Impacts of Soil and Water Conservation on Land Suitability to Crops: The Case of Anjeni Watershed, Northwest Ethiopia

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Abstract

Soil loss in Ethiopia due to water erosion is a serious economic and environmental problem. Soil and water conservation (SWC) practices provide multiple onsite and offsite benefits. Thus, the present study was carried out to examine the long-term impacts of SWC measures in improving ecosystem services in general and land suitability to crop production in particular. Land suitability classes (LSC) were accounted using the multi-criteria analysis (MCA) on bio-physical variables of the environment. LSC were sorted by combining the FAO framework of land evaluation with GIS tools. Thus, LSC for teff (*Eragrostis teff*), maize (*Zea mays* L.), barley (*Hordeum vulgaris* L.), and wheat (*Triticum aestivum* L.) were found S2 and S3 in 1984 and 1997 whereas in 2010, some areas were transformed to S1 classes for wheat and teff. Suitable land allocation for these crops was made and 50% of the watershed is found to be S1 class for wheat while about 40% is in S2 class for all crops. In 1997 barley and teff covered 29.2% and 28.9%, respectively. While in 2010, 19% of the area was covered by teff, 18.9% by maize, 16.9% by barley and 15.6% by wheat. Wheat and maize showed significant spatial expansions that are best indicator crops for the betterment of the land quality or soil improvement.

Keywords: land suitability, ecosystem service, soil conservation, Anjeni, Ethiopia

1. Introduction

Soil and water conservation (SWC) practices in upland areas can foster the production of various kinds of ecosystem services that have both upstream and downstream benefits. By implementing practices that maintain or restore the capacity of soil to retain water along with nutrients and organic matter, farmers can dramatically reduce agricultural water demand, reduce vulnerability to climate extremes of drought and flooding, and also increase soil carbon storage, as well as productivity. By reducing runoff and the need for chemical fertilizer inputs, downstream water quality improves (CA, 2007). As the supply of any of the services becomes more limiting, human well-being will increasingly depend on achieving an acceptable balance between the trades-offs (Aylward, 2004).

Soil erosion affects an estimated 1,100 million hectares of land worldwide resulting in the transport of 2.0-2.5 × 10^{10} Mg of soil to the oceans each year (Markus, 2004). Similarly, soil erosion is one of the principal environmental problems in Ethiopia resulting in reduction of productivity of arable lands. About 1.5 billion tons of soil is lost from Ethiopia and Eritrea alone per year (Hurni, 1987) and 2 million hectares of land in Ethiopia has been severely degraded (Jagger & Pender, 2003). An annual yield reduction of 1-2% is estimated due to soil erosion in Ethiopia (Hurni, 1993). Erosion removes the most productive portion of the soil, that is, the chemically active part such as organic matter and clay fractions. It also causes a deterioration of soil structure, moisture holding capacity through lowering soil depth, increasing bulk density, soil crusting, and reducing water infiltration. The typical Ethiopian farm family of about six persons now harvests less than a tone of grain a year-less than enough for the subsistence diet-and crop yields are steadily declining due to erosion and exhausted fertility

(Harrison, 1987). Hence, such conditions call for strong conservation works. Since the early 1980s, the Ethiopian Government, with aid from international agencies, has given much attention for conservation and environmental rehabilitation works. A package of conservation measures has been developed usually employing bunds, tree planting and closure of degraded areas. Between 1976 and 1988 food-for-work (FFW) programs funded the construction of 800,000 km of soil and stone bunds on cultivated lands; 600,000 km of hillside terraces were built; and 80,000 hectares were closed for regeneration and for afforestation on steep slopes (Assefa, 2007). The Ethiopian Government invited the Swiss Agency for Development and Co-operation to help establish a research network through the University of Berne; whereby, the Soil Conservation Research Program (SCRP) in Ethiopia was conceived for the first time in 1981. The main objective of the SCRP was to support soil conservation efforts in Ethiopia by monitoring soil erosion and relevant factors of influence, by developing appropriate soil and water conservation measures, and by building local and international capacity in this field of research (Hurni et al., 2007). It involved the selection of benchmark sites with various socio-cultural settings in several different agro-climatic zones of the country. Accordingly, test catchments (small watersheds) with traditional land use systems and a size between one and seven km^2 were chosen throughout the highlands of Ethiopia. The SCRP benchmark sites were selected at Maybar in Wello (1981), at Hunde Lafto in Harerge (1982), Andit Tid in Central Shewa (1982), Anjeni in Gojjam (1984), Afdeyu in Eritrea (1984), at Gununo in Wolayta (1982) and Dizi in Illubabor. From these sites, Anjeni that is found in the Amhara Region is the focus of this study.

Anjeni Research Station was established in March 1984 as the fifth SCRP research site. Situated in the Gojjam Highlands in the North western Ethiopia, the catchment lies at a favorable altitude and has optimum climatic conditions. The area is known by its intensively cultivated land. A new soil conservation technology and approach was introduced in Anjeni, first in a small area outside the catchment in 1985, then in the whole catchment from February to April 1986. In terms of technology, carefully designed graded Fanya Juu (throwing the soil uphill so that the basin is below the embankment) structures such as those originally introduced in Andit Tid Research Station were used to conserve the agricultural land. The local communities agreed to abandon open grazing system in the watershed for an initial three years; this measure included some reforestation and area closure. The conservation approach included negotiations conducted with the communities, who agreed to do conservation work on their land in exchange of an incentive- a clinic jointly built by SCRP and the communities. This approach, entitled "social infrastructure for soil conservation", was very successful, as both the conservation measures and the clinic exist up till now.

Land use is a set of biological and technological human activities, engaged in economic and social purposes (FAO, 1976). Any land use planning for sustainable development requires identification of the type of the current land-use with respect to the socially relevant utilization types and their requirements and comparison of recommended land utilization types with existing land use. Land suitability is defined as the fitness of a specific area of land for a specified kind of land use the so called land utilization type (LUT) under a stated system of management (FAO, 1976). Land is assessed for its suitability for a LUT by considering climate, soil and site factors as they might affect potential productivity (FAO, 1976; 1983; 1984; 1993; & 2007). Land is ranked in several classes from S1 (best) through N (worst) to indicate the low payment capacity relative to increasing development and continued production costs. Either a greater cost is required to achieve the same yield, or yields will be lower under the same costs.

Assessing the suitability of land use under certain production conditions helps farmers and planners for sustainable land use decision-making and monitoring agricultural production. For example Mansfield (1979) conducted land capability classification for annual rainfed crops in Nigeria based on soil physical limitations, i.e. soil depth, drainage, texture and the presence of course materials. Evaluating land capacity, adopting appropriate land use and employing farming systems that realize the potential of the land and restore its productivity are some of the important considerations in long range planning for effective development and sustainable use of land resources. Delineating land units into homogeneous suitability classes is an effective way of allowing the users and decision makers to see which areas are highly suitable, moderately suitable, marginally suitable or unsuitable for a given land utilization or crop production purposes. There is, therefore, an increasing need to match land and land uses in the most rational way to maximize agricultural production and to satisfy the different needs of the people. Since Anjeni watershed is located in a favorable altitude (around 2450 m asl) and has good climatic conditions for agriculture and living, it is densely populated. As a result, it is intensively cultivated with no fallow periods which lead to high runoff, soil erosion and sediment loss. The study watershed has been under SWC practices for more than a quarter of a century. Thus, the objective of this study is to examine the long-term (1984-2010) impacts of SWC measures in improving ecosystem services in general and soil loss regulation & agricultural land suitability changes in particular. The main objective of this research was to analyze the role of soil and water conservation

measures on ecosystem services (changes in agricultural land suitability) at Anjeni watershed in the upper Blue Nile Basin. In light of the overarching objective, the study has addressed the following specific objectives:

- estimate changes of land suitability for selected crops grown in the watershed due to the SWC practices in the last 30 years
- prepare land allocation maps of the watershed for the selected crops at its best potential suitability using the current land suitability map identify the opportunity to environmental resilience and improvement of ecosystem services due to SWC practices

2. Materials and Methods

2.1 Description of the Study Area

2.1.1 Location of the Study Watershed

Anjeni is found in Dembecha district, Amhara region, northwest of Addis Abeba located at 10°40'59'' N, 37°31'57'' E (Geographic Center of the Watershed) as shown on Figure 1.
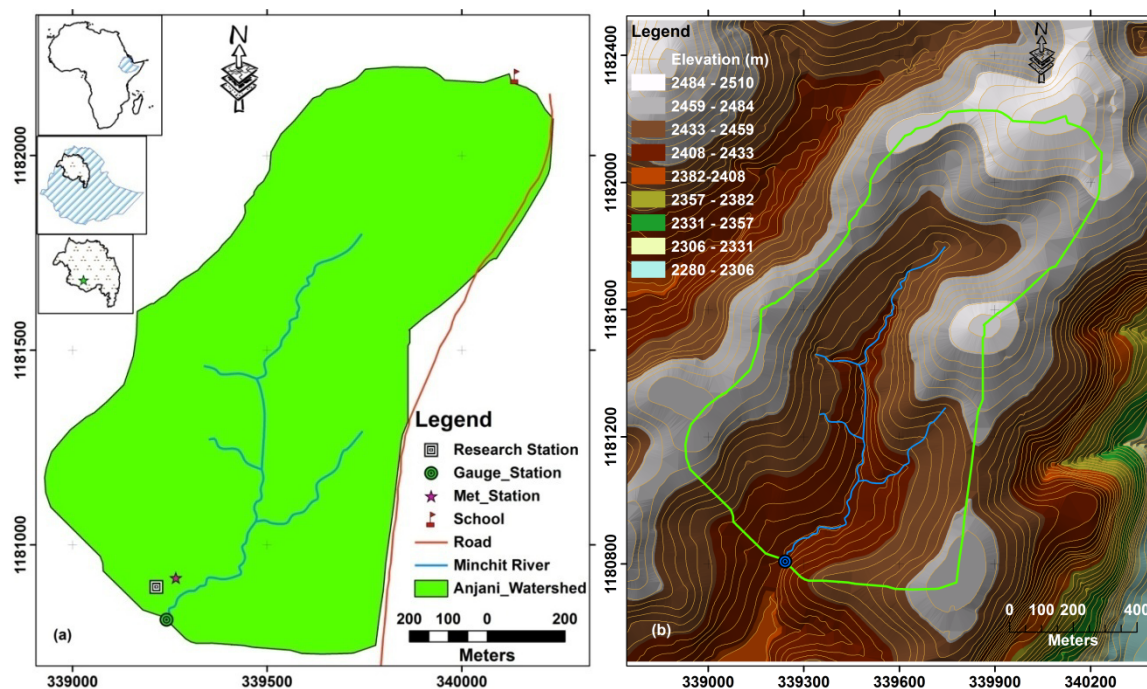

Figure 1. The location (a) and topographic set-up (b) of Anjeni catchment

2.1.2 Climate and Agro-ecology

The area of Anjeni is contained within the agro-climatic profile of Mount Choke at an altitude of 2,425 to 2,510 m asl, lying at the transition zone of sub-humid and cool climatic zones (Figure 2). It shows the characteristics of a wet sub-humid (Wet Weyna Dega) zone with a unimodal rainfall regime with five months during which rainfall exceeds 100 mm (Figure 2). The climate is characterized by sub-humid with a pronounced rainy season between May and October that have a mean annual rainfall of about 1,834 mm, mean annual temperature of 16°C and a growing period of 242 days. The long-term mean annual minimum and maximum temperatures of the area are 9.0°C and 23.3°C, respectively. The mean monthly minimum and maximum temperature range between 6.2 and 26.1°C with a lowest recorded temperature of 0°C and the highest has reached 33°C (Zeleke, 2000).
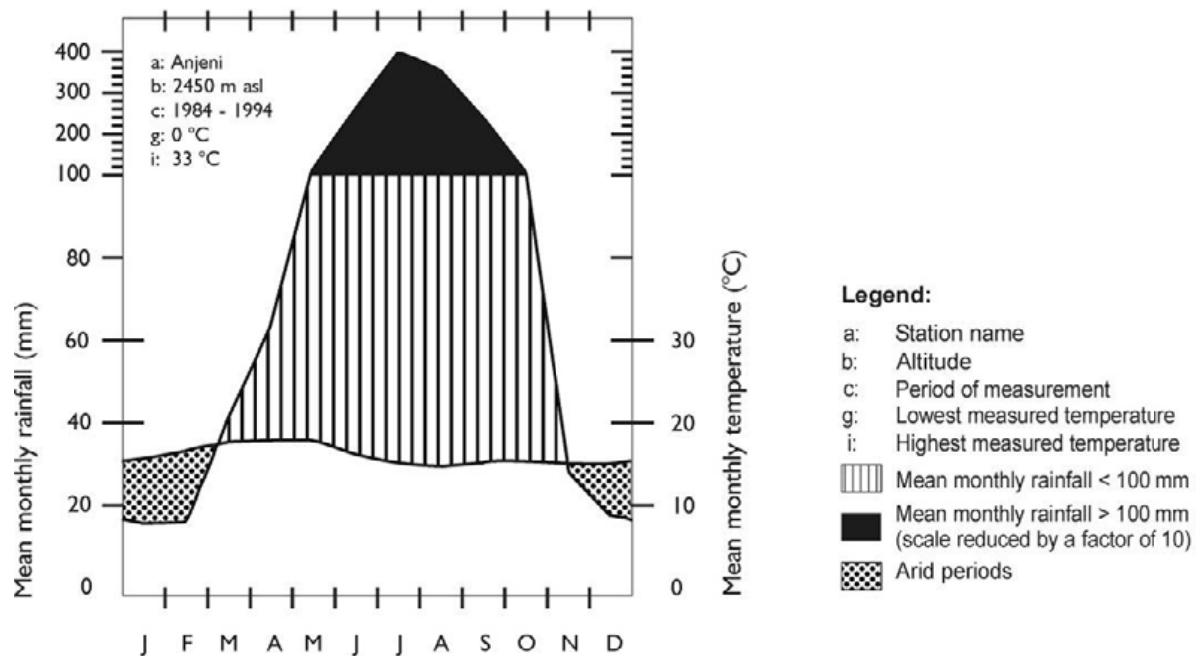
Figure 2. Climate Diagram for Anjeni at 2407 m asl (SCRP, 2000)

2.1.3 Geology and Soils

Geological formation of the catchment area belongs to the basaltic Trapp Series of the Tertiary volcanic eruptions and is similar to most parts of the central highlands of Ethiopia (Zeleke, 2000). The topography of the area is typical of Tertiary volcanic landscapes deeply incised by streams, resulting in the current diversity of landforms. The genesis of the soils is then from the volcanic and reworked material and rarely from sedimentation processes. According to Zeleke (2000), the soils of Anjeni vary within a short distance resulting in eight major soil units and ten sub-groups (Figure 3). Alisols cover 41 percent of the total land area of the catchment occupying the valley floors and the depressions of the foothill land units. The gently sloping, convex to linear land units are covered by the moderately deep Nitosols amounting to 23.8 percent of the land area. The steepest land units are convex shaped and covered by the Regosols and Leptosols (12.4 percent) which are shallow in depth that are assumed to be derived from the truncation of the Nitosols in the process of degradation by soil erosion. The hilltop of the catchment and partially the medium steep sloped land units are covered with moderately deep Dystric Cambisols (19 percent). Pockets of Luvisols, Lixisols and Acrisols are also found on different land units in the catchment. The soils of the catchment are generally acidic (5.4-6.2) low in organic matter (1.42-3.78%), have low to medium nitrogen (0.15-0.24%) and available phosphorus (6.9-8.36 ppm). The cation exchange capacity of the catchment ranges from 19.61-22.88 centi mole per kilogram of soil.
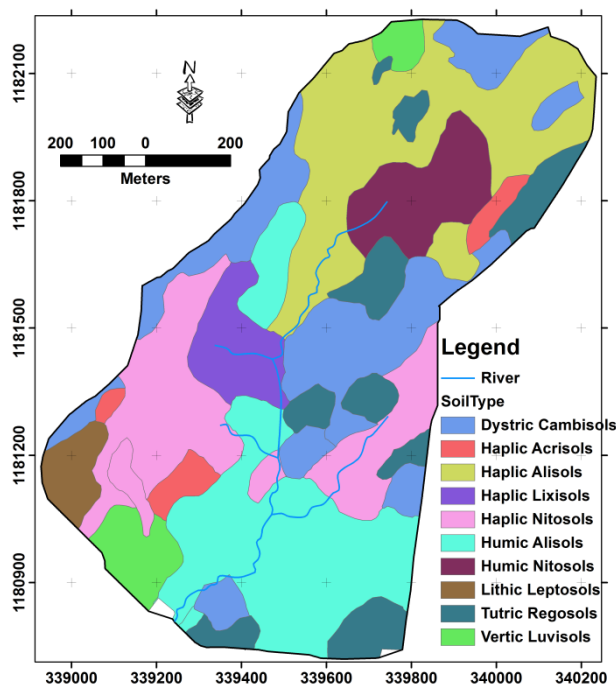
Figure 3. Soil Map of Anjeni Watershed (Zeleke, 2000)

2.1.4 Farming Systems and Socioeconomic Set-up

The Anjeni catchment is located in the upper part of the Wet Weyna Dega (SCRP, 2000) and is typical representative of the intensively cultivated area in Gojjam. Due to increasing human and livestock population, tremendous pressure has been created on the land that land degradation is a critical problem clearly observed in the area. The total population and population density of Anjeni area increased by 185 percent within 38 years i.e from 43.85 persons per km^2 in 1957 to 125.26 persons per km^2 in 1995 (Zeleke, 2000). The same study also shows that the natural forest cover decreased from 27.1 percent in 1957 to 0.3 percent in 1995. On the other hand, cultivated land increased from 39.4 percent in 1957 to 77 percent in 1995. The cropland expansion was towards fragile lands such as to steep slopes (from 19.4 percent in 1957 to 79.5 percent in 1995) (Zeleke, 2000). Furthermore, the open grazing management of the livestock and the cereal based farming system that require intensive tillage, make the landscape vulnerable to water erosion. Land and agriculture are the sole source of livelihood of the community at Anjeni area. Due to its location being far from the main cities and main roads, little or no access to market, social services and to off-farm economic activities.

2.2 Methods of Data Collection and Analysis

2.2.1 Soil Sampling

For the soil loss and land suitability change analysis, the soil samples for the study area was taken following the same route for the 12 pits that have been made by (Kejela, 1985), and 16 pits by Gete (Zeleke, 2000). Toposequence-based surface soil samples were also collected (Figure 4). Each soil sample was taken from small within 30 cm soil depth.
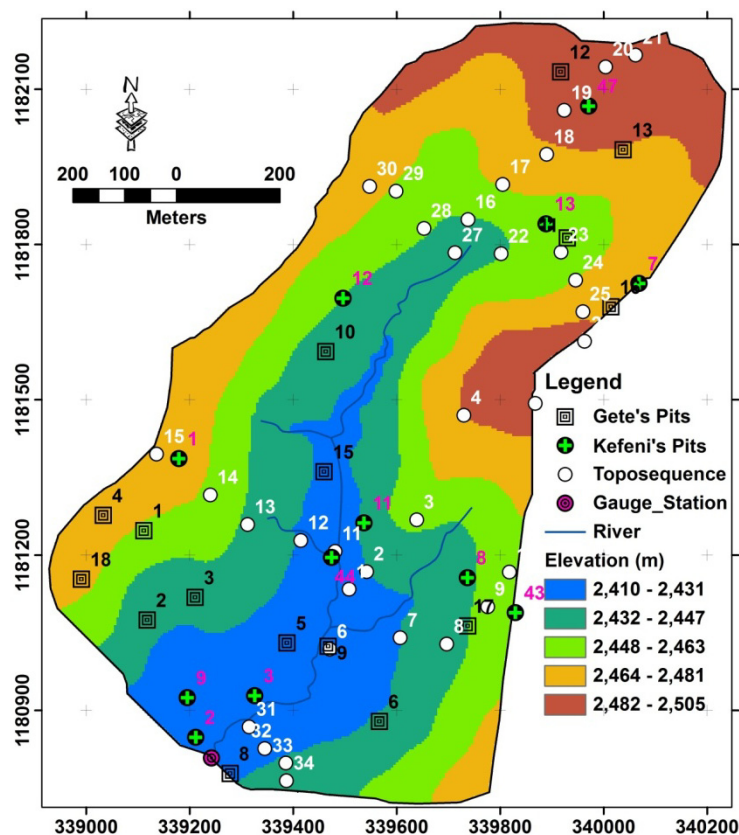
Figure 4. Soil sampling points at Anjeni catchment

2.2.2 Determination of Soil Physical and Chemical Properties

The collected soil samples were air-dried at room temperature, finally ground using mortar and pestle, and sieved to pass through 2mm mesh. Soil textures were analyzed using hydrometer method (Sertus & Bekele, 2000). Soil pH of the soil was measured by both water and 1 mole of potassium chloride (KCl) using glass electrode pH meter. SOC was determined following the wet digestion method used by Walkley and Black (Sertus & Bekele, 2000). Organic matter was computed from organic carbon by multiplying the value with a constant 1.724 (Sertus & Bekele, 2000).

2.2.3 Tenure or Land Use/Land Cover Mapping

Even though varying yearly, tenure maps for Anjeni watershed has been developed by the SCRP research unit. However, tenure map of the year 2010 was made and comparatively analyzed against those made in 1984 and 1997. Moreover, these tenure maps were used to analyze the land suitability maps of the respective years and to analyze whether the actual LUTs correlate with the potential land suitability classes. Land use/land cover information for the Anjeni watershed was developed from plot-by plot tenure maps developed by ground survey.

2.2.4 Selection and Description of LUTs

The definitions of the major kinds of land use types refer directly to relate to the physical suitability of the land. In this study, rainfed crop production was considered as major land use. The rainfed crop production of Anjeni watershed is characterized by low capital, labor intensive and non-mechanized agriculture. The size of farm fields assigned for each farmer is small (less than 1 hectare per household), and their major sources of traction for plowing are oxen, which is largely subsistence-oriented with some amount for marketing.

The land utilization types (LUTs) that were evaluated to the suitability of the land against their biophysical requirements were selected through discussion with the informant farmers and through Preliminary Resource Appraisal (PRA) conducted for the catchment. When crop selection was carried out through discussion with the informant farmers, area coverage and importance of the crops in the livelihood of the concerned community were considered.

2.2.5 Multi Criteria Evaluation (MCE)

The integration of multi-criteria methods with the GIS tools provides a great potential for obtaining land suitability maps or selecting sites for a particular activity (Eastman et al., 1995). In developing weights, an individual or group compares every possible pairing and enters the ratings into a pairwise comparison matrix or ratio matrix (Eastman, 2000). While GIS provides an appropriate framework for managing spatial data, the multi-criteria evaluation procedures adds to the GIS the means of performing trade-offs on conflicting objectives, while taking into account multiple criteria and the knowledge of the decision maker (Carver, 1991). GIS can be used not only for automatically producing maps, but it is unique in its capacity for integration and spatial analysis of multisource datasets (Malczewski, 2004).

2.2.6 Selection of Evaluation Criteria (Land Use Requirements)

The evaluation criteria are measurable variables on which decisions about land quality and its suitability for a specified use can be made (Eastman et al., 1995). After the determination of the problem, the set of evaluation criteria which includes attributes and objectives should be designated (Jankowski, 1995). This stage involves specifying a comprehensive set of objectives that reflects all concerns relevant to the decision problem and measures for achieving those objectives which were defined as attributes. Because the evaluation criteria are related to geographical entities and the relationships between them, they can be represented in the form of maps which are referred as attribute maps.

Logically, criteria identification can be done using the participatory approach by a group of experts from various disciplines. However, based on the crop requirements for specific soil parameters, climate and topographic data, FAO (1976) has given a framework for land suitability analysis from highly suitable (S1) to the level of not suitable (N). In this study, criteria identification was done based on various literatures and guidelines and data availability (FAO, 1984; Landon, 1991; Sys et al., 1993). Hence, the following evaluation criteria were considered to address the suitability of the land for agricultural crops in the study area. These were: soil physical properties (depth, drainage, and texture), soil chemical properties (organic matter and pH), climate factors (temperature and rainfall), and topographic factor (DEM and slope) and land use type.

2.2.7 Hierarchical Organization of the Criteria

Malczewski (2000) cited in Prakash (2003) states that relationship between objectives and attributes has a hierarchical structure. At the highest level one can distinguish the objectives and at the lower levels, the attributes can be decomposed. Figure 5 shows the hierarchical organization of the criteria used in this study while Figure 6 shows the FAO adopted general model of land evaluation in GIS and Remote Sensing platform.

2.2.8 Criteria Standardization

The need for data standardization in GIS based land suitability evaluation often arises as a consequence of the need to integrate into the evaluation process data measured not only in different units but also in different scales of measurement, such as nominal, ordinal, interval and ratio scales (Pereira & Duckstein, 1993). Since some criteria are measured on different scales, it is necessary that factors be standardized before used for combined analysis, and that they are transformed. There are a number of approaches that can be used to make the attribute map layers comparable. Linear scale transformation is the most frequently used GIS based approach for criteria standardization (Malczewski, 2003). The present study however used the module named re-class (in ArcGIS environment) for standardization of the factors. Thus, each factor will have an equivalent measurement basis before any weights are applied. Accordingly, all the factors used for this study were reclassified in to four classes (S1, S2, S3, and N) with the range of values 1 to 4, where the value of 1 takes the most suitable and 4 takes the least suitable for all factors considered. However, there are some factors that will not fulfill the whole range due to the crop requirements.
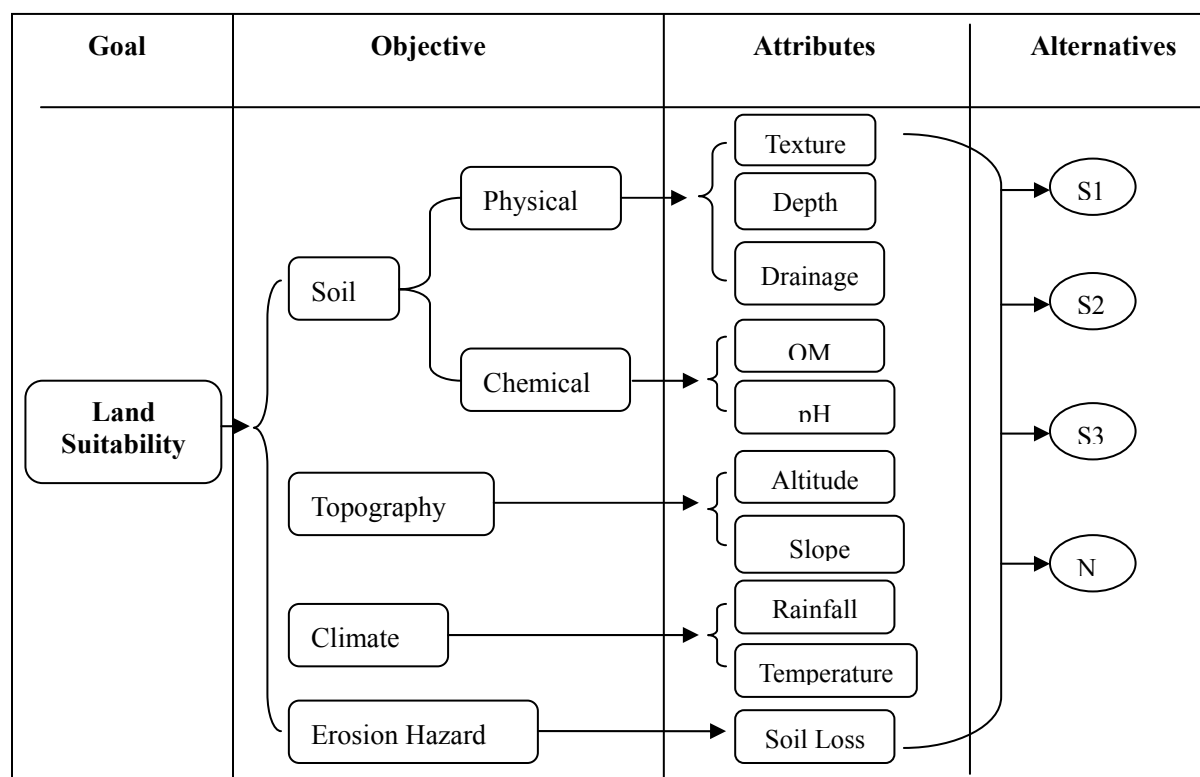
Goal	Objective	Attributes	Alternatives

Figure 5. Hierarchical organization of the criteria

2.2.9 Assigning Weights for the Criteria

The purpose of weighting in land suitability analysis for agricultural crops is to express the importance or preference of each factor relative to other factor effects on crop yield and growth rate. In the procedure for MCE, it is necessary that the weights sum to 1. Accordingly, in IDIRISI, the weight module utilizes the pairwise comparison technique to help develop a set of factor weights that will sum to 1.0. In a pairwise comparison matrix, factors are compared two at a time in terms of their importance related to the stated objective.

In developing weights, an individual or group compares every possible pairing and enters the ratings into a pairwise comparison matrix or ratio matrix (Eastman, 2006). Since the matrix is symmetrical, only the lower triangle actually needs to be filled in. The remaining cells are then simply the reciprocals of the lower triangle. To this end, after discussion and careful analysis of the set of evaluation criteria with experts, all the pairwise comparisons for the set of the considered criteria were made. After all possible combinations of two factors are compared, the   module calculates a set of weights and, importantly, a consistency ratio. This ratio indicates any inconsistencies that may have been arisen during the pairwise comparison process. The module allows repeated adjustments to the pairwise comparisons and reports the new weights and consistency ratio for each iteration.

2.2.10 Aggregating the Criterion Weights and the Standardized Criterion Maps

GIS can be used not only for automatically producing maps, but it is unique in its capacity for integration and spatial analysis of multisource datasets (Malczewski, 2003). These data are manipulated and analyzed to obtain information useful for a particular application such as land suitability analysis.

Once the criteria maps are developed, an evaluation (or aggregation) stage is undertaken to combine the information from the various factors. In the context of GIS, three decision rules i.e. Boolean overlay, weighted overlay and ordered weighted averaging are common for MCE (Jiang & Eastman, 2000; Malczewski, 2000; Malczewski, 2003). The simplest type of aggregation is the Boolean intersection or logical AND. This method is used only when factor maps have been strictly classified into Boolean suitable/unsuitable images with values 1 and 0. The evaluation is simply the multiplication of all the images. The present study, however, adopts the weighted overlay technique for developing the suitability maps for each LUTs and vector overlay analysis for deriving composite suitable land allocation map. Figure 6 shows the FAO adopted general model of land evaluation in GIS and Remote Sensing platform.
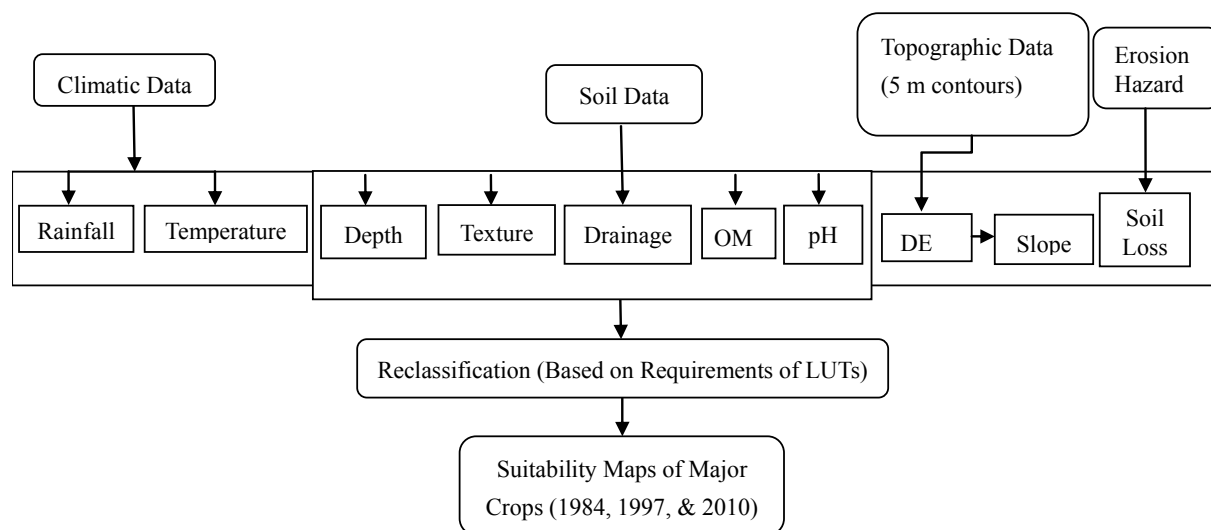
Figure 6. Generalized model of land evaluation

3. Results and Discussions

The spatio-temporal land suitability for the selected LUTs of Anjeni watershed was obtained.   Figure 7 shows the map of suitable land allocation for the evaluated crops. For instance in 2010, more than half of the watershed was found to be suitable (S1 class) for wheat production. These areas were found in the southern, southwestern and northwestern parts of the watershed. While the remaining falls in moderately suitable (S2 class). These areas were found in the northern, northeastern and eastern parts of the watershed (Figure 7). Relatively better organic carbon content in these areas contributes a lot for this suitability. None of the area in the watershed falls in to marginally suitable (S3) and unsuitable (N) class.
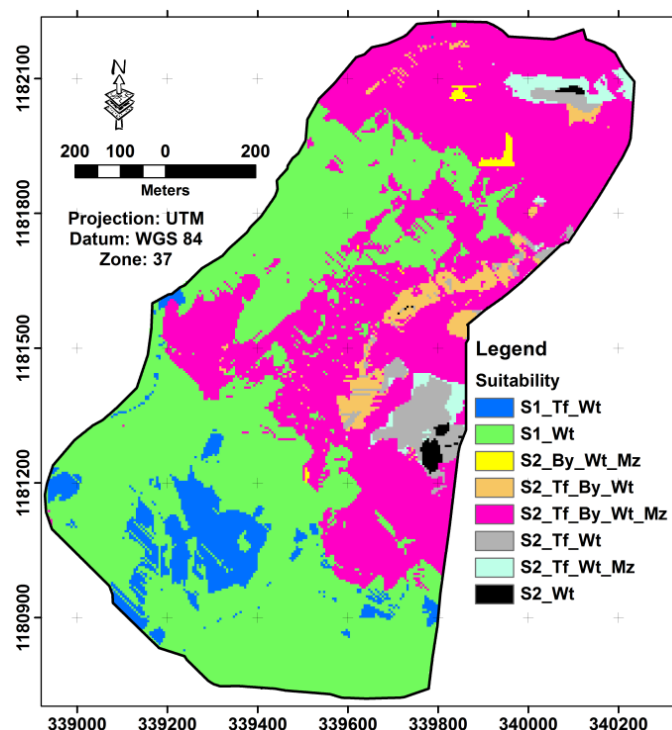

Figure 7. Appropriate land allocation map with their respective degree of suitability in Anjeni watershed (2010)

Note: S1 = highly suitable, S2 = moderately suitable, Tf = teff, By = barley, Wt = wheat, Mz = maize.

The land suitability result obtained for specific LUT only indicates the different suitability classes for that LUT in the study area. When different LUTs are involved in the evaluation, it seems good to indicate the appropriate parcels of land best suitable for the LUTs and which LUTs compete for the same parcel of land at its best suitability class. Overall land suitability analysis indicates the overall suitability of the land for each LUTs. It also indicates which LUTs compete for a parcel of land at the same level of suitability class. Overall land suitability analysis is an indicative of appropriate land allocation. Hence, the overall land suitability analysis is performed for the LUTs considered in the study area.

The overall suitability analysis result is obtained after conversion of the raster data to vector data performed in a vector overlay analysis in a GIS environment using Analysis Tool. Table 1 demonstrates the result of appropriate land allocation for the selected LUTs along with their best suitability classes. The result demonstrates that nearly half of the watershed is highly suitable for wheat. It also reveals the condition where a plot of land is suitable for one or more than one LUTs at the same level of suitability class. This indicates competing nature of LUTs for the same parcel of land. For instance, 5.8% of plot of land is highly suitable for both teff and wheat. Similarly, 40.2% is moderately suitable for all the selected LUTs. The detail of the result is presented in Table 1.

Table 1. Suitable land allocation for the selected agricultural crops along with their area coverage

Overall Suitability Analysis		
Code	Area (ha)	Area (%)
S1_Tf_Wt	6.21	5.8
S1_Wt	49.4	46.2
S2_By_Wt_Mz	0.35	0.3
S2_Tf_By_Wt	2.91	2.7
S2_Tf_By_Wt_Mz	43.0	40.2
S2_Tf_Wt	3.05	2.9
S2_Tf_Wt_Mz	1.59	1.5
S2_Wt	0.42	0.4

The major crops that have been grown in the watershed are teff, barley, maize, and wheat. Figure 8, 9 and Table 1 show the spatial and temporal distribution as well as area coverage of these crops. The maps are labeled by ranks of their area coverage. In 1997, much of the area was covered by barley (29.2%) and teff (28.9%). But in 2010, the agricultural fields were covered by teff (19%), maize (18.9%), barley (16.9%), and wheat (15.6%). Wheat and maize has shown a significant area expansion while teff and barley faced vast area shrinkage.
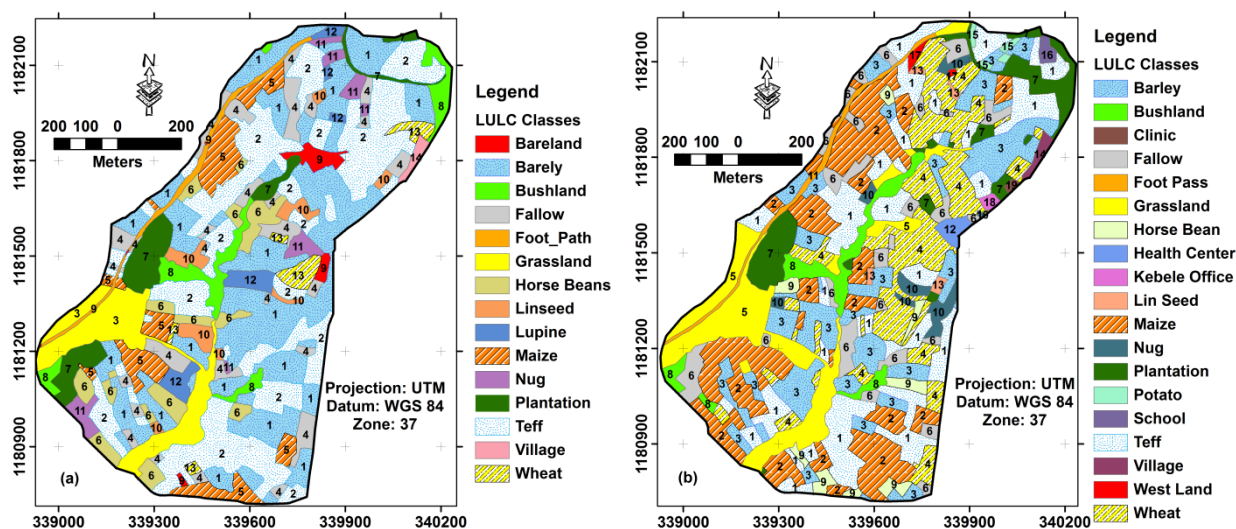

Figure 8. Temporal and spatial variations of land use in Anjeni watershed [1997 (a) & 2010 (b)]

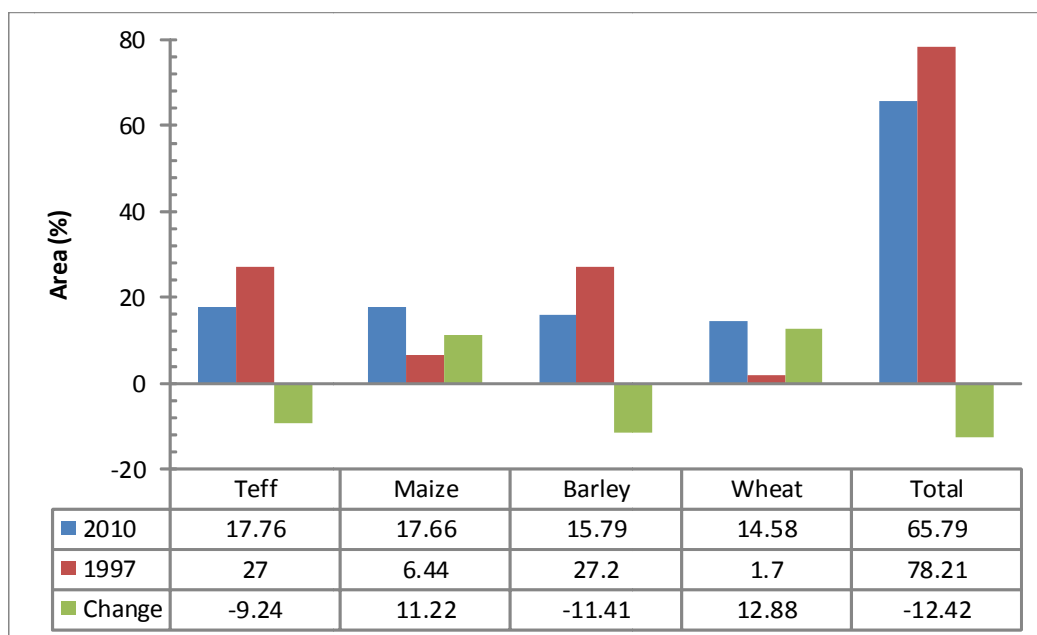|	Teff	Maize	Barley	Wheat	Total
2010	17.76	17.66	15.79	14.58	65.79
1997	27	6.44	27.2	1.7	78.21
Change	-9.24	11.22	-11.41	12.88	-12.42

Figure 9. Temporal variations of major agricultural crops in Anjeni watershed (1997 & 2010)

Figure 10. Maize performance at Anjeni Watershed, 2010 (Photo by Tadele Amare)

In general, maize requires a freely drained, well aerated, deep soil without compaction, free salinity or alkalinity, and gentle slopes. Maize is a very indicative crop for the improvement of the environmental conditions, particularly soil fertility (Figure 10). Nowadays there is an encouraging trend of land expansion for wheat. While the watershed is only S2 class for maize, there is about 200% expansion of this crop in the last few years (Figure 11).
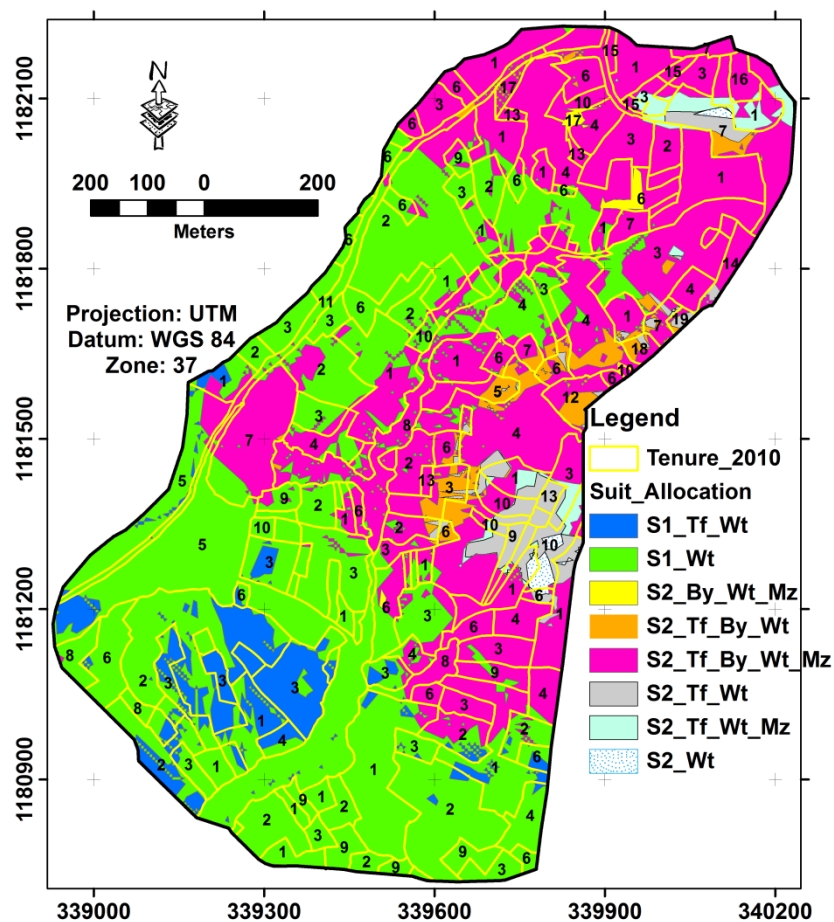
Figure 11. The 2010 actual tenure layer of Anjeni watershed superimposed on the major crops land suitability allocation layer

Table 2. Tenure system of Anjeni Watershed (2010)

LULC	Area in ha	Area (%)	Rank
Teff field	19.00	17.76	1
Maize field	18.90	17.66	2
Barley field	16.90	15.79	3
Wheat field	15.60	14.58	4
Grassland	11.40	10.65	5
Fallow land	6.57	6.14	6
Eucalyptus	6.24	5.83	7
Bush land	3.72	3.48	8
Horse bean field	2.20	2.06	9
Nug (Niger seed)	1.98	1.85	10
Foot path	1.48	1.38	11
Others land-uses (<1.0 ha)	2.91	2.71	
Total	106.90	100.00	

Therefore, the actual expansion of maize fields in the study watershed is a very good indicator of the improvement of these environmental conditions and thereby the general ecosystem services (Figure 10). Even though maize opens agricultural fields susceptible for erosion, the land between the loss and deposition zone is now changed into gentle slope. The expansion of wheat fields is an encouraging trend of land use that has been gained through improvement of the landscape, whereby, much of the area of the watershed was found to be S1 class for wheat production. Figure 10 and Table 2 show the 2010 tenure system of Anjeni watershed superimposed on the potential land suitability for the major crops. About 40% of the watershed was found to be S2 class for all the major cops while nearly half of the watershed was found to be S1 class for wheat. Despite the potential suitability of the land for wheat, previous tenure systems showed little land allocated for wheat production.

A socio-economic study by researchers (Adgo & Teshome, 2010) confirm the study results reported in this article that soil and water conservation had long-term benefits to smallholder farmers especially in the Anjeni catchment.. Terracing was impacting crop yields, with the percent increases of 93%, 203% and 125%, respectively, as compared to crops grown in the same area but without terraces.

Similar study in Kenya supports the present study that with construction of terraces grain yield improved dramatically; the yield is highest in maize production where it was more than double when the crop is grown on terraced farms as compared to non- terraced farms (Mulinge, 2010). They report that the highest increment in yield was realized in the upper slopes where maize yields were increased by more than 150% while beans yields increased by 200%. Food security can be also increased through improved land use and land management practices (Assefa, 2009). On the contrary, the findings of Shiferaw and Holden (1998) and Kappel (1996), except for low-cost technologies like grass strip; returns to soil conservation investments were too low. Negative NPV values for bench terraces were observed in Peru when crop yield data were actually measured and profitability was lower than farmers' estimation (Posthumus & Graaff, 2005). Soil conservation structures such as fanya Juu, soil/stone bunds; grass strips did not increase crop yield and biomass production in the highlands of Ethiopia and Eritrea (Herweg & Ludi, 1999; Kassie et al., 2008).

4. Conclusion

In this study, the role of SWC measures for the improvement of ecosystem services was assessed. Ecosystem services associated with SWC can be distinguished as provisioning (productivity), regulatory, cultural and supporting. The land suitability analysis result showed that the study watershed was found to be moderately (S2) and marginally (S3) suitable for the major crops of the watershed such as teff, barley, wheat, and maize in 1984 and 1997. The suitable area proportion for these crops in both years was found in their order of importance. However, significant improvement of land suitability was estimated in 2010. About half of the area has been changed to highly suitable (S1) for wheat and teff, and a large proportion of the remaining area has been changed to moderately suitable class (S2) for barley and maize. This shows that the soil conservation measures are now playing an important role in improving the ecosystem services in the form of improving suitability of the soils for most crops.

Based on the findings of this study, it can be concluded that terracing can be taken as a means to combat the impacts of land degradation due to the loss of soil fertility by water erosion, and as mitigation against impacts of climate change (extreme wet and dry conditions). It was also found that land suitability analysis for agricultural crops using multi-criteria in a GIS environment is a strong tool towards measuring and valuation of the long-term impacts of soil terracing on improvement of ecosystem services. However, the parameters used for land suitability analysis in this study were entirely biophysical; much improvement can be made if some socio-economic variables were considered. In addition, the land utilization types (LUTs) considered in this study were limited to four selected crops such as teff, barley, wheat, and maize, whereas further studies can be made so as to increase the choice and identify the best alternative use of a specific landscape parcel for different LUTs by considering pulses, oilseeds, cash crops , and livestock management.

References

Adgo, E., & Teshome, A. (2010). Effects of long-term soil and water conservation on agricultural productivity: A case study of Anjeni watershed, Ethiopia, a compendium on agricultural water management interventions bearing returns on investment in eastern and southern Africa. *Improved management of agricultural water in eastern & southern Africa (IMAWESA), IMAWESA Working Paper 17*.

Assefa, A. (2007). *Impact of terrace development and management on soil properties in Anjeni area, west Gojjam*. Master's thesis, Addis Ababa University, Ethiopia.

Assefa, A. (2009). *Agricultural land suitability evaluation for rainfed crops using GIS and remote sensing techniques: A case study of Debremewi watershed*. Master's thesis, Bahir Dar University, Bahir Dar, Ethiopia.

Aylward, B. (2004). Land use, hydrological function and economic valuation. In M. Bonnell, & L. A. Bruijnzeel (Eds.), *Forests-water-people in the humid tropics*. Cambridge: Cambridge University Press.

CA, Water for food. (2007). Water for life: A comprehensive assessment of water management in agriculture London, Colombo: Earth scan and the International Water Management Institute.

Carver, S. J. (1991). Integrating multi-criteria evaluation with geographical information systems. *International Journal of Geographical Information Systems, 5*(3), 321-339. http://dx.doi.org/10.1080/02693799108927858

Eastman, J. R. (2006). IDRISI Andes guide to GIS and image processing. Manual version 15, Clark University.

Eastman, J. R., Weigen, J., Peter, A. K., & James, T. (1995). Raster procedure for multi-criteria/multi-objective decisions: Photogrammetric Engineering & Remote Sensing, American Society for Photogrammetry and Remote Sensing.

FAO. (1976). A framework for land evaluation. *FAO Soils Bulletin, 32*. Rome, Italy.

FAO. (1983). Guidelines; land evaluation for rainfed agriculture. *FAO Soils Bulletin, 52*. Rome, Italy.

FAO. (1984). Crop environmental requirements; report prepared for the Government of Ethiopia by FAO acting as executing agency for the UNDP. *Land evaluation: Technical report 5, Part III*. Rome, Italy.

FAO. (1993). Guidelines for land use planning. *FAO Development Series 1. Rome, Italy.*

FAO. (2007). Land evaluation, towards a revised framework. *Land and Water Discussion Paper 6*. Rome, Italy.

Harrison, P. (1987). The greening of Africa: Breaking through in the battle for land and food, Great Britain: Paladin Grafton books.

Herweg, K., & Ludi, E. (1999). The performance of selected soil and water conservation measures-case studies from Ethiopia and Eritrea. *Catena, 36*, 99-114. http://dx.doi.org/10.1016/S0341-8162(99)00004-1

Hurni, H. (1987). Erosion-productivity-conservation systems in Ethiopia. In I. Plasentis (Ed.), *Soil Conservation and Productivity* (pp. 654-674). Proc. of the 4th Int. Soil Conservation Conference, Maracay, Venezuela.

Hurni, H. (1993). Land degradation, famine, and land resource scenarios in Ethiopia, In D. Pimentel (Ed.), *World soil erosion and conservation* (pp. 27-61). Cambridge studies in Applied Ecology and Resource Management.

Hurni, H., Bantider, A., Herweg, K., Portner, B., & Veit, H. (2007). *Landscape transformation and sustainable development in Ethiopia, background information for a study tour through Ethiopia*. 4-20 September 2006, compiled by the participants, Centre for Development and Environment, University of Bern, Switzerland.

Jagger, P., & Pender, J. (2003). The role of trees for sustainable management of less-favored lands: the case of eucalyptus in Ethiopia. *Forest Policy and Economics, 5,* 83-95. http://dx.doi.org/10.1016/S1389-9341(01)00078-8

Jankowski, P. (1995). Integrating geographical information systems and multiple criteria decision-making methods. *International Journal of Geographical Information Science, 9*(3), 251-273. http://dx.doi.org/10.1080/02693799508902036

Jiang, H., & Eastman, J. R. (2000). Application of fuzzy measures in multi-criteria evaluation in GIS. *International Journal of Geographical Information Science, 14*(2), 173-184. http://dx.doi.org/10.1080/136588100240903

Kappel, R. (1996). *Economic analysis of soil conservation in Ethiopia: Issues and research perspective.* University of Bern, Bern, Switzerland in Association with the Ministry of Agriculture, Addis Abeba, Ethiopia.

Kejela, K. (1985). The soils of the Anjeni area-Gojjam research unit, Ethiopia. *Soil Conservation Research Project, Research Report 27.* Centre for Development and Environment, University of Berne, Switzerland.

Landon, J. R. (1991). *Booker tropical soil manual: A handbook for soil survey and agricultural land evaluation in tropics and sub tropics.* New York: Longman Scientific and Technical Publishers

Malczewski, J. (2000). Review article on the use of weighted linear combination method in GIS: common and best practice approaches. *Transactions in GIS, 4*(1), 5-22. http://dx.doi.org/10.1111/1467-9671.00035

Malczewski, J. (2004). GIS-based land-use suitability analysis: a critical overview, progress in planning. *Progress in planning, 62*, 3-65. http://dx.doi.org/10.1016/j.progress.2003.09.002

Mansfield, J. E. (1979). Land capability for annual rainfed arable crops in Northern Nigeria based on Physical limitations. In R. Lal, & D. J. Greenland (Eds.), *Soil physical properties and crop production in the tropics* (pp. 407-426). New York: John Wiley and Sons.

Markus, W. (2004). ECA annual report, eastern and central Africa, Nairobi, Kenya. Retrieved from http://www.worldagroforestry.org/eca/downloads/ECAAnnualReport.pdf

Menale, K., Holden, S., Köhlin G., & Bluffstone, R. (2008). Economics of soil conservation adoption in high-rainfall areas of the Ethiopian Highlands. *EfD Discussion Paper 08-09, a joint publication of the Environment for Development initiative and Resources for the Future (WWW.rff.org)*, Washington DC. Retrieved from http://www.efdinitiative.org/research/publications/publications-repository/economics-of-soil-conservation-adoption-in-high-rainfall-areas-of-the-ethiopian-highlands-1

Mulinge, W. M., Thome, J. N., & Murithi, F. M. (2010). Impacts of long-term soil and water conservation on agricultural productivity in Kaiti catchment, Kenya. In B. M. Mati (Ed.), *Agricultural water management interventions bearing returns on investment in eastern and Southern Africa*. IMAWESA, working paper 17. Nairobi, Kenya: Improved management of agricultural water in Eastern and Southern Africa.

Pereira, J. M. C., & Duckstein, L. (1993). A multiple criteria decision-making approach to GIS based land suitability evaluation. *International Journal of Geographical Information Science, 7*(5), 407-424. http://dx.doi.org/10.1080/02693799308901971

Posthumus, H., & de Graaff, J. (2005). Cost-benefit analysis of bench terraces: A case study in Peru. *Land Degradation. Develop, 16*, 1-11. http://dx.doi.org /10.1002/ldr.637

Prakash, T. N. (2003). *Land Suitability Analysis for Agricultural Crops: A Fuzzy Multi criteria Decision Making Approach*. MSc thesis, ITC, The Netherlands.

SCRP (Soil Conservation Research Programme). (2000). Area of Anjeni, Gojjam, Ethiopia: Long-term monitoring of the agricultural environment 1984-1994. *Soil Erosion and Conservation Database, Soil Conservation Research Programme*. Bern: Centre for Development and Environment (CDE).

Sertus, S., & Bekele, T. (2000). Procedures for soil and plant analysis. *Technical paper no.74*, National Soil Research Center, Ethiopian Agricultural Research Organization, Addis Ababa, Ethiopia.

Shiferaw, B., & Holden S. T. (1998). Resource degradation and adoption of land conservation technologies in Ethiopian highlands: A case study in Andit Tid, North Shewa. *Agricultural Economics, 18*(3), 233-247. http://dx.doi.org/10.1016/S0169-5150(98)00036-x

Sys, C., Van Ranst, E., & Debaveye, J. (1993). Land evaluation part III, crop requirements. *Agricultural Publication No. 7*. Brussels, Belgium: General Administration for Development Cooperation.

Zeleke, G. (2000). *Landscape Dynamics and Soil Erosion Process Modeling in the North-western Ethiopian Highlands*. PhD dissertation, African Studies Series 16, Bern, Switzerland.