well be grouped into the same capability class since they share the same degree of limitation. Greater variations in management techniques may be required within capability classes than between classes. Socio-economic factors such as distance to market, types of roads, size and shape of the farm, location with in fields, ability and resources of individual land users, and other characteristics of land ownership are not taken in to account.

Davidson (1992) noted that Classes I to IV can be cultivable while the remaining classes i.e. Classes V to VIII are not. The general characteristics of the eight classes are as follows:

Class I: Soils with few limitations that restrict their use.

Class II: Soils with some limitations that reduce the choice of plants or require moderate conservation practices.

Class III: Soils with severe limitations that reduce the choice of plants or require special conservation practices, or both.

Class IV: Soils with very severe limitations that restrict the choice of plants or require very careful management, or both.

Class V: Soils with little or no erosion hazard, but with other limitations impractical to remove, that limit their use largely to pasture, range, woodland or wildlife food or cover.

Class VI: Soils with very severe limitations that make them generally unsuited to cultivation and limit their use to pasture or range, woodland or wildlife.

Class VII: Soils with very severe limitations that make them unsuited to cultivation and restrict their uses largely to grazing, woodland or wildlife.

Class VIII: Soils and landforms with limitations that preclude their use for commercial plant production and restrict it to recreation, wildlife, water supply or aesthetic purposes.

As Young (1973) suggested and backed by Davidson (1992), the outstanding advantage of the land capability classification is its flexibility, its apparent simplicity and its ease of comprehension by non-specialists. Consequently, the lack of quantitative details on classes, sub classes and units has a distinct merit. But phrases such as "gentle slope", "moderately susceptibility to wind or water erosion", or "less than ideal soil depth" clearly lack precision of definition, thus exposing them liable to diversity of interpretation. McRae and Burnham (1981) stated that implementation of the USDA land capability is very largely subjective since the criteria for class limits are not generally specified. It is, in effect, a formal representation of the best available experience and judgment, and Davidson (1980) said that in the USDA system soil information is visualized as only one set of inputs in order to determine the land capability for a particular land use.

4.3 The Canadian Method

Land capability assessment in Canada was initiated by the Canada Land Inventory (CLI), which was established in 1963 as a result of the Agricultural Rehabilitation and Development Act (ARDA) of 1961 (Mather, 1986; Davidson, 1992). The land inventory was a comprehensive survey of land capability and land use designed to provide a partial base for broad-scale resource evaluation and land use planning (Coppock, 1980). It is best for a broad planning at regional, provincial and national levels. It is a broad or reconnaissance assessment, thus it does not provide sufficiently detailed information at farm level.

As Davidson (1992) described it, the general approach of the Canadian land capability scheme is modelled on the USDA method, although some major differences must be stressed. In addition to the method of land capability classification for agriculture, there are separate land capability schemes for forestry, recreation and wild life. Unlike the USA, the Canadian capability system has seven classes instead of eight. The land capability classes for agriculture can be summarized as follows:

Class 1: Soils with no limitation in use for crops.

Class 2: Soils in this class have moderate limitations that restrict the range of crops or require moderate conservation practices.

Class 3: Soils with moderately severe limitations that restrict the range of crops or require special conservation practices.

Class 4: Soils with severe limitations that restrict the range of crops or require special conservation practices or both.

Class 5: Soils in this class have very severe limitations that restrict their capability to producing perennial forage crops, and improvement practices are feasible.

Class 6: Soils that are capable of producing only perennial forage crops and improvement practices are not feasible.

Class 7: Soils in this class have no capability for arable culture or permanent pasture.

Class 0: Organic soils (not placed in capability classes).

Like the USDA system, letters are used to indicate subclasses. The Canadian method recognises a wider range of limitations than the USDA, but the background assumptions of the Canadian scheme are very similar to those of the USDA (Mather, 1986).

According to Davidson (1992), the most outstanding result from Canada Land Inventory report was the recognition that good quality agricultural land in Canada was limited e.g. only 3,4% of land suitable for agriculture was in the highest capability category with a capability to grow a wide range of crops. Furthermore, good agricultural land occurs in the immediate vicinity of urban centres.

The main objective of the Canada land inventory was the publication of land capability maps. Concurrent with research on land capability during the 1960s was the development of computer methods for handling spatial data. According to Marble (1990), Canada was the first country to produce a fully operational geographic information system called Canada Geographic Information System (CGIS) in 1971.

4.4 Land capability classification in Britain

Davidson (1992) citing Stamp (1962) noted that the first national assessment of land grades in Britain resulted from the land utilization survey in the 1940s. According to this method land was ranked on the basis of land use characteristics and maps at a scale of 1:625000 were published. Such information was general and subjective, but that was the only available information to assist land use planning in the 1950s. Coppock (1980) stated that the assessment of agricultural land in Scotland has its origin in 1943. The Department of Agriculture attempted to prepare a map of the lowland at a scale of 1:10560 that indicate the lands over all quality. The map was consulted during surveying of the northern part of Great Britain but it was never published.

By the 1960s there was the growing realization that a more detailed and up to date assessment of land was needed. As Mather (1986) described it, the Ministry of Agriculture decided that a national series of agricultural land classification maps for England and Wales was required in order that good quality agricultural land could be protected against urban encroachment.

Mather (1986) indicated that the soil surveys of both Scotland and England and Wales adopted the USDA land capability classification and employed it after modification. The original eight classes of the USDA scheme were reduced to seven in the British scheme. The original subclasses were adopted, with the addition of extra ones to denote limitations imposed by gradient (largely in relation to the use of machinery) and soil pattern. In the USDA system the sub-classes were qualitatively defined, but quantitative definitions have been introduced in Britain. For example, Class 3 land is defined as land with gradient not exceeding 11^0, temperature below 14 ^{0}C, rainfall not more than 300mm greater than evapo-transpiration and rooting depth greater than 10 inches (254mm).

Davidson (1992), summarizes the land capability classes of the soil survey scheme of Britain as follows:

Class 1: Land with very minor or no physical limitation to use.

Class 2: Land with minor limitations that reduce the choice of crops and interfere with cultivation.

Class 3: Land with moderate limitations that restrict the choice of crops and/or demand careful management.

Class 4: Land with moderately severe limitations that restrict the choice of crops and/or require very careful management practices.

Class 5: Land with severe limitations that restrict its use to pasture, forestry and recreation.

Class 6: Land with severe limitations that restrict its use to rough grazing, forestry and recreation.

Class 7: Land with extremely severe limitations that can not be rectified.

As Davidson (1992) suggested, the system has a lot of criticism arising from its inability to meet all the criteria in assigning sites to a specific land capability class. During the late 1970s and early 1980s, the need for revision to the land use capability scheme became increasingly evident. Particular concerns were with improving quantitative guidelines as well as with incorporating better assessment of climatic parameters. The result, in England and Wales, has been the production of revised guidelines and criteria for grading the quality of agricultural land. In Scotland a system for classifying land capability for agriculture (LCA) has been published.

The LCA is based on very similar principle to that of USDA method; the obvious key point difference between the USDA scheme and the LCA is a far greater degree of quantitative specification on assessment criteria. In the earlier system of land capability assessment, little attention was paid to nature of upland areas. But in a country like Scotland, the upland areas play a major role in the agricultural economy through the grazing of sheep and cattle (Coppock, 1980). Thus the LCA scheme introduced an innovative assessment of the grazing value of the upland areas. The classification system retains seven classes with land in classes 1 to 4 being suited to improved arable cropping and land in classes 5 to 7 being suited only to improved grass land and rough grazing (Coppock, 1980). The classes in LCA for Scotland can be summarized as follows:

Class 1: Land capable of producing a very wide range of crops (covers less than 1 % of Scotland).

Class 2: Land capable of producing a wide range of crops (covers 1 % of Scotland)

Class 3: Land capable of producing a moderate range of crops (covers 15% of Scotland)

Class 4: Land capable of producing a narrow range of crops (covers 11% of Scotland)

Class 5: Land capable of use as improved grassland (covers 19% of Scotland)

Class 6: Land capable of use only as rough grazing (covers 48% of Scotland)

Class 7: Land of very limited agricultural value (covers 3% of Scotland)

The land classification for England and Wales evolved from the earlier one devised during the 1960s. The main changes focused on the assessment of climatic and soil wetness and draughtiness limitations. The main limiting factors used in these schemes were climate, site, soil and interactive limitations (wetness, soil erosion). Chemical limitations were taken into account only where they have a long-term detrimental effect on the physical condition of the soil, crop yield, range of crops, stocking rate or grazing management (Davidson, 1992). The grades and sub-grades are as follows:

Grade 1: Excellent quality agricultural land.

Grade 2: Very good quality agricultural land.

Grade 3: Good to moderate quality agricultural land (divided in to sub grades 3a and 3b).

Grade 4: Poor quality agricultural land.

Grade 5: Very poor quality agricultural land.

4.5 The Dutch System

The Dutch landscape is known for its intensity of use and land was under ever increasing pressure. It was not only important to preserve the soil most suitable for farming which plays a major role in the Dutch economy, but also space was needed for other land uses like new settlements, industrial areas, recreational areas, forestry and infrastructure. In the Netherlands land evaluation has a long tradition and the early work goes back to the 1950s, where soil survey was interpreted for crop production and for land reclamation and improvement. Much emphasis was given to soil survey in relation to town and country planning with the main contribution in the

Netherlands being preservation of soil particularly suitable for horticulture (Davidson, 1980, 1992).

In the Dutch system, the term suitability was used rather than capability. Davidson (1992), citing Vink and Van Zuilen (1974), defines suitability as "the degree of success with which a crop or range of crops can be regularly grown on a certain soil, within the existing type of farming, under good management, and under good conditions of parcellation and accessibility". Around 1960, qualitative evaluation was used to assess the land, with reference to the economic and technological situation of agriculture. Thus various assumptions are necessary before land or soil grading takes place. Changes in these assumptions therefore mean that the suitability assessment ought to be re-appraised.

Davidson (1992) compared the British and the Dutch schemes and indicated that in the British land capability system climatic limitation is given higher consideration. On the other hand, climatic variations within the Netherlands are minimal and hence soil limitations assume greater importance. Another important point of contrast with the British system is that, in the Dutch scheme agriculture is divided into arable and grassland activities and this is reflected in the classification system that can be summarized as follows:

Major class BG:	Arable land and grassland. (Soils generally suited to arable land and usually also to grassland) sub divided into seven classes (BG1 to BG7).
Major class GB:	Grassland and arable soils. (Soils generally suited to grassland and in many cases also to arable land) sub divided into three classes (GB1 to GB3).
Major class B:	Arable land soils. (Soils generally suited to arable land, but mostly poorly or not suited to grassland) sub divided into three classes (B1 to B3).
Major class G:	Grassland soils. (Soils generally suited to grassland, but mostly poorly or not suitable to arable land) sub divided into five classes (G1 to G5).

Major class O: Unsuitable soils. (Soils predominantly poorly suited to arable and to grassland) sub divided into two classes (O1 and O2) according to whether the soils are too dry or too wet respectively.

The above classification of the Dutch scheme gives more emphasis to grassland than the British scheme. Most of the time the objective of the assessment determines the type of classification one should follow. If an overall assessment is required to aid land use planning, then a multipurpose grading scheme is required. If more detailed comments are needed on land suitability for particular crops or agricultural activities, then more specific classifications are necessary.

4.6 FAO Framework and guidelines for Land Evaluation

So far we have seen different land capability schemes from different parts of the world. Attempts have been made to adopt and adapt the systems especially the USDA one, in various countries. For example, Beek (1978) noted that countries from Latin America like Venezuela, Nicaragua and Mexico used the USDA system after some modification to their local condition without rigidly following the system. Some countries modified the original eight classes of the USDA scheme, but according to McRae and Burnham (1981), countries like India, Pakistan, Australia and South Africa retain all the eight classes as it is. New Zealand also adapted the USDA type of classification with eight classes and modified it to be used in local conditions (New Zealand Ministry of Works, 1974).

Surveys in developing countries revealed shortcomings in using the land capability classification, and procedures were devised for comparing suitability of land for different uses. Dent and Young (1981), citing Haantjens (1965) and Mahler (1970), gave two examples. The first is from New Guinea, where a system that provides separate suitability ratings for annual crops, tree crops, improved pastures and swamp rice production were developed, and the second from Iran, where a manual of multi-purpose land classification was introduced.

The initiative for developing some measures of developing a common terminology and procedures was taken by FAO through a series of international discussions from 1970 onwards. McRea and Burnham (1981) observed some of the major events that contributed to the birth of the FAO Framework for land evaluation. These include a background document (FAO, 1972), a draft report (FAO, 1973) and the proceedings of two meetings of international expert consultants. In addition to these, reports on various pilot studies in developing countries like Malawi, Sri Lanka, Mauritius, Sudan, Cameroon, Brazil, and Kenya illustrate the development of the Framework towards its final format. The Framework was designed mainly for use in developing countries, but it can also be used in developed countries.

The FAO Framework for land evaluation (1976) is not a complete document to be able to conduct a full evaluation process by its own. To help evaluators FAO developed three different Guidelines, which can be used during the process of evaluation. These Guidelines are Land Evaluation For Rainfed Agriculture (FAO, 1983), Land Evaluation For Irrigated Agriculture (FAO, 1985) and Land Evaluation For Extensive Grazing (FAO, 1991). All these guidelines put more emphasis on the need to evaluate (a) crop requirement, (b) management requirement and (c) environmental and conservation requirements. At the same time they give more emphasis on the use of local criteria, where available, than outside criteria.

According to Dent and Young (1981), in the FAO Framework results of land evaluation should include three important components, these are:

Description of land utilization types: this is the description of the nature of the land use in a very detailed way, and it depends on the intensity and purpose of the survey. For example, the description of "rainfed arable farming based on groundnut and sorghum" might include farm size, crop varieties, levels of fertilization (other inputs), level of mechanization etc.

Suitability maps: This shows the suitability of each mapping unit for each defined kind of use. They could show that, certain mapping unit is highly suitable for arable farming, moderately suitable for grazing and not suitable for forestry. For example, a certain mapping unit could be highly suitable for groundnut inter-cropped with sorghum, some moderately or marginally suitable and others not suitable for that use. Such data can be presented as tabular or as a series of individual suitability maps.

Consequences, favourable and unfavourable, of applying each kind of land use to each area of land. These include information like estimated yield, kinds and amount of input required such as fertilizer, labour, machinery; assessment of environmental impact and of social consequences; and, in economic evaluation, estimated costs, benefits and profit. If a certain area of land is assessed as not suitable for specific use, then reasons should be given that makes it not suitable.

These kinds of information enable the parties commissioning the survey to make appropriate choices because information is provided on what farming systems or other kinds of land use are possible with in the surveyed area, where the best land for each use occurs, and the possible consequences of each use. The structure of the FAO Framework was discussed in chapter three.

4.7 Comparison of the USDA with the FAO Framework

Young (1976) observed some similarities and differences between the USDA and the FAO Framework. Their uses of terms are almost similar i.e. class, subclass and unit have the same meanings. As far as their differences are concerned, there are three main differences between the Framework and the USDA. These are firstly, in the Framework, suitability is assessed separately for each form of use; secondly, it makes use of land qualities instead of individual land characteristics and thirdly, that it places emphasis on economic aspects.

The most important advantages of the qualitative general-purpose land evaluation of the USDA system, according to Young (1976), are its flexibility, its simplicity, extremely versatile nature, and its emphasis on the adverse environmental effects. On the other hand, its shortcomings include that emphasis is put on arable land only; the system is not explicit, especially in relation to economic consideration; geographic factors such as distance to market, kinds of roads, size and shape of land areas, location within a farm or field etc. are not included. Most of all, the USDA system is a negative approach, which is based on limitations rather than positive potential. Generally speaking it is a very narrowly focused interpretative soil classification (Rossiter, 1994). The Framework is not a complete evaluation system and through the three guidelines (rainfall, irrigated and extensive grazing), it enables national or local system to be constructed out of it and this is the main advantage of the Framework over the USDA system (Davidson, 1992).

Practical application and utility are the most important factors that help to judge whether one land evaluation system is better than another system. As far as these factors are concerned land suitability evaluation is superior to land capability evaluation. This is mainly because land capability is effective only for farm planning and operates on small scale but land suitability evaluation puts forward alternative possibilities for changes in land use, predicts the consequence of such changes and it provides full evidence contributing to planning, management, and investment decisions. The system has been most fully tested, applied and proven in developing countries (Dent and Young, 1981).

The biggest difference, which should be highlighted very strongly, is that the USDA system is a negative system concentrating on conservation, while the FAO system is a positive system concentrating on the optimal use of each area of land. The USDA system does not make ample provision for looking at special measures/ techniques to use non-ideal land (Laker, personal communication).

4.8 The FAO's Agro-Ecological Zones (AEZ) Project

The project was initiated to make "from existing information" an approximation of the present and potential use of the world's land resources. It was mainly focused on rainfed potential and specifically on the twelve main crops of the world (Dudal, 1986). This is because during the start of the project the available information on ground and surface water was not sufficient to include irrigation potential. No major land improvement was considered and it takes into consideration only on farm improvements and input/output relations (FAO, 1978).

To arrive at the AEZ, a special climatic inventory was made the soils map of the world (1:5,000,000) was used as a database for soils and topography, and requirements of the selected crops were determined. The climatic zone map was superimposed with the soil map to produce AEZs. All the data was put on computer, and become available as an Agro-Ecological Database for farther studies (Purnell, 1986, as quoted by Smith, 1998).

The concept of AEZ emerged from the Framework for land evaluation (FAO, 1976) which emphasized the need for determining the land utilization type (LUT) as a necessary step to land evaluation and land use planning. It also considers the need to develop systems which could support the integration of the socio-economic factors of production (major focus on AEZ implementations). Other basic concepts are the overlaying of the thematic maps to define AEZ boundaries while, in recognition of the heterogeneity of the real world, giving chance for the existence of complex mapping units.

4.8.1 Methodologies

Sustainable land use, within the AEZ conceptual Framework, demands an integrated set of appropriate methodologies. These ranges from algorithms for the estimation of available growing period, through soil and climate classification systems to the characterization of production functions and optimization procedures while selecting among an infinite range of land use allocation possibilities (FAO, 1978).

The scale and purpose of a study as well as the preference of an individual evaluator determine the methodologies adapted in any given AEZ studies. Crop yield can be assessed by the "standard" AEZ biomass model or by the use of Crop Simulation Model (e.g. CERES). Soil erosion hazard could be assessed using the (Revised) Universal Soil Loss Equation (USLE/RUSLE), Soil Loss Estimation Model for Southern Africa (SLEMSA) or more sophisticated models such as Erosion Productivity Impact Calculator (EPIC) could be used (Smith, 1998).

4.8.2 Implementation tools

According to Smith (1998), there are different AEZ related products that have been developed during the past decade. This includes project reports and popularised summaries, workshop training material and computer and operating manual. Among these developments various software packages are the most important achievements as far as implementation is concerned. They are divided into two, viz. those which provide an AEZ "shell" giving multiple AEZ functions, and those which tackle individual AEZ components, e.g. soil moisture balance or crop suitability assessment or soil erosion.

Non FAO packages such as ALES (Land evaluation), PLANGRO (plant growth prediction), CERES (crop simulation), MUSLE (soil erosion) and EPNS (soil fertility), though they were not considered by their authors as AEZ components, can be (and are) used as partial or complete substitutes for the FAO related components of the AEZ system. Of course products like ALES (Cornell) and LECS (FAO) were designed as implementations of FAO's Framework for land evaluation and, as such, are highly AEZ compatible (Smith, 1998).

The implementation tools are the most dynamic components of the AEZ system and algorithms, software packages, manuals and related training materials are constantly being reviewed and enhanced (FAO, 1994b). These activities having both significant benefits and costs (FAO, 1994b).

4.8.3 The suitability classification

The final product of the AEZ study is land suitability classification. It takes into account all the land attributes and crop requirements and combining them into an easily understood and simplified picture of the suitability of land for various utilization types under rainfed conditions. Four final suitability classes were employed (very suitable, suitable, marginally suitable and not suitable), each linked to anticipated yields for all crops and levels of inputs considered. Thus it gives simple and concise data on the extents of land variously suited to the production of each crop, under two levels of input, and the production potential of these areas (FAO, 1978).

In principle, the suitability classification has been compiled depending on four main assumptions (FAO, 1978):

- Semi-quantifying (rating) agro-climatic constraints to the growth of different crops in the various lengths of growing period zones;
- Applying these constraints to the calculated constraints free yields from each zone;
- Dividing the resultant anticipated yields into four yield ranges (agro-climatic suitability) classes, and finally
- Modifying the computed extents of the various soils inventories in those areas, to arrive at the land suitability.

For each levels of input the land suitability classes employed, depending on the attainable yield, were classified into four. These are very suitable (80% or more of the maximum attainable yield); suitable (40 to less than 80% of the maximum attainable yield); marginally suitable (20 to less than 40% of the maximum attainable yield) and not suitable (less than 20%) (FAO, 1978).

Purnell (1986) as quoted by Smith (1998) draws some important conclusion of the AEZ studies. One of the most important focus was the significance of "sustainability", for without soil conservation measures it is unsustainable to use a very steep land for farming. Prediction of this effect must be a key element in any quantified land evaluation system. From operational point of view, one clear conclusion that emerged from this and subsequent activities, was the disadvantage of simultaneously combining and analyzing all factors at once in order to produce an initial overall results. The validity and reliability of each input and sub-model should be tested separately before testing the interactions and producing comprehensive results.

4.9 Crop Modelling in Land Suitability Evaluation

Crop modelling is an important and effective multipurpose tool in quantitative land suitability evaluation. It can improve agricultural yields, assist in timely preparations for anticipated crop short falls, and improving trade decisions, economic planning and related policy making (Smith, 1998). Crop modelling has marked advances that it can be used to make reliable predictions in many instances.

According to Smith (1998) crop models sometimes have the capacity to replace empirical research. On other occasion they can help land users and decision makers in making strategic and real time decisions, providing sufficiently accurate prediction of factors such as duration of the plant growth stage, plant bio-mass assimilation rates, and soil-water balance are possible. Ritchie (1991) as quoted by Mbatani (2000), acknowledged their uses by stating that they are the principal tools needed to bring agronomic sciences into the information age. Smith (1998) indicated that for such technique to become fully effective, improvements needs to be made in many areas. It is important to note that a model must be validated against real data, from conditions similar to those under which it is to be used, before it can be used for crop modeling in a specific region.

4.9.1 Classification of Crop Simulation Models

Types of model to be used depend on the purpose for which one wants to use a crop production model. Mostly the simplest model is used for large area production and includes little detail of the soil-plant system. But the most complex one explains the soil-plant-atmosphere system and needs a large quantity of input data, some of which may be not available (Smith, 1998). Therefore models can be classified depending on the purpose and detail.

Crop simulation models can be stochastic or deterministic. Procedures for the former one have not been developed to the level of usefulness but the latter model produce a unique results for a given set of events owing to the spatial variability of the soil and weather. But there is a great deal of uncertainty with the results (Smith, 1998).

Deterministic models can be classified into three basic types: statistical, mechanistic or functional. The uses of the models are determined by the purpose for which they are intended. Statistical model needs less information but mechanistic model needs more information.

4.9.1.1 Statistical Model

These are also known as empirical models (Dumanski and Onofrei, 1989, as quoted by Smith, 1998). They are used to assess the crop potential but not for direct land evaluation. The major problem with statistical model is that predictions are made outside the range of some of the weather and technology information from which the model was developed. Generally, statistical models are being used less than they were some 20 years ago. This is mainly because in global change issue, combination of weather elements will not be the same between regions as they used to be in the past and the technology from the past may not be highly relevant (Ritchie, 1994, as quoted by Smith, 1998).

4.9.1.2 Mechanistic Model

Theoretically this model is attractive, but they have several limitations for land evaluation. This is because the number of inputs needed is massive, with short period of time, and they are expensive to conduct for a large number of year and locations (Smith, 1998).

Ritchie (1994) as quoted by Smith (1998), concluded that such models are suitable as research tool to assist test hypothesis or to expose areas of incomplete understanding. Generally, mechanistic models are used for academic purposes rather than for problem solving (Smith, 1998).

4.9.1.3 Functional Model

These models use less input and require less calculation compared to mechanistic models. It is usually used for problem solving (specific type of problem) objectives where the input data are small or limited. These models, for example, make use of total radiation for a day as the amount of energy available for photosynthesis or transpiration, and then determine the actual daily amounts using empirical relations related to soil-water deficits or low plant leaf area. In general functional models can be used outside the area where they were developed without much problems (Ritchie, 1994, as quoted by Smith, 1998).

4.10 Application of GIS in Land Evaluation

A geographic information system (GIS) is a computer-based system for storage and manipulation of data which is organized by area or location (Burrough, 1986). It can offer valuable facilities for land evaluation and land use planning (FAO, 1996). Initial cost could be expensive but the use for the process of land suitability is much greater. As Burrough (1989) suggested, it is possible to link models and GIS effectively for quantitative land resource assessment. But he added that currently there is no commercial GIS which can link all kinds of models and GIS together.

Van Lanen, Van Diepen, Reinds, De Koning, Bulens and Bregt, (1992) as quoted by Smith (1998), showed the possibility of partial combination of GIS and physical land evaluation methods as a useful part of a sophisticated land use planning. Smith (1998) indicated that the linkage of physical land evaluation models and GIS substantially improves its usefulness as a tool. Evaluation models have better access to basic data and complement GIS to analyze and present interpreted data which are usually more important to policy making than the basic data themselves.

Legis (1983) as quoted by Burrough (1986), gave an example of a step by step application of GIS tool for identifying suitable area for the production of maize in the Kisii District of Kenya. In the process different maps (topographical, soil, contour, and climatic) were digitized and were overlayed to produce a suitability map for the production of maize. The suitability classification was based on the FAO Framework for Land Evaluation (1976) where selected land qualities (water availability, oxygen availability, nutrient availability and erosion hazard) where used to determine suitability. Land characteristics (e.g. slope class and soil series) were used to measure the land quality (erosion hazard). In this exercise it was proved that application of GIS as a tool could give a quick and effective results in suitability evaluation. The flow chart is presented in Figure 4.2.

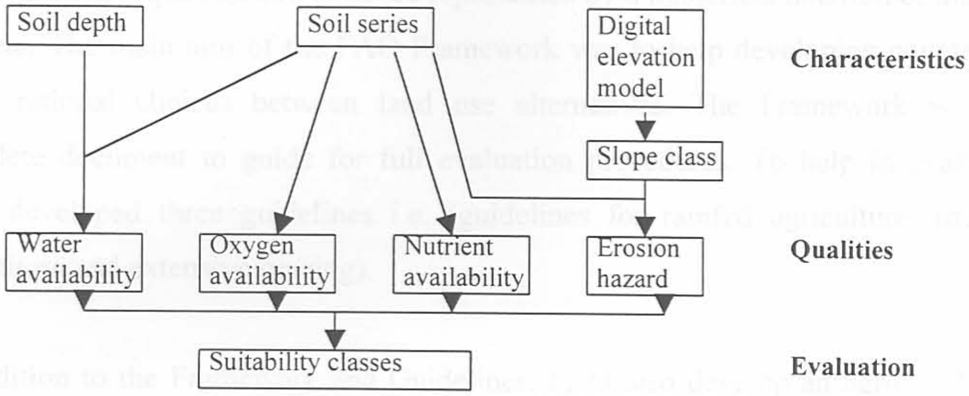


Fig. 4.2 Example of a GIS flow chart used in preparation of map of suitability classes for maize using the FAO Land Evaluation procedures (From Burrough, 1986)

4.11 Conclusion

Land has been a means of survival for many years and it will continue its role as a major resource in this planet. On the other hand, population pressure and the need of land for other purposes rather than agriculture are the main threats. These can result in the invasion of prime and unique agricultural land by non-agricultural sectors like housing, road construction, etc. To minimise such threats and to protect the land against erosion and degradation, a proper *land resource survey* and *evaluation* is necessary.

Land capability classification has a long history and the first attempt recorded was in 1930s in the United States. The main objective of such classification was to protect the land from erosion hazards. Since then different countries have adopted and/or adapted the USDA system as it is or after modifying it to their local condition. The scheme was also used in some developing countries but there was concern about its shortcomings in resource poor countries.

Through different international discussions, the FAO Framework for land evaluation was developed in 1976 that proves to be effective for developing countries. In its basic structure the Framework resembles the USDA land capability classification. The S1, S2 etc. and N1, N2 etc. classes of the Framework parallel classes I-VIII in the land capability classification. In both systems subclasses are represented by a letter notation after the class number, which denotes the main kind of limitation (or improvements required), and units are represented by a numerical notation of the form 1, 2 etc. The main aim of the FAO Framework was to help developing countries to make rational choices between land use alternatives. The Framework is not a complete document to guide for full evaluation procedures. To help in evaluation FAO developed three guidelines i.e. (guidelines for rainfed agriculture, irrigated agriculture and extensive grazing).

In addition to the Framework and Guidelines, FAO also develop an agro-ecological zone map to help in identifying and allocating of the suitability of twelve main crops of the world. During the process crop requirements of the selected crops were identified. By superimposing climatic zone and soil maps, an agro-ecological zone was formed. Crop modelling and a GIS tool could also play a major role in suitability classification by providing data that enable decision-makers to decide on proper land use.

Classifying land according to its capability or suitability helps land users and planners to direct their resources to particular type of production to the best area and protect the highly suitable area of land from invasion by non-agricultural practices. Depending on the socio-economic and environmental consequences that can result from the introduction of new practices, suitability classes can provide policy makers with information to make their choices among alternatives. These is because, during the process of evaluation all the three i.e. the land utilization types, the land mapping unit and the environmental and other socio-economic consequences, would be addressed before the final decision on a particular land use is made.

For a country like Eritrea, where the natural resources are limited, a strategy of land evaluation which guarantee the conservation of natural resources and achieve the objectives of the government (food security) should be in place. In the following chapter a step by step procedure of land suitability evaluation for Eritrea will be proposed.

CHAPTER FIVE: PROPOSED STRATEGY AND STRUCTURE OF LAND SUITABILITY EVALUATION FOR ERITREA

5.1 Introduction

Individual land users operating within a large set of environmental and legal systems always make different choices of land use. So it is no surprising, therefore, that differences should exist within the structures of land uses in different countries, even within more developed countries. The climate and other aspects of the physical environment, population density and land area are totally different and these factors have a very significant effect on the structure and composition of land uses (Mather, 1986). To improve existing land use or to establish a new one, effective evaluation of land is necessary.

As it has been stated in the previous chapter, different land capability and suitability classifications are used in different parts of the world. These classification types, though they are different, all have the objective to evaluate the land and classify it to the most suitable use it can offer without degrading the environment. The adoption of such evaluation strategy as it is or after modifying it to fit into their respective situations has been practised in both developed and developing countries. The FAO Framework for Land Evaluation (1976) proves to be more flexible and easy to manipulate for developing countries like Eritrea than the land capability system of the USDA, which is a broad and rigid classification system (Smyth, 1977). In this chapter, the present land evaluation system of Eritrea will be analysed and a more suitable land evaluation strategy and structure will be proposed.

5.2 Present land evaluation in Eritrea

As it has been mentioned earlier, Eritrea was officially declared an independent country on May 24th, 1993. Since then the government has tried to consolidate different related ministries into one major ministry dealing with land. Land was initially under the Ministry of Agriculture, but because of its importance and sensitive nature, it became the responsibility of the Commission on 1994. In 1997 it became the responsibility of the Ministry of Land, Water and Environment. The ministry has three departments and land use and cartography is a branch under the Department of

Land and its major activities include allocating of land for commercial agriculture. In the process land is evaluated using the USDA system (Klingebiel and Montgomery, 1961) at a broad or small-scale level to judge its potential and categorize it according to its capability. To help its activity the ministry printed a very broad agro-ecological zone map of Eritrea at a scale of 1:1,200,000 in 1997. The map is presented on page 18 of chapter one.

As far as land use experts are concerned, the branch has only 13 experts who are mostly new graduates from university and one senior person with a doctor's degree who has a very good background in land use planning, as their facilitator. This indicates the shortage of experts in the field. Human resource development is a main objective of the government and the ministry however. Because of this three students are presently conducting postgraduate studies in land use planning in South Africa and the program will continue to minimize the existing shortages. There is no strategy of land evaluation except the USDA system (Araya, personal communication) and it is believed that the following proposal for a land evaluation system could be used as a guideline for evaluation at different levels of intensity. The USDA system can also be used at a reconnaissance level to identify the potential arable land at national level.

5.3 Proposed strategy of land evaluation for Eritrea

Land suitability evaluation scored marked achievements over the past two to three decades in defining the most suitable area of land for a specific use. During the process of suitability evaluation, sustainability should be maintained and input/output ratio should be satisfactory for the land user. Eritrea as new nation should learn more from the past experience of this discipline. Even though the process is long and demanding (capital and experts), effort should be put for achieving a sustainable land use. Eritrea is a country in which the climate is suitable for several field crops, fruits and vegetables, but the erratic nature of the rain does not allow for practicing a sustainable rainfed agricultural production. This calls for effective and careful planning in terms of using the scarcest resource i.e. moisture availability. For the purpose of this paper, two cereal crops, i.e. wheat and sorghum, have been chosen as examples. The main reason for choosing these two crops are firstly they are highly consumed by the majority of Eritrean people and secondly they represent crops adapted to the highland and lowland climate of Eritrea respectively. In the future this process can be repeated for other crops. The climatic and soil requirements of other crops grown in Eritrea are presented in appendix 3.

Land could be evaluated for general purpose, where the land utilization type is not known or for a specific purpose, where the land utilization type is specified in a very detailed manner. In the latter case, evaluation is done to find areas of land which satisfy the requirements of the land utilization type with reasonable economic return and little social and environmental disturbances. For such evaluation, land suitability classification can give the required information, while for the former kind of land evaluation the USDA system (land capability) could be adequate. Such system, though effective, is only a subjective way of classifying land, i.e. it doesn't include economic comparisons between alternative uses. On the other hand, it gives the limitations of certain land for specific land uses, and this helps to indicate the actions needed to control erosion and other forms of soil degradation and thus improve the condition of the land.

Land amelioration in terms of fertilizing, irrigating, desalinization etc. could improve the quality of land and shift the land class e.g. from Class IIIe to Class IIe, but the cost of amortization should be borne in mind. If the government or NGOs subsidize the cost, the benefit-cost ratio could be greater than one which is feasible but if individual farmers are expected to pay for such kind of land improvement, the benefit-cost ratio will be less than one which makes the land not suitable (Moormann, 1981).

FAO (1976) and Dent and Young (1981) described step-by-step procedure of land evaluation for specific purposes (Figure 5.1). If economic and other factors allow, this procedure can be adopted after few modifications to the Eritrean situation. The procedures that need to be followed are:

I. Initial consultation (objectives, data and assumption and planning of the evaluation).
II. Description of the relevant kinds of land uses (major kind or LUT's).
III. Ascertaining the requirements of each land use type.

IV. Description of land mapping units through soil/land resource survey.

V. Rating the land qualities relevant for the land use type concerned.

VI. Comparison (matching) of land use requirement with land quality.

VII. Land suitability classification (qualitative and quantitative).

VIII. Presentation of the land evaluation results.

It should be emphasized here that land suitability evaluation is an interdisciplinary activity involving many scientific disciplines from natural and social sciences and should, therefore, be carried out by a team of specialists representing both scientific camps (Breimer, Van Kekem and Van Reuler, 1986). The structure of the suitability evaluation process is shown in Figure 5.1.

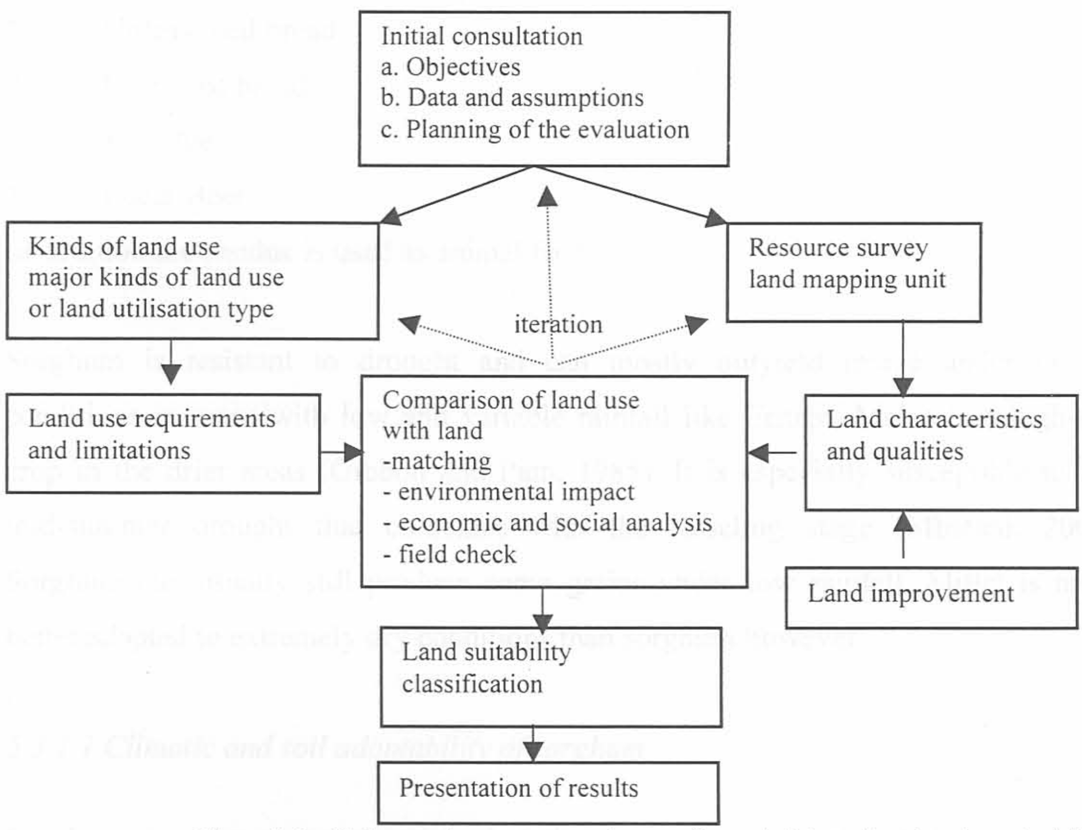


Fig. 5.1 Schematic presentation of activities in land suitability evaluation (From Dent and Young, 1981)

Taking the objective of the Eritrean government as to be self sufficient in food, the next procedure would be to find a strategy to achieve this objective. One way of doing this is through producing enough carbohydrate and protein that fulfills the demand of the people. Sorghum and wheat are among the major cereal crops, which have high carbohydrate content. The requirements of these two crops should be specified so that efforts could be directed to satisfy those needs. These needs of the crops can only be fulfilled from the land so efforts should be directed for investigating the quality and limitations of the land. The following section deals with the establishing of the requirements and identifying the most limiting land qualities for its successful production.

5.3.1 Requirements for Sorghum production (Sorghum bicolor)

Sorghum is the fourth important tropical cereal crop after wheat, rice and maize. It is one of the staple foods in Eritrea. It is used for human consumption in the following four main ways and is one of the most highly consumed crops:

1. Unleavened bread
2. Leavened bread
3. Porridge
4. Local Beer

In addition the residue is used as animal feed

Sorghum is resistant to drought and can mostly outyield maize under rainfed conditions in areas with low and variable rainfall like Eritrea. Maize is a high-risk crop in the drier areas (Gibbon and Pain, 1985). It is especially susceptible to any mid-summer drought that coincides with the tasseling stage (Mbatani, 2000). Sorghum can usually still produce some grains under low rainfall. Millet is much better adapted to extremely dry conditions than sorghum however

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5.3.1.1 Climatic and soil adaptability of sorghum

Sorghum is a warm season plant but there are some varieties that can grow in temperate regions. With the advancement of breeding of early maturing varieties, sorghum can grow on average annual rainfall of up to 380 mm (Rios and Weibel, 1984). In general sorghum can tolerate drought than maize. Gibbon and Pain (1985) gave five possible reasons for this, these are:

I. Sorghum has very deep and extensive root system and becomes well established before the stem and leaf growth accelerates.

II. The roots contain silica, which maintain their form during drought period.

III. The leaf area is limited and can be reduced further by inward rolling during drought.

IV. Sorghum usually has a much greater water use efficiency than maize.

The plant can suspend growth during periods of drought and resume growth when conditions become favourable.

Boedt and Laker (1985) showed that maize could actually extract nearly 20% more water than sorghum from the soil before it shows the first sign of stress. They found that sorghum extract much more slowly than maize, however. This gives two advantages of sorghum over maize:

(i) The total water requirement of sorghum over the whole growing season is less than for maize.

(ii) Sorghum will not run out of water so easily between successive rainfall events and can thus survive the effects of prolonged periods between rains than maize.

The minimum temperature for germination of the seed ranges from 7-10 but the minimum temperature for subsequent plant growth is about 16°C. Maximum temperature more than 38°C are detrimental, particularly during the panicle development stage (Rios and Weibel, 1984).

Sorghum has different reactions to photoperiod and temperature changes but, as Gibbon and Pain (1985) suggested, the timing of flowering is influenced by the interaction of genotype, photoperiod and temperature. According to them, based on the work done in Northern Nigeria, some successive shorter days may induce flowering.

Sorghum can grow well in a wide range of soils but it prefers Vertisols and Alfisols with good drainage (Norman, Pearson and Searle, 1984). Vertisols have high water holding capacity, which makes them good for sorghum production by allowing the plant to use the stored water through its deep and extensive root system. Vertisols hold their water very tightly and release it slowly. This slow release is compatible with sorghum, which extracts water slowly. Based on experience many farmers all over the world, from the commercial farmers in the "Blacklands" of Texas to small-scale tribal farmers of South Africa, Know that they can grow sorghum on these black clay soil, but not maize. In the drier areas, like the central plateau of Burkina Faso, small-scale farmers grow sorghum on the clayey soils and millet on the sandy soils (Laker, personal communication). In Eritrea farmers prefer clay soils on account of their water holding capacity and sandy loam soils for their workability. The experience of other countries should be used as a learning process and could be applied in Eritrea for land evaluation and land use planning through technology transfer. The ideal texture for sorghum production is medium to heavy clay soils but it can survive on sandy soils as well. The favourable pH for the plant ranges from 5.5 to 8.4 (Landon, 1991).

5.3.1.2 Cultural practice for sorghum production

Sorghum prefers well-prepared seedbed free from weeds, when the soil is sufficiently moist to initiate rapid germination. One of the main parameters in the CYSLAMB crop model for maize is the determination of planting opportunity, when there is adequate moisture available in the soil for planting (Mtabani, 2000). A similar parameter should be developed for sorghum in Eritrea. The amount of seed to be sown per hectare depends on variability of seed, soil moisture availability and nutrient status of the soil. These factors also determine the number of plants per hectare (Rios and Weibel, 1984). In marginal land low plant density could give good results. Mbatani (2000) for example, found that with a plant density of 14 000 plants per hectare, 3.5 tonnes/ha of maize was found in the Northwest Province of South Africa. In contrast higher plant densities gave lower yields in marginal land (with moisture stress as a limiting factor) in Awassa, Ethiopia. With a plant density of 53 000 per hectare of maize, the yield found was only 2.9 tonnes/ha (Urage and Dauro, 2000). At a later stage during the growing season thinning was done to reduce the plant population. But in areas where moisture is a limiting factor, thinning at a later stage is not a solution because the plants, which were thinned out later, were depleting the limited moisture available before they were thinned out. This then can reduce the amount of moisture left for the plant (Laker, personal communication).

In Eritrea moisture availability is the most limiting factor for sustainable rainfed agriculture. Therefore it is proposed that appropriate planting density should be established and low plant density with relatively low input aiming at low production with minimum risk should be practised rather than high planting density with high probability of crop failure.

The use of artificial fertilizer should be adjusted according to the fertility status of the soil and the attainable yield as determined by climate (Rios and Weibel, 1984). Since fertilizer might not be available to farmers because of infra-structural or economic reasons, manure or green manure crops could be used to improve fertility. In addition some cultural practices like fallow and crop rotation could also increase production. Under rainfed agriculture crop yield could vary from 300 to 3000 kg/ha depending on management and inputs used.

5.3.1.3 Persistent weeds, pests and diseases

Successive planting of sorghum in the same area of land for longer period could result in a range of weeds that can compete for moisture and nutrients during the early stage of development. Most serious is the establishment of the semi-parasitic weed striga. This weed attaches itself to the roots of flowering plant mostly grasses. According to Gibbon and Pain (1985) such parasitic weeds have the ability of producing thousands of seeds and can stay dormant for many years. The damage to the plant is done before it emerges and when it is entirely parasitic on the roots. They have the capacity of reducing around 80% of the expected crop yield. This is a problematic weed in Eritrea and their preventive measure is through crop rotation.

The major pests that can attack sorghum includes shoot fly (*Atherigona varia soccata)*, stalk borer (*Chilo partellus, Busseola sorhicida)*, and (*Sesamina calamistis)* (Gibbon and Pain, 1985). Birds can also cause a considerable damage. The most important pest in Africa is the weaverbird (*Queleu quelea* L) which lives in large colonies and can attack mature sorghum or millet (Norman *et al.* 1984). In Eritrea the problem of bird attack is serious and farmers hire somebody to chase the birds and sometimes, to reduce the yield loss, farmers plant sorghum collectively.

There are many diseases which can attack sorghum and includes leaf spot, downy mildew, rust, anthracnose and blights (Rios and Weibel, 1984). There is not enough evidence to substantiate the level of loss from diseases, but the problem of rust is high in lowland Eritrea where the dominant crop is sorghum.

5.3.2 Requirements for Wheat production (Triticum aestivum L)

Principally wheat is a temperate crop but it can also grow in cool parts of the tropical and sub-tropical regions of the world. The grains vary from hard to soft, and from red to white. Attempts have been made to develop caltivars that can survive in sub-tropics and in higher altitudes in the tropics. As a result different varieties including a dwarf that can suit warmer countries (Ghana) have been developed. At the same time varieties that resist diseases (rust) have been developed to be grown in Kenya (Purseglove, 1986). In the cool highlands of Turkey wheat cultivars developed in cool areas of the former Soviet Union performed much better than the so-called "high yielding varieties" developed by CYMMIT (Winkelman; as cited by Laker, 1979). In an un-written presentation by an Egyptian soil scientist at the congress of the Egyptian Soil Science Society in Cairo in October 2000, it was mentioned that studies in Egypt showed that locally developed wheat cultivars gave better results than a "good" cultivar imported from Syria (Laker, personal communication). This further emphasises the importance of using cultivars that are adapted to (or have been developed for) specific environmental conditions.

At the same time varieties that resist diseases (rust) have been developed to be grown in Kenya (Purseglove,1986). New rust strains develop continuously which infest "rust resistant" cultivars. In rust prone areas, like the Western Cape province of South Africa, new wheat cultivars must, therefore, be developed continuously which are resistant to the new rust strains (Laker, personal communication). Selection of appropriate planting dates can in some areas minimize the rust problem (Khuvutlu &

Laker, 1993). In the latter study, it was found that rust was mainly a problem in crops planted late because of an efficient government ploughing scheme for small farmers (Laker, personal communication).

In Eritrea wheat is grown in the cool areas of the highlands. The main use of the grain is for bread and the crop residue is used as animal feed. Mostly it is grown under traditional, animal drawn implement, with low inputs. However the Ministry of Agriculture, through the approach of collective farm project, is providing machinery and inputs as a loan to farmers and their fields are ploughed and planted collectively with the same crop (wheat, sorghum etc.) to facilitate management and other cultural practices (crop protection). The project has three years and so far the achievements are encouraging.

5.3.2.1 Climatic and soil adaptability for wheat production

Wheat has a wide climatic adaptability (especially temperature) but such adaptation must coincide with the selection of appropriate cultivars that can do well in a specific location. Therefore care should be taken during importing varieties in such a way that the new varieties should be developed under or for conditions similar to Eritrea. If local varieties have to be developed in Eritrea, They must be screened under the climates where they will be grown in farmers' fields.

Generally in East Africa, wheat can do well in areas with altitude ranges of 1600-3000 m above sea level, and it can be said that wheat can be grown under a variety of temperature conditions. It can be grown under high temperature provided that this does not coincide with periods of high atmospheric humidity. Wheat can give good yields on area with annual rainfall of 500-700 mm on heavy soils that can hold more water. For example in Kenya wheat yields best on annual rainfall of 250-500 mm on heavy soils (Purseglove, 1986).

Wheat can be grown on variety of soils, but fertile soils with reasonable drainage and good water holding capacity are preferred. The ideal texture for wheat production ranges from fine to medium with soil depth of 60-90 cm. The soil reaction or pH range of 6.0-7.0 is satisfactory. The crop needs high nutrient and has medium tolerance to salinity (Landon, 1991). Generally high yielding varieties require very fertile soils and high fertilizer inputs, especially nitrogen. Under such conditions they give good yields but under unfavourable conditions they perform very poorly. Therefore in such circumstances, varieties that tolerate the prevailing condition are better than high yielding varieties. In Eritrea breeding should focus to develop varieties that can perform well under the available soil conditions.

Wheat has an exceptionally deep root system and can tolerate subsoil compaction where crops like maize or cotton fail. In contrast wheat is very sensitive to soil crusting (surface sealing) and it is very difficult to get a wheat crop established on a soil that is prone to crusting (Laker, personal communication).

5.3.2.2 Cultural practices for wheat production

The land should be well prepared and levelled before planting and seeds can be sown on rows or broadcasted. This practice determines the seeding rate. For hand sowing, depending on varieties, seeding rate of 120-150 kg/ha is recommended. For tropical Africa the semi-dwarf varieties are suitable because of their short growing time but they require fertile soils and high fertilizer input. In Eritrea wheat is sown during cool season of June-July and harvested on December. Rotation of wheat with legumes and maize is good to consider, so that the N used by the crop can be easily replaced through N fixing ability of legume crops. Wheat responds well to fertilizer application, particularly nitrogen, phosphate and potash. The amount of fertilizer depends on nutrient content of the soil and climate.

5.3.2.3 Pests and Diseases

An important pest of wheat is stem borer (*Sesamia calamistis*). Burning the crop residue after harvesting and using resistant varieties could be used as a control measure.

Different diseases caused by fungus, virus and bacteria could attack wheat. The most common are the stem and leaf rust and smut and the steak and mosaic virus diseases.

The occurrence, severity and the consequent yield loss vary depending on the growth conditions as well as the cultivar used. To control such diseases seed dressing and using resistant varieties could be practised (Yayock, Lombin and Owonubi, 1988). In Eritrea, the author does not know the severity of such problem, and serious investigation is needed for the future.

5.3.3 Strategies for application of Land Suitability Evaluation Findings in Land Use Planning (the Sorghum and Wheat)

Table 5.1 summarizes the most important climatic and soil requirements for wheat and sorghum production. Such information is vital for allocation of certain areas of land for specific land uses because all land does not have the same potential to support the need of a certain land use.

Table 5.1 Climatic and soil requirements for sorghum and wheat production

Crop	Total growing period	Mean daily temperature for growth (°C) optimum (and range)	Day length requirement for flowering	Specific climatic constraints / requirements	Soil requirement	Sensitivity to salinity
Sorghum *Sorghum bicolor*	100-140+	24-30 (15-35)	Short day/day neutral	Sensitive to frost; for germination temperature must be >10 °C; cool temperature causes head sterility	Light to medium or heavy soils, relatively tolerant to periodic water logging pH 6-8	Moderately tolerant
Wheat *Triticum Spp*	Spring: 100-130 Winter: 180-250	15-20 (10-25)	Day neutral/long day	Spring wheat: sensitive to frost; winter wheat: resistant to frost during dormancy (>15 °C), sensitive during post dormancy period; requires a cold period for flowering during early growth. For both, dry period required for ripening.	Medium textured is preferred; relatively tolerant to high water table: pH 6-7	Moderately sensitive.

A strategy is required to approach land suitability evaluation. For the Eritrean situation two alternative strategies can be proposed. The choice of the strategy depends on the overall objective and on the available resources. The strategies are:

(i) Allocation of alternative crops for specific areas.
(ii) Allocation of alternative areas for specific crops.

The first strategy is applicable where the potential of a specific area is known and different land uses compete on the basis of their economic importance, the overall importance to the fulfilment of the general objective of the country, etc. For instance, in lowland (Southwest) Eritrea where the fertility of the soil is relatively high, the land uses (crops) that should be allocated must be those which are important for the attainment of the food security objectives of the country. The second strategy is employed to protect crop failure by applying the principle of selecting the right crop for the right area of land. For example sorghum is better adapted to relatively dry areas and heavy (vertic) soils than maize. The slow release of water from such soils causes less stress in sorghum than maize. So it is better to plant maize in areas where the availability of moisture is high and on soils that release water fast. Therefore, it is better to allocate areas with less favourable climate and soil for sorghum production. Planting sorghum on highly favourable areas and maize in less favourable area should be avoided, because the maize will not be able to handle the less favourable conditions well.

Wheat as a crop is adapted to a wide range of temperatures, provided the right cultivars are chosen for specific conditions. It can tolerate problems of clay soils and problems like compaction associated with fine sandy and silty soils better than maize. Areas with cool climates can be allocated to wheat production where sorghum (which requires warm climates) is not adapted. Generally it is not advisable to grow wheat in hot areas with maximum temperatures of more than 25°C.

In a country (like Eritrea) or area/region where arable resources are limited and production of maize, sorghum and wheat is required, the following strategy would thus be recommended: Reserve the higher rainfall areas and soils with easy water release (sandy to medium textured) for maize. This could be stretched to drier areas, provided that low planting densities and low fertilizer inputs are used (Mbatani, 2000). Allocate the warm, drier areas and/or more clayey soils with slow water release to sorghum. Allocate the cooler areas to adapted wheat cultivars.

Similar strategies could be used for other crop combinations.

5.4 Land qualities that should be assessed

The above types of strategies can only be employed when the requirements of the crop and land qualities of the area are known. FAO (1983) recognises 25 land qualities that can be assessed depending on the objectives of the evaluation (Appendix 4). The most important land qualities that should be assessed in relation to rainfed agriculture in Eritrea are as follows:

(i) Moisture availability
(ii) Nutrient availability
(iii) Rooting condition
(iv) Erosion hazard

5.4.1 Moisture Availability

This quality affects plants through the effect of moisture stress. Moisture stress occurs where the available water is below the needed quantity. The result will be wilting and finally total crop failure. In Eritrea such problem affects crops during the months of September-October when the crops are at a flowering stage. The erratic nature of rainfall calls for different strategies to avoid such crop failure. One way of doing this is to select short season varieties or to adjust planting dates. Most crops are susceptible to moisture stress during emergence or establishment and at the flowering stage.

Generally climate determines the availability of moisture in certain area, but soils and landforms are also important factors to consider. Different soils have different water holding capacities. Landforms are also influencing the ability of crops to use the available water or not. For example in steep areas, because of high runoff, the amount of moisture infiltrated into the soil is small and as a result the available water for the crop is limited, but in areas with gentle slope the available moisture is high. In Eritrea, where the amount of rain is small, landforms that facilitate infiltration of almost every drop of rain into the soil are preferred to decrease the probability of crop failure by increasing the available water in the root zone. The total amount, variability and distribution of rain are important factors. The amount of water readily available for crops is the difference between total rainfall received and the rate of evapo-transpiration. Therefore, it is obvious that the same crop grown in warm areas of Eritrea needs more water than in cooler areas.

Both sorghum and wheat require 460-650mm of water per growing period (Landon, 1991). But sorghum can survive in areas with as little as 380mm moisture provided the soils are clay or sandy-clay to hold more water. Based on the amount of rainfall received, sorghum can grow in all agro-ecological zones of Eritrea except in the semi-desert zone where the rainfall is less than 200mm. In some relatively dry zones only short season varieties can be grown. Wheat on the other hand can only grow in moist highland and moist lowland but moisture is only one factor. Others like soils, temperature regime, etc. restrict the ability of wheat to grow in the moist highlands of Eritrea. This indicates that amount of rainfall alone cannot determine the final suitability of an area for specific crop. Other factors such as variability, distribution, temperature regime, soil type, and landforms should be assessed before one decides on final suitability. For techniques and methods of assessment of these variables, reference should be made to Berhane (2000).

5.4.2 Nutrient Availability

This is one of the three most important qualities that determine successful rainfed agriculture. It refers to the ability of soils to supply plants with important nutrients for growth. The parent material in which the soil is formed and the ability of plants to use the existing nutrients determine the fertility of the soil. The supply of nutrients can be presented into ways i.e. (a) nutrient availability (the ability of soils to supply nutrients) and (b) nutrient retention (the ability of soils to retain nutrients against leaching).

In the Eritrean situation the distribution of fertilizer is limited and the buying power of farmers is low. The main focus should, therefore, be on the natural fertility of soils and ways to improve it through addition of manure and fallowing (resting). To determine the fertility status of a soil, it is important to conduct chemical analyses. On the other hand it is not economical for each farmer to do chemical analysis of his/her field. A quick analysis of soils can give some indication on the fertility status of soils, however. This includes checking the pH of the soil, i.e. nutrient availability is higher in soils with the pH range of 6.0-7.5 and decreases at both high and low values of pH (FAO, 1983). The amount of fertilizer to be added is determined by the fertility status and the attainable yield and varieties. For example semi-dwarf wheat gives high yields but requires very high fertilizer inputs and ideal soils for its successful production (Laker, personal communication). Therefore, such varieties are not applicable for Eritrea, but varieties that are developed for/under the Eritrean situation should be selected.

For the Eritrean situation it is proposed to have a well-established soil laboratory at a national level that can assist in determining the soil fertility. Generally there are certain indicators that show favourable or unfavourable characteristics for high soil fertility. According to Young (1976) these characteristics are as shown in Table 5.2.

Table 5.2: General conditions for soil fertility (Young, 1976)

Soil property	Conditions favouring high soil fertility	Conditions unfavourable to high soil fertility
Soil depth	>150cm	<100cm
Texture	Loam, sandy clay loam, sandy clay, clay (if structure and consistence favourable)	Sand, loamy sand; heavy clay
Structure and consistence	Moderate to strong, fine or medium structure; friable consistence	Massive, or coarse structure, with very firm consistence
Moisture conditions	Free drainage with good moisture retention	Substantial drainage impedance; low moisture retention and rapid permeability
Plant nutrients	High level	Low level
Cation-exchange capacity	Medium to high levels (>20 me/100g in topsoil, >10 me/100 g in low horizon)	Low level
Weatherable minerals	Present within 200cm	Absent above 200cm
Reaction	Generally pH 6.0 to 7.5, but varies with crops	<6.0 and >7.5
Salinity	Low soluble salts and exchangeable sodium	High soluble salts and exchangeable sodium
Organic matter	Adequate in relation to levels under natural vegetation	Low levels

5.4.3 Rooting Condition

This quality refers to the effective depth a root can reach to extract nutrients and moisture and at the same time to anchor the plant firmly in the ground. If the growth of the root is restricted at relatively shallow depth by rock, hard layers like petroplinthic, petrocalcic, etc. horizons, dense clay, a water table, etc. then the development of the plant will be limited. According to Landon (1991) both sorghum and wheat have a deep root system i.e. 100-200cm and 120-150cm respectively. These are, in fact, under estimations of the rooting depths of grain crops. Boedt and Laker (1985) found that in deep fine sandy soils wheat and maize roots extract as much water at 250cm depth as in the topsoil. In California it was found that maize extracts water up to 300cm depth from Yolo silt loam soils (Laker, personal communication). Therefore the best soils for these crops are deep and easily accessible to roots. Deep soils have high plant extractable water storage capacities.

In South Africa most of the soils in which wheat is grown commercially are **very** shallow (<40cm). Success is achieved with low planting density/low input strategies and by selecting adapted cultivars. In the Eastern Free state area of South Africa extension officers and plant breeders were upset because the farmers refused to stop planting two old cultivars in favour of new "better" ones. Subsequent trials on different soils showed that **only** the two old cultivars, used by the farmers, gave reasonable yields on the shallow soils, which covered more than 50% of the wheat producing lands. The new cultivars did well only on good, relatively deep soils, which are scarce in the area. So the indigenous knowledge of the farmers was better than the knowledge of the extensionists and breeders in regard to optimum utilization of problem soils by using adapted cultivars (Laker, personal communication). Similar selections are possible for other crops, including appropriate rootstock selection for growing fruit trees, vines, etc.

5.4.4 Erosion Hazard

If the above three qualities, i.e. moisture availability, nutrient availability and rooting condition are suitable for crop production, efforts should be focused on avoiding human-induced soil degradation, especially water and wind erosion. Erosion will reduce the volume of the soil, which can result in low nutrient content (especially since the fertile topsoil is removed), shallow soils and low water holding capacity of the soil. The final result would be poor soils with low production capacities. The assessment for erosion hazards should involve two aspects, i.e. the susceptibility of land to erosion and the resulting loss in productivity of the land affected (FAO, 1983). During assessment factors like climate (rainfall intensity), soil erodibility, slope (angle and length) and vegetation factors should be assessed. Different assessment methods are known, ranging from a large number of international methods like the USLE (Universal Soil Loss Equation) and the FAO Soil Degradation Assessment (FAOSDA) methodology, to a regional methodology like the SLEMSA (Soil Loss Estimator for Southern Africa) to local methods based on slope and observed present erosion (FAO, 1983).

There is a tendency in developing countries to use USLE, or an adaptation of it, as basis for estimating the erosion potential of areas. It must always be kept in mind that differences between different regions of the world are so big that USLE cannot simply be used in its original form. Even in the USA, where the USLE was developed, it has been found that it is applicable only to the north-eastern corner of the country (where it was originally developed) (Laker, personal communication). Consequently RUSLE (revised soil loss equation) was derived from it for the Midwest of the USA. Soils (especially in regard to parent material) and climates in Africa differ so drastically from those in other continents (except Australia) that USLE or RUSLE cannot be used in African countries without major adaptations.

After drastic modification and adaptation USLE (or RUSLE) could be adapted for Eritrea. This method has some shortcomings, however. Its main problem is the vast amount of data it requires and the difficulty of measuring values for the various factors. This could be a major problem in Eritrea because of shortages of experts, know-how and capital to run the research. For modification one needs experiment stations that develop local standards, which need more money and other resources which Eritrea cannot afford at the current stage of development.

Furthermore USLE was designed for predicting soil loss from a given field, as a basis for selection of conservation practices for a specific site. It was not intended for predicting soil loss from watersheds or large areas.

As a first approximation a more viable approach may be the very simple empirical one used by D'Huyvetter and Laker (1985) in the former Ciskei homeland of South Africa. By means of aerial photographs, slope and soil studies and studies of present erosion in pilot areas of different regions they derived simple equations to predict the erodibilities of different soils under cultivation.

In Eritrea, there has been some work done on the estimation of soil loss in specific research areas (Afdeyu, Eritrea). It is not known what methods were used and the current activity of the research.

For the current Eritrean situation, it is proposed that local knowledge should be used to estimate present erosion through observation and asking local farmers about the state of the soil some 5-10 years ago. Some indicators, e.g. presence of many stones in highland Eritrea, exposure of plant roots, etc. could be used to explain the actual situation of erosion in a specific area. In order to conserve moisture different conservation measures should be planned and implemented (with full participation of local farmers) in order to conserve moisture and the soil.

Table 5.3 shows some of the important land qualities and their corresponding land characteristics that are used to measure land quality for rainfed agriculture. Through collecting information on the quality of the land, one can easily compare with the requirements of the crop. Rating of the area can follow, depending on its capacity to support specific crop.

Table 5.3: Land qualities for rainfed production and their corresponding land characteristics that are used to measure the quality (From FAO, 1996)

Land quality	Land characteristics used to measure the quality
Availability of energy	Sunshine hours in growing season, Temperature regime
Availability of water	Evaporative demand set against rainfall, soil water storage and rooting.
Conditions for ripening	Period of successive dry days with specified sunshine and temperature
Climatic hazards	Frequency of damaging frost, hail or winds during growing period
Sufficiency of oxygen in the rooting zone	Soil drainage class, depth to water table, texture, structure and consistence
Sufficiency of nutrients	Soil nutrient level, pH, organic matter content
Erosion hazard	Rainfall and wind erosivity set against soil cover, slope angle and length and soil permeability
Toxicity	Levels of soluble Al and Fe; pH

5.4.5 Irrigated agriculture and extensive grazing

The above-mentioned qualities are exclusive to rainfed agriculture only and depending on the scale, objectives and economic status of the land user, other qualities could be assessed. On the other hand different land qualities are used to evaluate the capacity of an area of land for irrigated agriculture and extensive grazing. For example the most important qualities as far as extensive grazing is concerned are availability of pasture and drinking water. The qualities that should be assessed for evaluating irrigated agriculture and extensive grazing are presented in Appendices 5 and 6 respectively.

5.5 Comparison of land use with land

This stage of suitability evaluation is crucial where the qualities of the land are compared with the requirements of crops. Generally, this stage has three main activities that should be performed before one decides on the final suitability rating. These are physical matching of the crop requirements with land qualities, environmental impact of the use, and economic feasibility and social acceptability of the use by the community concerned.

5.5.1 Physical matching of land use with land

This refers to the physical comparison of the requirements of the proposed land uses with the qualities of the land (FAO, 1976). This could be done by checking measured values for each land quality or characteristic against the class limit or by allocating each land unit to its land suitability class according to the most severe limitation. Sometimes one limitation is sufficient to render the land unsuitable for the proposed use. For example, for maize production, it is of no use having level land and sufficient rainfall if the soils are highly saline (FAO, 1996).

In cases where the land is rated unsuitable, different measures could be employed to improve the suitability rating of the land. One way is to modify the land use type so as to overcome the limitations. For instance, if suitability has been downgraded because of erosion hazard, a new land-use type could be designed with the addition of contour-aligned hedgerows or other soil conservation measures. Another example is that the introduction of fast maturing varieties could be helpful to overcome the problem of production reduction in areas with a short rain season.

Another possibility is to improve the land itself. Inputs which can bring about relatively permanent improvements in the characteristics of the land could be used. Terracing of a steep land can improve the quality of the land for a certain kind of use. Improvement needs capital for its initial construction and maintenance, so it should be considered during suitability evaluation.

5.5.2 Environmental consequences of the proposed use

Environmental impact of the new land use should be considered during the process of comparison. Such effects can be divided into two, i.e. on site-effects (effects on the land on which the changes are implemented) and off-site effects (effects on another area of land) (FAO, 1976). On site-effects may include erosion and degradation of the land and measures should be taken to prevent such hazards. The off-site effect, on the other hand, refers to problems which can arise indirectly, e.g. a malaria problem that may result from the construction of a dam near a settlement; effects of bush clearance that can increase runoff on down stream river flow, etc. It is very difficult to reverse such damages; the best thing to do is to predict such problems before they occur and take measures to prevent them.

5.5.3 Economic feasibility and social acceptability of the use

Economic and social analysis is another important part of comparison and deals with economics, i.e. the input-output relationship and the overall return to the land user should be estimated before decisions on suitability is made. Social analysis refers to the acceptability of any change by local people. If community members do not approve the proposed land use, it is difficult for its continuity. One of the FAO Framework (1976) principles states that suitability should be done relative to the physical, economic and social condition of the area concerned.

5.6 Land suitability classification

This is the most important part of the evaluation process but it also depends on how all the other parts of the evaluation process were done. There are different ways of determining the suitability ratings, depending on the physical environment, but this must not be taken as final because others like environmental impact and socio-economic consequences should also be considered before the final suitability is decided. Rossiter (1994) proposed three methods of determining suitability ratings depending on the physical environment only, these are:

I. Maximum limitation method

II. Algebraic combinations

III. Subjective combination

5.6.1 Limiting condition

This method puts more emphasis on the most limiting factor for successful production and is sometimes known as the "law of minimum" in agriculture, which states that crop yield will be determined by the plant production factor which is most limiting (FAO, 1976).

This procedure should always be followed when there is an assessment of N (not suitable). For instance, if the rooting depth is a limiting factor for a certain LUT, a land mapping unit with shallow soils, but ideal temperature regime, moisture availability, etc. will have an overall suitability of not suitable, because the proposed crop can not grow in a shallow soil.

The advantage of this method is its simplicity. The disadvantages, on the other hand, include its failure to take account of interactions and it does not differentiate between land areas with several limitations and those with only one, as long as the maximum limitation is the same (Rossiter, 1994).

5.6.2 Algebraic combination

The overall physical suitability of a land area for a LUT is computed according to a formula based on the individual factor ratings. For instance, the average of the LQ levels, or a weighted average giving more weight to more severe limitations, or some rule similar to “3 moderate limitations are equivalent to 1 severe limitation”. It can be said that this is a more flexible version of the maximum limitation method.

5.6.3 Subjective combination

This is an *ad hoc* combination, which depends on subjective judgement of the suitability rating and prior knowledge of the ecology and technology of the land utilization type is important. So the evaluator can compare to the qualities of the land subjectively.

There are mainly two disadvantages of this method. Firstly, two evaluators may not have the same judgement on one issue. Secondly, it needs very experienced evaluators who have a good knowledge of all crops. If the evaluator is experienced, the system is very fast and this can be the main advantage (FAO, 1976).

For the Eritrean situation the limiting factor approach can give more satisfactory results than the other two. This is mainly because the remaining two needs experienced experts (which Eritrea doesn't have currently) and certain results of research. In Eritrea the most limiting factor is the low availability of moisture, so every proposed land utilization type should be related to the conservation of water and effective use of available water.

5.7 Presentation of results

The overall objective of land suitability evaluation is to classify a certain area of land according to its suitability for a specific use. The final result, therefore, should include maps, tables and a supporting report. There are two ways in which a mapped suitability could be presented. Firstly, the base map that was used for field survey can be used as a final suitability map but this is not recommended because of problems of neatness, so another map with the same scale is preferred. The second way is by compiling different suitability maps, i.e. one for each kind of land use. This way, if coloured maps are used, is effective in attracting readers and map users. On the other hand it is more expensive than the first method.

As far as tabular presentation is concerned, suitability could be presented for current (without major improvement) and for potential (after major improvement) situations (Tables 5.4 and 5.5). During presentation for potential suitability, all proposed improvements, including their financial demands, should be indicated in the report. This helps decision-makers to decide whether a particular improvement is more applicable than another is.

The supporting report should specify all the procedures used, assumptions made and objectives considered. It must avoid using scientific words and should be presented in such a way that all concerned people should read it and understand it easily. A well-written report that can only be understood by specialists (e.g. soil scientists) is useless for other parties involved in land use planning. Therefore, a report should be written in simple words that could be easily understood by extension workers and land users.

Table 5.4: Tabular legend for current suitability (from FAO, 1976)

Land mapping unit	Kinds of land use				
	A	B	C	D	E (etc.)
1	S1	S3	N2	S1	S2
2	S2	S1	S2	N1	N2
3 (etc.)	S3	S1	N1	S3	S1

Table 5.5: Tabular legend for potential suitability (from FAO, 1976)

Land mapping unit	Kinds of land use	
	A	B (etc.)
1	S3m / S2	N2e / N1e
2 (etc.)	N2m / S3s	N2e / N1e

Current suitability / Potential suitability

5.8 Conclusion

Land suitability evaluations can be employed for two specific reasons, i.e. to find a suitable area of land for a specific land utilization type or to allocate a suitable land utilization type to a specific area of land. These two strategies can be used alternatively, depending on the circumstances of a specific country or area. The latter strategy needs comparison (economic) between two or more land uses before one decides on the use of a particular land. The more profitable use, whether poultry or dairy farms or horticultural crops or grain crops, will be considered. So the determining factor in choosing a strategy is the objectives of the evaluation. For example, if the objective of a country is to find areas of land for specific commercial crops (tea or coffee) or to grow some selected grain crops (wheat, sorghum or maize) in order to achieve self-sufficiency in food, then the former strategy is suitable. This strategy gives priority for selected crops to be grown in more suitable areas of land but it also needs strategic allocation of land for a specific crop. For example it is not wise to allocate areas with enough moisture and good soil conditions for sorghum and areas with less available moisture and relatively less fertile soils for maize, but the opposite will give good results. This is because naturally sorghum can do well in areas of less moisture and relatively poor soils than maize. Such strategy is suitable for Eritrea today because the main objective of the country is to be self sufficient in food by growing selected crops on suitable lands.

In order to reach a final suitability ratings, it is important to know the requirements (climatic, soil, landforms, etc.) of the proposed crop and qualities of each specific area of land. Through the process of physical matching the suitability rating of an area can be decided for a specific use. But this is not a final suitability. Others, like environmental consequences, economic feasibility and social acceptability of the use must be evaluated before reaching on final suitability rating. Improvements of land qualities can be proposed in order to bring both the requirements of the crop and qualities of the land in harmony. The cost involved during land improvement (major improvement) should be considered during evaluation. Land suitability evaluation is a dynamic process in a sense that when circumstances change, the objectives can also be changed. As a result different uses can be proposed for certain area which is currently under a specific use.

CHAPTER 6: CONCLUSION AND RECOMMENDATION

Land suitability evaluation, unlike land capability classification, takes both the descriptions of land utilization types and soil and other resource surveys into consideration. It starts by stating the clear objective of the evaluation. This leads to the selection of major kinds of land use and later the establishment of land utilization types in a more detailed way. This part of the process helps the evaluator to identify what to look for during surveying. The requirements and limitations (climatic, soil, landform, etc.) of each land utilization type will be determined. At the same time the mapping of land will resume where land qualities and land characteristics are used to measure or estimate the fitness of the land. At this stage land improvement could be introduced to improve the quality so that it can easily be matched.

Comparison of the requirements of the land utilization types and qualities of the land will follow. This part of the evaluation has three parts i.e. first it can be compared physically but this is not enough to decide on the final suitability of the land. In order to be able to decide on the final suitability it is important to also consider the other two factors, i.e. socio-economic acceptability and feasibility and environmental sustainability of the proposed land use. Different iteration or modifying decisions could be considered before one decides on the final suitability. For example, if the objective was to find an area of land for small scale coffee farming and the available resources might not be able to support the proposed land use. It is advisable to suggest to the government or other body to reconsider the objectives and consider changes to the original objective of the evaluation. On other occasions the iteration process could be done to introduce land improvement or modifying the land use type so as to match the proposed land use and the land qualities in harmony.

The rating of suitability of each land mapping unit will be decided including the possible reasons for putting a certain land in a specific category. The suitability of any piece of land is decided in relation to a specific land use only. This indicates that certain area could be marginally suitable (S3) for a specific land use but the same land could be highly suitable (S1) or moderately suitable (S2) for another kind of land use.

The final stage of suitability evaluation is the presentation of results. This includes printing of maps showing the rating of suitability of each mapping unit and a well-written report stating all the procedures and reasons for allocating a certain area of land under specific level of suitability.

Generally two strategies can be used to approach suitability evaluation. These are (a) allocating alternative crops for specific areas and (b) allocation of alternative areas for specific crop. These strategies can be applied in different circumstances but in the case of the Eritrean situation the latter is more applicable. This is because if there are priority crops that should be planted to secure food self-sufficiency for the masses of the people, there is no choice but to find/allocate areas of land for the production of such crops. Sorghum and wheat are among the priority crops in Eritrea, so by using the second strategy areas suitable for the successful production of these crops should be identified.

Such activity of land suitability guides planners and decision-makers towards sustainable land use. Any improper land use could cause destruction to the available land resources and reduce the yield and the production. As a result land users could abandon the use of the land and migrate to towns and industrial areas. The general plan should be drafted in such a way that the use of any piece of land (agricultural or otherwise) should comply with the overall objective of the country and should ensure the sustainable use of the land resources. The following points should be considered during the allocation of land for particular use in Eritrea:

(a) The use in question must be very important to the general objective of the country.

(b) The use must ensure income to the land user or to the community.

(c) The use should comply with the real situation of the local community.

(d) The use must be sustainable, i.e. it must not result in degradation and erosion of the natural resources of the country.

To accomplish these and other related objectives, there should be a land use committee at a national level that evaluate the existing condition and decide accordingly. The committee could be at ministerial level and feedback from land use experts can follow to enable the committee decide on proper land use.

In Eritrea the availability of moisture is a limiting factor and any planning for rainfed agriculture should consider this quality seriously. So soil and water conservation and water harvesting techniques should be given high priority, at the same time selecting crops that survive on the available climatic conditions should be encouraged. Another water conserving and nutrient replenishing technique is through fallowing. This practice, sometimes, could clash with the low land availability but it must be seen in relation to the average yield that can be obtained, not the total production.

In any land use program the involvement of local communities should be given attention. Local knowledge is unique to certain communities (Warren, 1991). The use of RRA or PRA could be helpful in identifying the needs of the people. The latter gives the necessary information about any community and increases the confidence of the people but it needs more time compared to RRA. If time and capital allows, the use of PRA is recommended for the Eritrean situation.

Continuous training of both agricultural experts and land users on proper use and conservation of land resources should be the main agenda of the ministries concerned. Since land evaluation is a multidisciplinary activity, exchange of experts (e.g. from the ministries of Agriculture and Land, Water and Environment) should be encouraged for fruitful planning.

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Appendices

Appendix 1: Major soil units of Eritrea and their characteristics (FAO-UNESCO, 1990)

Soil units	Origin of the name and its major features
Arenosols	From L. *arena,* sand; connotative of weakly developed coarse textured soils.
Calcisols	From L. *calx,* lime; connotative of accumulation of calcium carbonate.
Cambisols	From late L. *cambiare*, to change; connotative of change in colour, structure and consistence.
Fluvisols	From L. *fluvius*, river; connotative of alluvial deposits.
Gypsisols	From L. *gypsum*; connotative of accumulation of calcium sulphate.
Leptosols	From Gr. *leptos,* thin; connotative of weakly developed shallow soils.
Lixisols	From L. *lixivia*, washing; connotative of accumulation of clay and strong weathering.
Luvisols	from L. *luere*, to wash, 'lessiver'; connotative of accumulation of clay.
Nitisols	From L. *nitidus*, shiny; connotative of shiny ped faces.
Regosols	From Gr. *rhegos*, blanket; connotative of a mantle of loose material overlying the hard core of the earth.
Solonchaks	From R. *sol*, salt, and *chak;* connotative of salty area.
Vertisols	From L. *vertere,* to turn; connotative of turn over of surface soils.

L = Latin Gr = Greek R = Russian

Appendix 2: Lists of requirements of Land utilization types for rainfed crop production (FAO, 1983)

A. Crop Requirement

Energy	-Radiation -Photoperiodocity	
Temperature	-Total requirement -Critical period	Growth cycle
Moisture		
Oxygen (soil drainage)		
Nutrient availability		
Nutrient retention		
Rooting condition		
Conditions affecting germination or establishment		
Air humidity as affecting growth		
Condition for ripening		
Flood hazard		
Climatic hazard	-Frost -Storm	
Excess of salts	-Salinity -Sodicity	
Soil toxicities		
Pests and diseases		

B. Management Requirement

Soil workability	
Potential for mechanization	
Conditions for land preparation and clearance	
Conditions affecting storage and processing	
Conditions affecting timing of production	
Access with in the production unit	
Size of potential management unit location	-Existing accessibility -Potential accessibility

C. Conservation Requirements

Erosion hazard
Soil degradation hazard

Appendix3: Climatic and soil requirements of selected grain, vegetable and fruit crops (Dent and Young, 1981).

Crop	Total growing Period (days)	Mean daily Temperature For growth (°C) Optimum (And range)	Day length Requirements for Flowering	Specific climatic constraints/requirements	Soil requirements	Sensitivity to salinity
Bean (*Phaseolus vulgaris*)	Fresh: 60-90 Dry: 90-120	15-20 (10-27)	Short day/day neutral	Sensitive to frost, excessive rain, hot Weather	Deep, friable soil, well drained: optimum pH 5.5-6	Sensitive
Banana (*Musa spp*)	300-365	25-30 (15-35)	Day neutral	Sensitive to frost; temperature <8 °C for longer periods causes serious damage; requires high RH, wind <4 $m\ s^{-1}$	Deep, well drained loam without stagnant water; pH 5-7	Very sensitive
Cabbage (*Brassica oleracea*)	100-150+	15-20 (10-24)	Long day	Short periods of sharp frost (-10) are not harmful: optimum RH 60-90%	Well drained: optimum pH 6-6.5	Moderately sensitive
Citrus (*Citrus spp*)	240-365	23-30 (13-35)	Day neutral	Sensitive to frost (dormant trees less), strong wind, high humidity; cool winter or short dry period preferred	Deep, well aerated, light to medium textured soils, free from stagnant water: pH 5-8	Sensitive
Cotton (*Gossypium hirsutum*	150-180	20-30 (16-35)	Short day/day neutral	Sensitive to frost, strong or cold winds; temperature required for boll development: 27-32 (20-380°C range); dry ripening required	Deep, medium-heavy textured soils: pH5.5-8 with optimum pH 7-8	Tolerant
Groundnut (*Arachis hypogaea)*	90-140	22-28 (18-33)	Day neutral	Sensitive to frost; for germination temperature should be >20°C	Well-drained, friable, medium textured soil with loose top soil: pH 5.5-7	Moderately sensitive
Maize (*Zea mays*)	100-140+	24-30 (15-35)	Day neutral/short day	Sensitive to frost; for germination temperature >10°C; cool temperature causes problem for ripening	Well-drained and aerated soils with deep water-table and without water logging: optimum pH 5-7	Moderately sensitive

Onion *(Allium cepa)*	100-140 (+30-35 in nursery)	15-20 (10-25)	Long day/day neutral	Tolerant to frost; low temperature (<14-16) required for flower initiation; no extreme temperature.	Medium-textured soil: pH 6-7	Sensitive

Appendix 3 (continued)

Crop	Total growing Period (days)	Mean daily Temperature For growth (°C) Optimum (And range)	Day length Requirements for Flowering	Specific climatic constraints/requirements	Soil requirements	Sensitivity
Pea (*Pisum sativum*)	Fresh: 65-100 Dry: 85-120	15-18 (10-23)	Day neutral	Slight frost tolerant when young	Well-drained and aerated soils: pH5.5-6.5	Sensitive
Pepper *(Capsicum spp)*	120-150	18-23 (15-27)	Short day/day neutral	Sensitive to frost	Light-medium textured soils: pH 5.5-7	Moderately sensitive
Potato (*Solnum tuberosum)*	100-150	15-20 (10-25)	Long day/day neutral	Sensitive to frost; night temperature <15°C required for good tuber initiation	Well-drained, aerated and porous soils: pH 4.5-6	Moderately sensitive
Sesame Sesame indicum syn. S. orientale	80-180	27-33 (17.5-40)	Short day/day neutral	Sensitive to excessive rain and water logging	Moderate fertile, good structured, well drained sandy loam is preferred: pH 5.5-8.0	Sensitive
Tomato (*Lycopersicon esculentum*)	90-120 (>25-35 in nursery)	18-25 (15-28)	Day neutral	Sensitive to frost, high RH and strong wind; optimum night temperature 10-20°C	Light loam, well drained without water logging: pH5-7	Sensitive
Watermelon (*Citrullus vulgaris*)	80-110	22-30 (18-35)	Day neutral	Sensitive to frost	Sandy loam is preferred: pH5.8-7.2	Moderately sensitive

RH= Relative humidity

Appendix 4: Land qualities that need to be assessed for rainfed crop production (FAO, 1983)

Qualities related to crop growth

LQ1	Radiation regime:	Total radiation Day length
LQ2	Temperature regime:	
LQ3	Moisture availability:	Total moisture Critical period Drought hazard
LQ4	Oxygen availability to roots (drainage)	
LQ5	Nutrient availability	
LQ6	Nutrient retention capacity	
LQ7	Rooting condition	
LQ8	Conditions affecting germination and establishment	
LQ9	Air humidity as affecting growth	
LQ10	Conditions for ripening	
LQ11	Flood hazard	
LQ12	Climatic hazard	
LQ13	Excess salts:	Salinity Sodicity
LQ14	Soil toxicities	
LQ15	Pests and diseases	

Qualities related to management

LQ16	Soil workability	
LQ17	Potential for mechanization	
LQ18	Land preparation and clearance requirement	
LQ19	Conditions for storage and processing	
LQ20	Conditions affecting timing of production	
LQ21	Access within the production unit	
LQ22	Size of potential management unit	
LQ23	location:	Existing accessibility Potential accessibility

Qualities related to conservation

LQ24	Erosion hazard
LQ25	Soil degradation hazard

Appendix 5: List of class-determining factors (i.e. as land use requirements or limitations or as land qualities) with some land characteristics, input and land improvements for consideration in setting critical limits for irrigated crop production (FAO, 1985)

	Class-determining factors: -land use requirements or limitations -land qualities (where applicable)	Representative land characteristics, inputs, land improvements and other relevant considerations
Agronomic:	**-crop requirement /limitation** **-the crop environment**	
1.	Growing periods: -growing period requirement -growing period	Growing cycle of crops. Dates and duration (days)
2.	Radiation -radiation requirements -radiation regime	Day length, extra-terrestrial radiation; solar radiation (Rs); photosynthetically active radiation (PAR); actual sun shine hours (n); possible number of sunshine hours (N); net short wave radiation Rns; total net radiation (Rn), mm of evaporation (Rn=cal/cm2/min approximate equivalent to 1 mm water/hr).
3.	Temperature: -temperature requirement -temperature regime	Temperature data. Heat units. frost free periods.
4.	Rooting: -rooting requirement -rooting conditions	Effective soil depth for roots. Root room. Volume % of stones. Penetration resistance or soil Strength.
5.	Aeration: -oxygen & aeration requirement -oxygen supply and soil aeration	Periods with or without adequate aeration during the growth period. (Depth and fluctuation of ground-water)
6.	Water quality: -water requirement -water supply -total water -critical period	Water balance, water storage. yield vs. evapo-transpiration relationships; deficient periods Run-off, run-on, seepage and porcolation, ground water contribution, effective precipitation. Stream flows, diversions, storage releases, aquifer safe yields.

Appendix 5 (continued)

Class-determining factors: -land use requirements or limitations -land qualities (where applicable)		Representative land characteristics, inputs, land improvements and other relevant considerations
7.	Nutrients (NPK): -nutrient requirement -fertilizer requirements -nutrient supply -fertilizer supply	NPK uptakes by crops & response to NPK. Loses of NPK (leaching, volatilization, fixation, etc.). N fixation. soil nutrients & their retention. CEC fertilizer requirement & availability including manure, etc.
8.	Water quality: -crop tolerance to water quality -water quality	Total salt concentration. Ionic composition. Sodium adsorption ratio (SAR),pH, carbonates and bicarbonates.
9.	Salinity: -crop tolerance to salinity -salinity regime (salt balance)	Plant salt tolerances, present and future soil salinity, inputs of salt through water supply, losses of salt by leaching, salt balance. Seasonal salt movement in profile, salt from groundwater.
10.	Sodicity: -crop tolerance to sodicity -sodicity regime	Predicted pH, ESP and/or SAR of soil solution, predicted effect on soil structure, infiltration and permeability. Sodium toxicity.
11.	pH, micronutrients and toxicities: -crop tolerance, susceptibilities -toxicity or micronutrient regime	On non rice crop land, pH effects and crop tolerances and susceptibilities to excesses or deficiencies of Ca, Mg, Zn Fe, S, B, Cu, Mn, Mo, Al.
12.	Pest, Disease, Weeds: -crop tolerance, susceptibilities -pest, disease, weed hazard.	Crop tolerances and susceptibilities. Wild animals, birds, arthropods etc. Fungal, bacterial, viral pathogens. Weeds. Pesticides, fencing, inputs.
13.	Flood, Storm, Wind, Frost: -crop tolerance, susceptibilities -flood, storm, wind, frost hail hazard	Frequency and severity of floods, storms wind, frost and hail if any.

Appendix 5 (continued)

	Class-determining factors: -land use requirements or limitations -land qualities (where applicable)	Representative land characteristics, inputs, land improvements and other relevant considerations
	Management: **-management requirements and limitations.** **-conditions affecting management**	
14.	Location: -location requirement -location	Closeness to markets, processing unit. Access to inputs and services. Access to water (gravity, pumped). Travel & transport problem & cost. Day to day management problems. Accessibility of machinery.
15.	Water application management: -limitation of irrigation method -conditions affecting water appl-ication management.	Size, shape of management unit. Labour requirement. Availability. Conditions affecting uniformity of Water application, rate, frequency and duration of application.
16.	Pre-harvest farm management: -pre-harvest farm management requirements & limitations -conditions affecting pre-harvest farm management	Effects of timing of pre-harvest opera-tions (e.g. soil workability) including land preparation, nurseries, seeding, transplanting, fertilizer application, irrigation, weeding, spraying etc.
17.	Harvest and post harvest Management: -requirements and limitations -conditions affecting	Atmospheric wetness, dryness, wind. Soil wetness, dryness. Effects of soil or humidity on the quality of the crop produce.
18.	Mechanization -requirements for mechanization -conditions affecting potential for Mechanization and on-farm Transportation	Slope angle, rock hindrances, stoniness, soil depth, soil texture, shape and size of fields. Effects of soil compaction. on-farm transportation.

Appendix 5 (continued)

Class-determining factors: -land use requirements or limitations -land qualities (where applicable)		Representative land characteristics, inputs, land improvements and other relevant considerations
	Land development and improvement **-land development requirements** **-factors affecting cost of land clearing**	
19.	Land clearing: -land clearing requirements -conditions affecting cost of land clearing	Forest: underbrushing, felling, burning stacking; costs, value of timber, charcoal time period to development. Persistent weeds: mechanical cultivation, flooding chemical control; costs, time period to development. Rocks and stones: removal costs.
20.	Land grading and leveling: -grading and leveling requirement -conditions affecting land grading and leveling costs	Slope, microrelief, macrorelief, cover. Field size and shape, cut and fill, earthmoving costs.
21.	Physical, chemical and organic aid and amendments -requirements -conditions affecting costs	Need for deep ploughing, subsoiling, profile inversion, sanding, marling; gypsum, lime, organic matter, costs.
22.	Reclamation leaching: -leaching requirement -conditions affecting leaching	Primary or one-time reclamation leaching requirements mm of water; continuous or intermittent, costs.
23.	Irrigation engineering -irrigation engineering requirements conditions affecting engineering works and costs	Earthwork and other structures for diversion, storage, conveyance, and regulation of water. Topography, substratum conditions, permeability channels, access to construction sites, cost of engineering works.

Appendix 5 (continued)

	Class-determining factors: -land use requirements or limitations -land qualities (where applicable)	Representative land characteristics, inputs, land improvements and other relevant considerations
	Conservation and environmental: **-conservation and environmental requirements and limitation** **-conditions affecting conservation and the environment**	
24.	Long-term prevention of salinity and sodicity: -requirements and limitations -conditions affecting long-term salinity and sodicity hazards	long-term inputs of salt, water quality water depth, permeability, drainage tidal swamp conditions, intrusion saline water into an aquifer, control measures and their costs.
25.	Long-term control of ground water and surface water: -requirements and limitation -conditions affecting long-term Control	Protection of catchment areas, degradation of catchment, sedimentation of reservoirs, control of groundwater, and their cost.
26.	Erosion hazard: -requirements and limitations -conditions affecting erosion	Erosion control. Maximum acceptable soil loss and effects of climate, soil, topography, land use factors costs.
27.	Environmental hazard: -environmental control requirement and limitations -conditions affecting long-term environmental risks	wildlife, water-borne human diseases (e.g. malaria), needs for environmental control of vectors.
	Socio-economic: **-socio-economic requirements and limitations** **-socio-economic conditions**	
28.	Farmers' attitudes to irrigation	Will the farmers utilize the irrigation facilities.
29.	Other socio-economic limitations that may be class-determining	Water rights, tenurial and land ownership complications, disincentives of taxation, fragmentation, etc.

Appendix 6: Requirements and limitations of land utilization types for extensive grazing (FAO, 1991).

I. Primary production level

A. Growth requirements

1. Radiation
2. Temperature
3. Moisture
4. Aeration (soil drainage)
5. Nutrients
6. Rooting condition
7. Salinity/sodicity
8. Soil toxicities
9. Hazards fire
10. Flood
11. Frost
12. Genetic potential of vegetation

B. Management requirements

13. Ease of control of undesirable plant species
14. Mechanized operation
15. Size of potential management units

C. Conservation requirement

16. Tolerance to soil erosion
17. Tolerance to vegetation degradation

II. Secondary production level

D. Growth requirements

18. Grazing capacity
19. Drinking water availability
20. Climatic limitation
21. Biological hazard
22. Accessibility for animals
23. Conditions for hay and silage

E. Management requirements

24. Ease of fencing or hedging
25. Location

Appendix 7: Checklists of headings for description of land utilization types (FAO, 1983)

Headings		Descriptions
I.	Cropping system	Single, multiple or compound LUT. Crops grown,cultivars,cropping calendar,cropping intensity. Perennial cropping systems, cultivation factor,cropping index.
II	Markets	Subsistence, commercial or both, domestic or export, or both.
III.	Water supply	Seasonal supply and quality.
IV.	Irrigation method	Gravity or lift, runoff-river or storage releases, surface overhead, drip, etc.
V.	Capital intensity	Value of capital investment and recurring cost per ha.
VI.	Labour intensity	Family and hired labour, man-months per ha, seasonal peak periods, festivities and holidays.
VII.	Technical skills and attitudes	Experience, response to innovation and change, literacy.
VIII.	Power	Extent of human, animal and tractor power impact on land preparation, harvesting, etc.
IX.	Mechanization and Farm operations	Which operations are mechanized or partly mechanized.
X.	Size and shape of Farms	Farm size, size by LUTs, fragmentation of holdings, rainfed and irrigated areas.
XI.	Land tenure	Free hold: family farm, corporately owned estate. Tenancy: cash rent tenancy, labour tenancy, share cropping. Communal ownership: cooperative (collective) farming, village land with rights to cultivate etc. State ownership: state farm, national park.

Appendix 7 (Continued)

Headings		Descriptions
XII.	Infrastructure	Assumptions about processing facilities, storage deposits, markets, access to farm inputs. Roads, housing, schools, medical facilities, electricity, domestic water supplies. Research and extension, services and facilities.
XII.	Irrigation infra-Structure	Assumptions about irrigation and drainage infra-structure and access to irrigated land.
XIV.	Cultivation practice	Preparation of land for irrigation including clearing. Tillage operations (including duration for ploughing, leveling etc. Fertilizer application (timing and methods), weeding crop protection, harvesting and processing.
XV.	Material inputs	Prior assumption about quantities and quality of inputs especially for seed, planting material, fertilizers, pesticides, herbicides, etc.
XVI.	Livestock	For traction, milk or meat, manure, forage requirements, including crop by-products, field grazing, zero grazing, stall-fed, etc.
XVII.	Associated rainfed	Influence of LUT of competing rainfed agriculture, shifting cultivation or agro-forestry, timber trade from land cleared for irrigation.
XIII.	Yields and production	Yield per unit area on S1 land (ceiling value for relative yield). yield per unit of water (per m^3) especially during periods of water shortage.
XIX.	Environmental impact	Public health problems (i.e. Bilharzia, malaria, river blindness, diseases transmitted by water). Downstream effects on water supply and quality siltation, flooding, etc. Effects on wildlife conservation.
XX.	Economic information	Market prices, input costs and availabilities, sub-sidies, credit.