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.

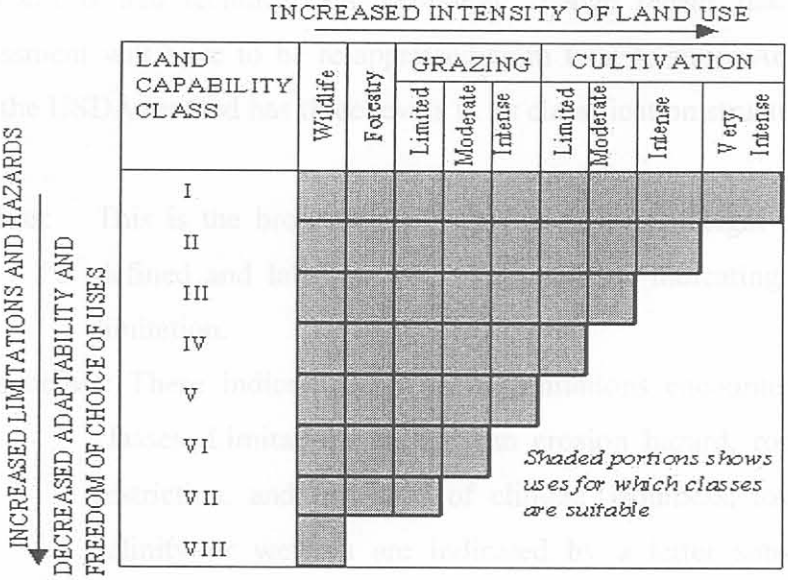

Fig. 4.1:the relation ship between USDA land capability classification Classes and intensity with which each class can be used safely (From: Davidson, 1992)

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.

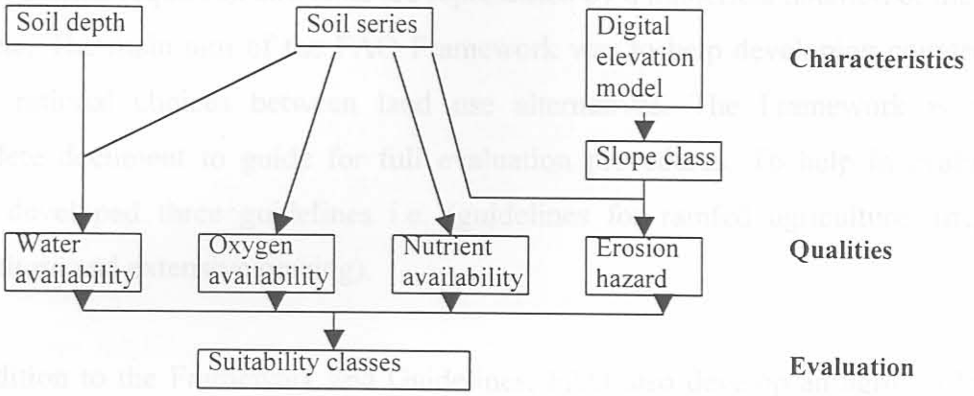

Fig. 4.2 Example of a GIS flow chart used in preparation of map of suitability classes for maize using the FAO Land Evaluation procedures (From Burrough, 1986)

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.