A Land Suitability System for Spate Irrigation Schemes in Eritrea: The case of 'Sheeb' spate irrigation scheme.

Mehreteab Tesfai

University of Asmara, College of Agriculture, Department of Land Resources and Environment, P.O.Box 1220, Telefax 291-1-162236, Asmara, Eritrea. E-mail: mehreteabt@yahoo.com

Abstract

Spate irrigation is a system used for wetting land prior to planting. Use is made of seasonal rivers (wadis) producing flash floods in the highlands, which are diverted by structures to irrigate fields in the lowlands. A land suitability system for spate irrigation schemes was studied in the Sheeb area of Eritrea with and without improvements. The availability of floods and soil moisture appeared to be the most limiting land qualities for spate-irrigated sorghum and maize growth, while salinity hazard has only a minor effect in the spate irrigation system, due to the flooding of fields. Without improvements to spate irrigation system, about 60% of the study area were suitable for spate irrigation development. Three suitable classes (S1/S2, S2, and S3) for sorghum and two suitability classes (S2 and S3) for maize cultivation, and one unsuitable class (N1) were identified. However, with improvements to the spate irrigation system (such as construction of permanent flood diversion structures), the land suitability classes would be upgraded and the area of land suitable for spate irrigation development would expand. The land suitability system presented in this study could be applied in other spate irrigation schemes of Eritrea and perhaps in other countries also.

Keywords: Spate irrigation, land suitability, Eritrea, Sheeb area.

1 Introduction

With the explosion of population in the world in general and in sub-Saharan African (SSA) countries in particular, the need to increase food production is becoming imperative. To meet the food demand of the population of SSA, agricultural production should be increased either by expanding the area of cultivated land (extensification) or by increasing the yield of individual crops per unit area (intensification). The increasing demand for intensification of existing cultivated areas or opening up of new areas of land, however, requires that land be classified according to its suitability for different kinds of use (FAO 1983).

In Eritrea, the need for land suitability studies is unquestionable in view of the ever-increasing demand of land for agriculture in order to satisfy the food demand of the country's population, estimated 4.0 million. About 70-80% of the population of Eritrea makes a livelihood on agriculture (World Bank 1994; FAO 1997).

In the eastern lowlands of Eritrea, agriculture is practised with spate irrigation. Spate irrigation can be defined as a pre-planting system of irrigation, in which use is made of seasonal rivers (wadis) producing flash floods in the highland areas are diverted by structures to irrigate fields in the lowlands of the country (UNDP/FAO 1987; Tesfai 2001). During the rainy season (July-September) the wadis springing from the Eastern Highlands of Eritrea transport large amounts of runoff with sediments to the eastern lowlands, such as the Sheeb area. The farmers in this area divert the runoff into adjacent irrigable fields using temporary diversion structures called locally ‘agims'. The diverted runoff with its sediments is conveyed into the earthen canals, called locally ‘misghas' and finally collected in the fields that are surrounded by earthen bunds. Seeds are sown in these fields and crops are produced using the residual moisture.

Spate irrigation has a number of peculiar land use requirements and therefore the classical land suitability systems are not applicable. For example, an adequate number of floods and good water holding capacity of the soils are some of the basic land use requirements for spate irrigation system (SIS) to function in a sustainable way. Hence, a study was undertaken (1) to design a land suitability system for spate irrigation schemes, and (2) to assess the land suitability classes with and without improvements of the SIS in the Sheeb area of Eritrea.

2 Methods

2.1. Site characteristics

The study area is located in the Red Sea coastal plains of Eritrea at latitude 15 ° 52 ' N and longitude 39 ° 01 ' E. The Sheeb area covers about 10 km 2 . The area has an arid climate, with a mean temperature of 36 ° C in the flood season (July to September) and 25 ° C in the cropping season (October to February). The main wadis, Laba and Maiule transport the seasonal floods produced from the adjacent highlands to the Sheeb spate irrigation area. The study area has a flat topography with 1-2% slope downward from west to east. The dominant types of soils are the alluvial soils, which are found in the irrigated fields. These soils have been accumulated as a result of the build-up of sediment over the years, and now often exceed a depth of 3 m. The soils are presumed to be fertile with good water-holding capacity and are well drained. Furthermore, the soils are said to be non-saline, because the deep flooding (that is, a characteristic of spate irrigation) leaches the soluble salts deep into the soil profile (Halcrow 1997; Tesfai 2001).

2.2. Selection criteria for land qualities

The suitability of any area for development of irrigated agriculture is dependent on the availability and quality of water for irrigation, and the properties of soils. The main land qualities limiting the suitability for spate irrigated field crops (notably sorghum and maize) are water and soils under the conditions of the Sheeb area. Hence, the selection of land qualities was based on the water availability and soil quality in the schemes.

Two major land units (Land unit A: irrigable land and Land unit B: non-irrigable land, found inside and outside the spate fields, respectively) were identified in the study area. The availability of floods, soil moisture, flood hazard, nutrient status, soil drainage and salinity hazards were the main land qualities selected for land suitability assessment in the study area. The corresponding land characteristics identified were: the number of floods diverted to the fields, available water capacity of the soils, occurrence of damaging big floods, organic matter content, drainage classes and salinity values. Rooting conditions of crops (as affected by soil depth), soil pH, slope and climate (temperature, rainfall, etc) have not been included in the selection criteria since these are relatively homogenous throughout the Sheeb area and/or are not limiting factors for spate irrigated agriculture.

2.3. Land suitability ratings

In land suitability ratings for spate irrigation, only the main crops (sorghum and maize) are considered because they have different land use requirements. Millet has more or less similar requirements as sorghum. Therefore, a land class, which is suitable for sorghum, is also assumed to be suitable for millet.

In this study, land suitability-rating classes are expressed in qualitative terms: highly suitable (S1); moderately suitable (S2); marginally suitable (S3), and currently unsuitable (N1), as described by FAO (1985).

The arithmetic method suggested by Dent and Young (1981) and FAO (1991) was used to combine individual land suitability ratings into an overall suitability assessment for the spate-irrigated sorghum and maize. Each suitability class was assigned a numerical value as follows: S1 = 3.0, S2 = 2.0, S3 = 1.0 and N1 = 0.0. These values were totalled for the six land qualities mentioned earlier. Finally, the following suitability classes were defined with the ranges S1 = 15-18, S2 = 9-15, S3 = 5-9, and N1 = 0-5 out of a maximum score of 18.

3. Results

3.1 The land use requirements

Tables 1 and 2 shows the land use requirements for spate irrigated sorghum *(Sorghum bicolor, L.)* and maize (*Zea mays,L.*) in Sheeb area.

According to Tables 1 and 2, except for requirement of floodwater, soil moisture and salinity tolerance, the other land use requirements are similar for sorghum as well as for maize growth. The requirements of sorghum for flooding are less than maize because sorghum is more drought resistant than maize. The crop water requirements for sorghum ranges between 350-650 mm in the growing period, while for maize is about 500-800 mm (Doorenbos and Kassam 1979). Sorghum is moderately tolerant to soil salinity, at which yield loss starts at ECe 7 d S m^{-1} , where as maize yield loss starts at ECe 2.5 d S m^{-1} (Landon 1991).

Table 1. Rating of land use requirements for spate irrigated lowland sorghum in Sheeb area.

Crop requirements		Diagnostic factor ratings			
Land qualities	Land characteristics	Highly suitable	Moderately suitable	Marginally suitable	Not suitable
S1	S2	S3	N1		
Floodwater ava.	No. of floods diverted	> 4	3-4	1-2	nl
Soil moisture ava.	Ava. water (mm m^{-1})	> 200	150-200	100-150	< 100
Flood hazard	Big flood frequency (yr)	1 in 10	1 in 6-10	1 in 3-5	1 in 1-2
Nutrient status	OM content (%)	> 3.0	1.0-3.0	0.5-1.0	< 0.5
Drainage condition	Soil drainage (class) †	5	4	3, 6, 7	1, 2
Salinity hazard	Soil salinity ECe‡ (d S m^{-1})	0-6	6-9	9-16	> 16

† 1 = Very poorly drained; 2 = poorly drained; 3 = imperfectly drained; 4 = moderately drained;

5 = well drained; 6 = somewhat excessively drained and 7 = excessively drained, FAO (1985). nl: nil and ava.: availability, ‡ ECe: Electrical conductivity of a soil saturated extract.

Table 2. Rating of land use requirements for spate irrigated lowland maize in Sheeb area.

Crop requirements		Diagnostic factor ratings			
Land qualities	Land characteristics	Highly suitable	Moderately suitable	Marginally suitable	Not suitable
S1	S2	S3	N1		
Floodwater ava.	No. of floods diverted	> 5	3-5	1-3	nl
Soil moisture ava.	Ava. water (mm m -1)	> 250	200-250	150-200	< 150
Flood hazard	Big flood frequency (yr)	1 in 10	1 in 6-10	1 in 3-5	1 in 1-2
Nutrient status	OM content (%)	> 3.0	1.0-3.0	0.5-1.0	< 0.5
Drainage condition	Soil drainage (class)	5	4	3, 6, 7	1, 2
Salinity hazard	Soil salinity (d S m -1)	0-2	2-6	6-9	> 10

3.2. The land characteristics

Table 3 presents the average values of land characteristics in land unit A for upstream, midstream and downstream spate irrigated fields and land unit B in the non-irrigable land.

The land use requirements listed in Tables 1 and 2 have been matched with the land characteristics in Table 3 to identify the suitability classes in Table 4 for spate-irrigated sorghum and maize cultivation.

Table 3. The measured average values of land characteristics for land units A & B without improvements.

Land characteristics	Land unit-A				Land unit-B
Upstream	Midstream		Downstream		
	LU A-1	LU A-2			
Floods diverted to the fields (no.)	4	3	3 †	1-2	nl
Soil moisture availability (mm m - 1)	200-250	150-200	150-200	150-200	100-150
Big flood hazard (years)	1 in 2-3	1 in 8	1 in 8	1 in 3-5	nr
Organic matter (%)	1.04	1.06	1.42	0.59	0.45
Soil profile drainage (class)	5	4	4	3	6
Soil salinity, ECe (d S m -1)	2.0	2.5	9.0	1.0	17.0

LU A-1: currently, spate irrigated land, LU A-2: currently, unirrigated land, and nr: not relevant.

† Estimated no. of floods diverted when the land was utilised for spate irrigation.

4. Discussion

4.1 The land suitability classes for the SIS (without improvements)

Without improvements to the spate irrigation system (i.e. under the present condition), three suitability classes: S1/S2, S2, and S3 for sorghum and two suitability classes: S2 and S3 for maize were identified. In this study, only one class with N1 (currently Not suitable land) has been identified because no physical factors (such as steep slopes) or social and economic factors (marketing, water rights, land rights, etc.) have been found to classify any part of the study area as N2 (permanently not suitable land) for cultivation of sorghum and maize.

The major growth limiting factors for spate irrigated sorghum and maize in land unit-A in the upstream fields were flood hazard (h) and nutrient status (n). The upstream fields being nearer to the diversion sites are often susceptible to big flood hazards. Moreover, a large amount of coarse textured soils (brought by the wadis) settled out in the upstream fields, which are poor in plant nutrients and organic matter.

The most limiting land quality for crop production in the midstream spate irrigated fields (in land unit A-2) was salinity hazard (s). The probable reason for the salinity hazard was this land has not been irrigated for about 50 years. In this time, salts have accumulated on the top of the soil surface through upward movement of saline ground water originating from parent materials, which contain salt minerals like evaporites and limestones (NRCE 1996). Moreover, wind blown salt particles from the Red Sea coast (which is about 40 km from Sheeb area) might have also contributed to the development of salt in this land unit.

Two major limiting factors for crop production in downstream spate irrigated fields, were availability of floodwater (f), and flood hazard (h). According to water rights system, this land receives water after all the upper fields have been sufficiently irrigated. Mostly, few floods reach the site, which petered out before they irrigate all the fields. Sometimes, this land might not even receive flood at all. Moreover, some part of this land is also threatened by severe gully erosion caused by sporadic damaging big floods discharged from nearby smaller wadis, Haramazo and Gersile.

In land unit-B, the three major limiting factors are availability of floodwater, availability of soil moisture, and salinity hazards. In this land, there is no flood reaching the area and the soils are dry for most of the year and therefore, salinity problems are severe.

Table 4. Suitability classes for spate irrigated lowland sorghum and maize in Sheeb area.

Land qualities	Land unit-A								Land unit-B	
	Upstream		Midstream				Downstream			
			LU A-1		LU A-2					
	c	v	c	v	c	v	c	v	c	v
				Sorghum						
Ava. of flood water (f)	S1	3	S2	2	S2	2	S3	1	N1	0
Ava. of soil moisture (m)	S1	3	S2	2	S2	2	S2	2	S3	1
Big flood hazard (h)	S3	1	S2	2	S2	2	S3	1	nr	-
Nutrient status (n)	S2	2	S2	2	S2	2	S3	1	N1	0
Drainage condition (d)	S1	3	S2	2	S2	2	S3	1	S3	1
Salinity hazard (s)	S1	3	S2	2	S3	1	S1	3	N1	0
Overall LSC & value	S1/S2	15	S2	12	S2	11	S3	9	N1	2

Land suitability subclass	S1/S2hn		S2fm		S2s		S2/S3fhn		N1fns	
					Maize					
Ava. of flood water(f)	S2	2	S3	1	S3	1	S3	1	N1	0
Ava. of soil moisture (m)	S2	2	S3	1	S3	1	S3	1	N1	0
Big flood hazard (h)	S3	1	S2	2	S2	2	S3	1	nr	-
Nutrient status (n)	S2	2	S2	2	S2	2	S3	1	N1	0
Drainage condition (d)	S1	3	S2	2	S2	2	S3	1	S3	1
Salinity hazard (s)	S1	3	S2	2	S3	1	S1	3	N1	0
Overall LSC & value	S2	13	S2	10	S2	9	S3	8	N1	1
Land suitability subclass	S2hn		S2fm		S2s		S3fmh		N1fn	

c: class, v: value, nr: not relevant, and LSC: Land Suitability Class.

Nonetheless, there are opportunities to improve the traditional SIS so that the major limiting factors (mentioned above) could be rectified through various interventions (such improved irrigation structures) into the spate irrigation system. These interventions will upgrade the land suitability classes and eventually expand the area of land suitable for spate irrigation development in the Sheeb area.

4.2. The land suitability classes for the SIS (with improvements)

Table 4 shows the estimated land characteristics values for the spate irrigation system with improvements. It is envisaged with improvements of the SIS, the six land qualities (listed in Table 4) will be improved which in turn raises the land suitability classes. For example, the S1/S2 land class could be upgraded into S1, when permanent flood diversion structures are constructed at the wadis (Laba and Maiule). This is because, the improved structures will divert the floodwater more effectively so that more water will be available for irrigation. These structures could also withstand the force of big floods, which reduce the frequency of flood hazards. Furthermore, applying organic fertilisers like manure and incorporation of crop residues into the spate-irrigated fields will improve the OM and N contents of the spate soils.

The S2s land subclass in land unit A-2 could be revived and be utilised for crop production by constructing canals to the irrigable fields and by repairing the field bunds. Through successive floodings of the fields, the soluble salts present in the topsoils could be leached out. By doing so, this subclass could be upgraded into S1/S2 land class.

The most severe limitation in S3 land class is that very few floods are available in most of the years. The primary improvement required would then be to build permanent flood diversion structures at the upper reaches of the wadis (Laba and Maiule). These structures would divert the floods more effectively so that the floodwater could reach and irrigate the downstream fields of S3 land. Secondly, the local government and other development agencies should assist the farmers (by providing earth-moving machines) to construct embankments in order to control the expansion of gully erosion in the irrigable lands. With such land use improvements, a large part of the area could be upgraded into S2 land.

Table 5. The estimated average values of land characteristics of the SIS with improvements.

Land improvements (major)	Land characteristics	Value

Improved irrigation structures †	Floods diverted to the fields (no.)	> 4
Improved irrigation structures	Soil moisture availability (mm m -1)	> 200
Improved irrigation structures	Big flooding hazard (years)	1 in 10
Application of fertilisers	Soil organic matter (%)	> 3
Improved irrigation structures	Soil drainage (class)	4,5
Improved irrigation structures	Soil salinity, ECe (d S m -1)	< 2

† Improved irrigation structures include improving flood diversion structures, canal structures and field bunds.

When the permanent flood diversion structures are in place at the wadis (Laba and Maiule), more water could be available for spate irrigation. Consequently, some parts of N1 land could be developed for crop production. However, before implementing irrigation schemes in this type of land, a comprehensive and detail social and economic evaluation should be carried out.

5. Conclusions

At present, the bulk of the land (about 60%) in Sheeb spate irrigation schemes is considered to be suitable for crop production, primarily for sorghum, but also for maize cultivation. The remaining 40% of the study area were found to be currently unsuitable for spate irrigation, mainly due to a lack of water and poor soils.

In general, the information and data presented in this study should be further validated by undertaking quantitative land suitability evaluation in the Sheeb area at a field scales. However, the methodology of land suitability developed in this study could be applied in other spate irrigation schemes of Eritrea and possibly in other parts of the world, where similar systems are practised.

6. References

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