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

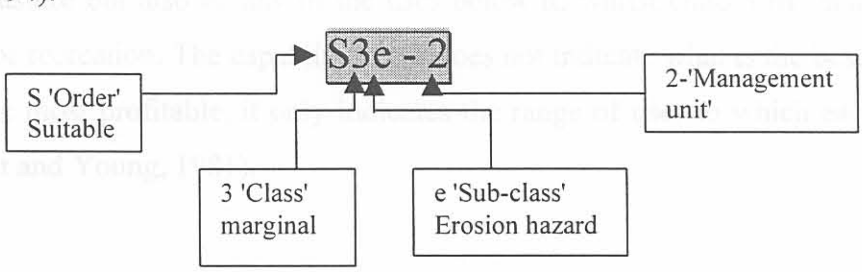
Order	Class	Sub-class	Unit
S (suitable)	S1 S2 S3 etc.	S2m S2e S2me etc.	S2e-1 S2e-2 etc.
Sc (conditionally suitable)	Sc2m		
N (not suitable)	N1 N2	N1m N1e etc.	

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 $1000 kg^{-3}$ 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.