GIS Application for analysis of Land Suitability and Determination of Grazing Pressure in Upland of the Awash River Basin, Ethiopia

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Summary
As part of the country, expansion of cultivation and settlements even in unsuitable land has increasingly grown inmost part of the most part of the uplands of Awash River basin. This expansion clearly illustrates the fact that the growths of agriculture and other human activities have exerted pressure on the extents of grazing lands and forests. Therefore, it is of paramount importance to identify suitable land for various uses in optimum utilization while causing minimum impact to the environment. In this study, an attempt was made to identify suitable areas for livestock, crop production and forest by incorporating different spatial information using GIS techniques. Based on the analysis an attempt was also made to determine the grazing pressure in upland of the Awash River basin. The result showed that areas, which are very near to water points and dominated by low slope gradients, were identified as most suitable to agricultural crop production. Marginal lands with high slope gradient were designate as suitable for forest. The other land, which is dominated by moderate slope gradient and near to water sources were identified as suitable for livestock. The amount of DM that can be produced from the land if set the land suitability as the above result, ranges from 591.85 to 2473.72 kg/ha/year. The total DM value expected would be 301362 ton/year. However, the amount of DM that can be produced as compared to the existing livestock number could not sufficiently fulfil the demand.
Key words: Land suitability, GIS, Grazing Pressure, Awash Rriver basin

Introduction

Uses of the land to humankind are multi-facet. As a source for primary production system, it serves as a store of water and nutrients required for plants and other living organisms. Land resource is one of limited resource. The use of land not only determine by the user but also the land capability. The land capability is governed by the different land attributes such as the types of soil, which is critical for productivity, underlying geology, topography, hydrology, etc. These attributes limit the extents of land available for various purposes. To get the maximum benefit out of the land, proper use is inevitable.

In Ethiopia, land resource degradation is major threat that affects the existence and livelihood of the community. The degradation of land resource due to overexploitation and misuse and consequent economic, social and environmental impacts has intensified the pressure on the land resources of the country (EFAP, 1994). As part of the country, expansion of cultivation and settlements even in unsuitable land has increasingly grown inmost part of the most part of the Awash river basin. This expansion clearly illustrates the fact that the growths of agriculture and other human activities have exerted pressure on the extents of grazing lands and forests. Especially shifting of grazing lands and forestland in to cultivation land is a common practice and a great threat for livestock and forest resources. Therefore, it is of paramount importance to identify suitable land for various uses in optimum utilization while causing minimum impact to the environment.

Proper use of land depends on the suitability or capability of land for specific purposes. The suitability of a given piece of land is its natural ability or the biological productivity of land to support a specific purpose. FAO (1976) analyze suitability mainly based on the land qualities, such as erosion resistance, water availability, and flood hazard that are not measurable. These land qualities, however derives from land characteristics that can be quantified. Some of land characteristics are slope angle and length, rainfall and soil texture and others.

The common way of determination of land quality from land characteristics is mainly by assessing and grouping the land types in orders and classes according to their aptitude. The order of suitability ranges from suitable (S), that characterizes a land were sustainable use and will give good benefits; to not suitable (N) which indicates a land qualities do not allow the considered type of use, or are not enough for sustainable outcomes (IAO, 2003).

In order to utilize the land resources in sustainable way, a land-use plan that incorporates the different land characteristics has a paramount importance. To incorporate the different land attributes that differ spatially and to identify the best suitable land use, GIS has proved to be the best. Geographical Information system (GIS), which incorporate database systems for spatial data, were designed and developed enabling the acquisition, compilations analyzing and displaying topological interrelations of different spatial information. Moreover the surface and overlay analysis capabilities in GIS can effectively facilitate in handling vast amount of spatial information (Ekanayaki and Dayawansa, 2003). In this study, an attempt was made to identify suitable areas for livestock, crop production and forest by incorporating different spatial information using GIS techniques. Based on the analysis an attempt was also made to determine the grazing pressure in upland pf Awash River basin.

Methodology

Study Site

The study area is located in central part of Ethiopia with a location of 8^0 22’ - 8^0 57’ N and $38^0$47’ - $39^0$11’ E. The Adaa woreda comprised about 0.16 million ha in size and consists of various topographical features dominated by flat terrain. Elevation ranges from 1580 to 3024 meter above sea level (m.a.s.l). The average mean annual rainfall of the area ranges from 851-1130mm. The basin also comprised with different soil types dominated by Cambisol and Vertisol. Agro-climatically the woreda is dominated by ‘Woinadaga ‘(warm moist).

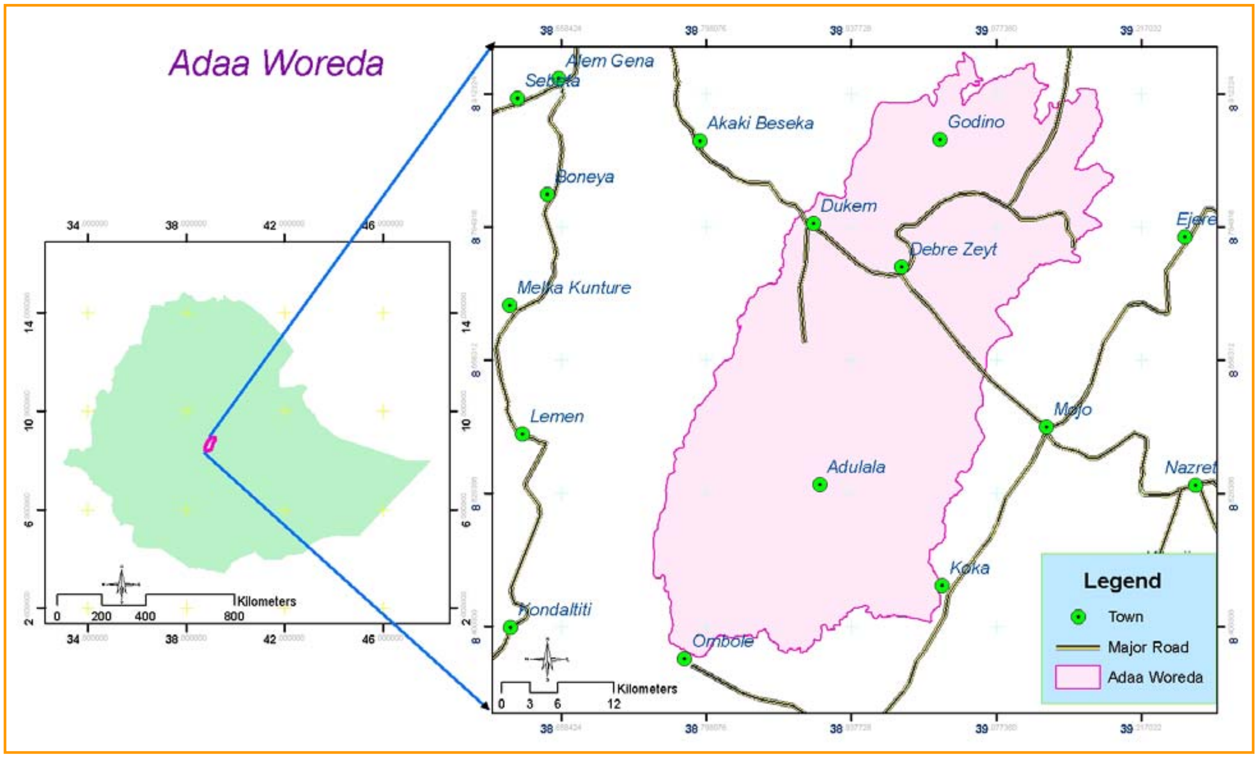


Figure 1. Location of the Study area

Data Source

Different data source were refereed to analyse the land suitability and grazing capacity of the woreda. Thus area a digital Elevation model (DEM), rainfall, land cover, soil, river, lake, road, administrative boundary and livestock population of the woreda (Annex5).

Method

Soil Erosion Hazard

The universal soil loss equation, an empirical model developed by Wischmeir and Smith (1978), was employed to assess the amount of soil loss existed in the area. Mathematically the equation is denoted by:

$$A_{\text{(ton/ha/year)}} = R * K * L * S * C * P \quad \text{--------------- } \textbf{Eq. 1}$$

Where A is the mean annual soil loss, R is the rainfall erosivity factor, K is the soil erodability factor, L is the slope length factor, S is the slope steepness factor, C is the crop management factor and P is the erosion control practice or land management factor.

The Rainfall erosivity factor (R) was analyzed based on Roose (1995, cited in Morgan 1994) equation ($R = 0.5 * P * 1.73$) for its simplicity and possibility of using only precipitation data.

The Soil erodability factor (K) was derived from FAO soil dataset by incorporating the values given by Helleden (1987)(Annex 1.1).

The slope length (L) and slope Steepness (S) was calculated as single index as given by Wischmeir and Smith (1978) [$LS = (Flow\ accumulation * Cell\ value / 22.1)^{m} * (0.065 + 0.045 * S + 0.0065 * S^{2})$]. The slope and flow accumulation were derived from DEM.

Moreover the values of crop management factor(C) and erosion management practice factor (P) were also adapted from Wischmeir and Smith (1978) (Annex 1.2 and1.4).

Land suitability classification

In this study, the land suitability classification was developed by considering different land characteristic factors. The major factors considered were soil type, slope gradient, erosion risk, distance from water body and rainfall. Based on the suitability of each factors for each land use, a weight values was given from 0 (unsuitable) to 1 (most suitable) (Annex2). The weighted value of each factors were reclassified for each land uses. The process steps are depicted in figure (2).

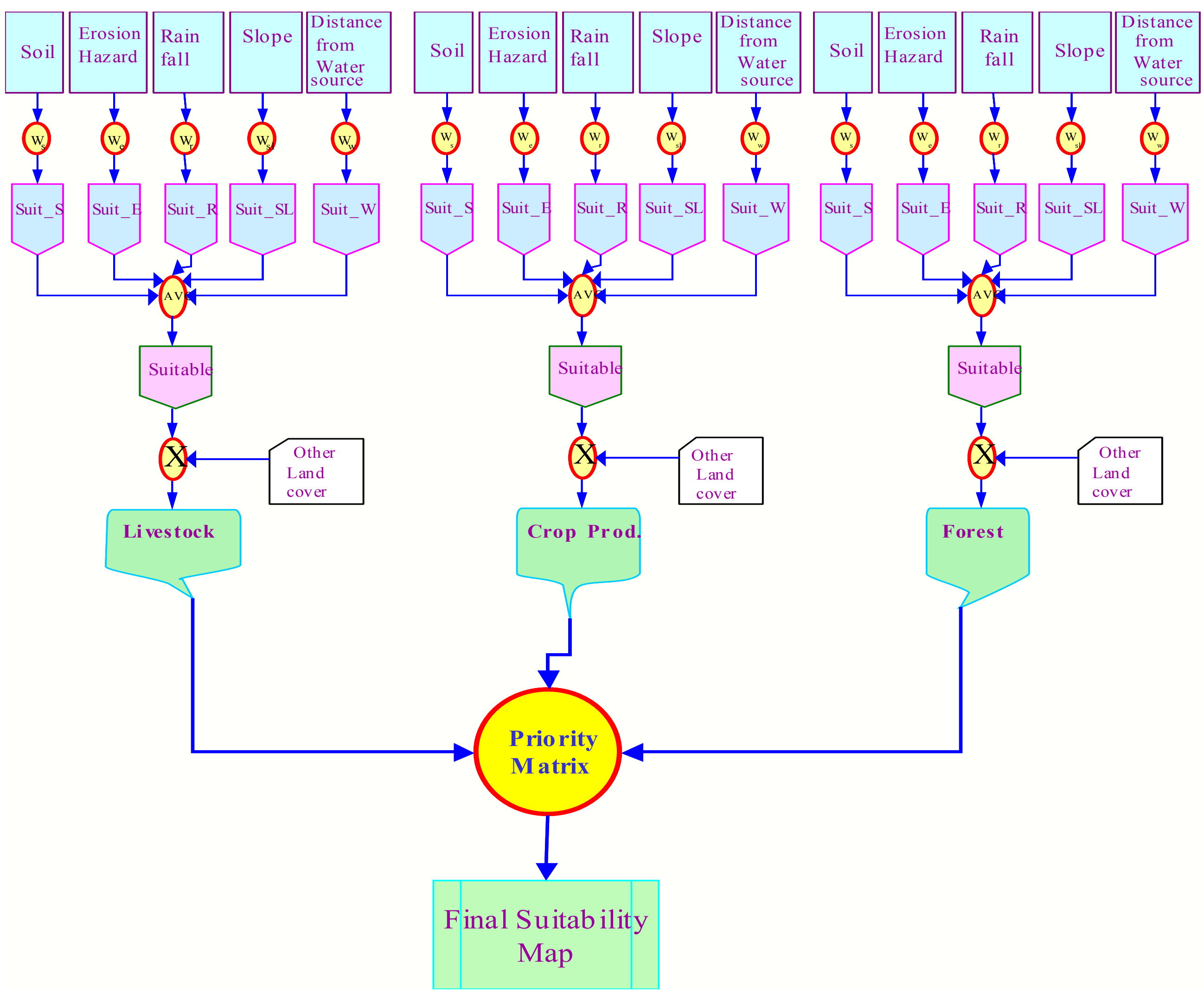


Figure 2. Process steps for analysing land suitability

The result from the soil erosion-hazard assessment was used as one of the input for land classification. The amount of soil loss in each grid cell was classified based on its assumed impact on each land use and was given a weight value. To determine distance from the water source, river and lake data set were used. Euclidian distance was derived in Arc/Info for each water points. The distance value then classified and a weight values was given. Moreover, amount of rainfall and soil type also classified and given weight value based on their suitability for each land use type.

Land uses covered by water body, which are unlikely to be changed, were avoided from computations by assigning NODATA.

The weighted value of each land characteristic factors were added and the average value of them were taken to determine the suitability of the land for each land use types. The average value then categorised in to five suitable classes to get the final suitability for each land uses (Table 1).

Table1. Suitability class (FAO)

Order	Class	Description
Suitable (S)	S1 (Highly suitable)	Land having no, or insignificant limitations to the given type of use
	S2 (Moderately suitable)	Land having minor limitations to the given type of use
	S3 (Marginally suitable)	Land having moderate limitations to the given type of use
Not Suitable (N)	N1 (Currently not suitable)	Land having severe limitations that preclude the given type of use, but can be improved by specific management
	N2 (Permanently not suitable)	Land that have so severe limitations that are very difficult to be overcome

Priority matrix

The intention of analysing priority matrix is to avoid overlap of suitable area and to assign each grid cell a value for which it is best applicable. The property matrix value negotiate the values that was derived from the above calculation and assign the best land use that can be practiced in the specific area. Based on the priory matrix, a given cell was assigned a land use type to get the final land use map (Annex 3).

Grazing Pressure Index

The grazing pressure index is the animal to forage ration in a given instance (Scarnecchia & Kothmann, 1982). Forage can be produced from pasture, crop residue and from forest leaves. The amounts of dry matter (DM) that can be harvested differ depending of the source. Since the LUCC map of the study area classified the area roughly as cropland, forest, grazing land and water body, an attempt was made to estimate the amount of dry matter that can be produced from each land use types in the study area.

The area coverage of each of the major crop types in the study area is different (Annex 4). To estimate the average DM production from agriculture crops grown in the area, a weighted average of each of the crop types was taken (Eq 2).

$$DM = \sum(C_i * A_i / At) \text{ ------------------------------------ } \textbf{Eq. 2}$$

Where ***DM*** = Dry Matter (Kg/Ha), C_i = Crop type, A_i = Area of Crop type *i*. and A_t = Total Cultivated area. However, the DM value for grassland and forest was taken as single value.

The DM production at any given location was then determined by the following equation 3.

$$DM_{il} = S_{il} * DM_i \text{ ------------------------------------ } \textbf{Eq. 3}$$

Where DM_{il} = dry matter production at location *l* of land use type of *i,* S_{il} = Suitability of land use *i* at location *l*, and DM_i = DM production of land use *i.*

After determining the DM value of each grid cell, the grazing pressure index was calculated. The TLU of the livestock was calculated to the whole woreda and divided by the amount of DM at each grid cell to determine the GPI at each location as shown in equation 4.

$$GPI_l = TLU / DM_l \text{ ------------------------------------ } \textbf{Eq. 4}$$

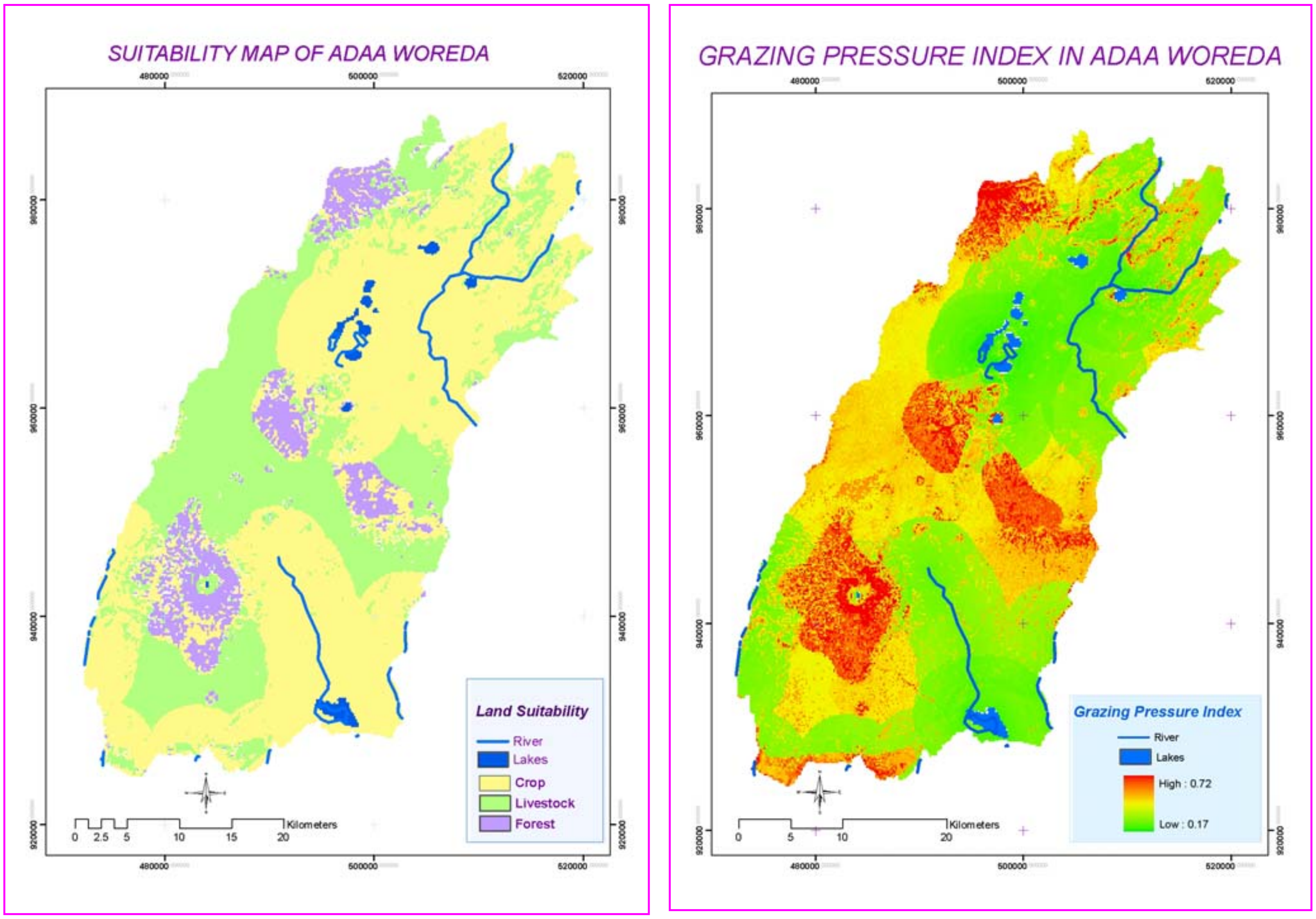
Where GPI_l = Grazing Pressure Index at location *l*, ***TLU*** = Tropical Livestock Unit and DM_l = Dry Matter content at a given location *l.*

Result and Discussion

Land Suitability

Based on the analysis areas, which are very near to water points and dominated by low slope gradients, were identified as most suitable to agricultural crop production. Marginal lands with high slope gradient were designate as suitable for forest. The other land, which is dominated by moderate slope gradient and near to water sources were identified as suitable for livestock. Generally out of the total area 56 % was suitable for crop production, 33% for livestock and 8% for forest. The other 3% was covered by other land uses (figure 3(a)).

Generally, comparing the result of the study with the land cover map of the woreda, there was comparable similarity in the total coverage of the land uses. However, the coverage of agricultural land found from this result is lower than the existing cultivated land. The forest area found from this study is slightly greater than the existing forestland. The land suitable for livestock from the analysis is much greater than the existing grazing land in the woreda. The compensation of the above land use in the result comes from the existing cultivated land. This is mainly due to the fact that, high sloppy area and poor soil fertility areas, which are not suitable for cultivation, are under utilization for crop production.



(a) (b)

Figure 3. Land suitability for Crop, Livestock and Forest (a), Grazing pressure Index (b) in Adaa Woreda

Grazing pressure Analysis

The amount of DM that can be produced from the land if set the land suitability as the above result, ranges from 591.85 to 2473.72 kg/ha/year. The total DM value expected would be 301362 ton/year. However the amount of DM that can be produced as compared to the existing livestock number could not sufficiently fulfil the demand.

The most productive areas of the woreda show the least grazing pressure index and those marginal lands shows the highest grazing pressure index (figure 3(b)). This is mainly because; the net primary product in these fertile lands would be high as compared to the marginal lands. Especially areas near to rivers or lakes have high productivity rate and low grazing pressures. The possibility of irrigation practice provides an opportunity to produce more than once in a year. This would help to fill the livestock forage demand. However, in the most part of Awash River basin, the trend is opposite. Even though there is high production of NPP in the irrigated areas, farmers have intensified agricultural crop production than livestock production (Yesuf, et.al, 2004).

Conclusion

GIS provides a great advantage to analyze multi-layer of data spatially and quantitatively. Depending on the available spatial data, the accuracy and reliability of the result using GIS application could be high. As it has shown in the study, even marginal lands which could not provided sufficient product are still under cultivation. The mismanagement and underutilization of the land for only crop production affects the coverage of forest and grazing lands. This in turn could affect the livestock population of the woreda.

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Annex 1. Soil Erosion Factors

1.1. Soil Erodability factor (Modified from Hellden, 1987)

Soil color	Black	Brown	Red	Yellow	Grey	White
K factor	0.15	0.2	0.25	0.3	0.35	0.40

1.2 Land Management Factor (P)

Land use type	Slope (%)	P-factor
Agricultural land	0-5	0.1
	5-10	0.12
	10-20	0.14
	20-30	0.19
	30-50	0.25
	50-100	0.33
Other Land	All	1.00

1. 3. M-value (Wischmeier and Smith 1978)

M-value	Slope (%)
0.5	> 5
0.4	3-5
0.3	1-3
0.2	<1

1.4 Land Cover Factor (C) (Wischmeier and Smith 1978)

Land Cover Type	C-Value
CI/CPEL	0.25
CRCL	0.35
CRCM	0.35
CRCM/GM	0.25
CRCM/SHO	0.1
FBO	0.001
FMC	0.001
FPC	0.001
GB	0.01
GB/GM	0.01
GL	0.01
GL/CRCL	0.01
GM/FPC	0.001
HH	0
HSP	0.01
HSS	0.01
SHD	0.01
SHD/GB	0.01
SHO	0.01
SHO/SHD	0.01
U	1

Annex 2. Weight Values for different Land Characteristics

Slope

Slope (%)	Livestock	Crop	Forest
1 - 5	1	1	1
5 - 10	0.9	0.9	1
10 - 15	0.8	0.7	1
15 - 20	0.7	0.5	0.9
20 - 30	0.6	0.3	0.8
30 - 40	0.5	0.1	0.7
> 40	0.3	0	0.6

Rainfall

Rainfall (mm)	Livestock	Crop	Forest
< 700	0.2	0.1	0.1
700-800	0.3	0.2	0.2
800-900	0.5	0.4	0.4
900-1000	0.6	0.6	0.6
1000-1100	0.7	0.8	0.8
> 1100	0.9	1	1

Erosion Hazard

Soil Loss (t/ha)	Livestock	Crop	Forest
0 - 1	1	1	1
1 - 5	0.9	0.9	0.9
5 - 10	0.8	0.8	0.8
10 - 20	0.7	0.5	0.7
20 - 50	0.6	0.3	0.6
50 -100	0.4	0.1	0.5
100 - 500	0.2	0.05	0.2
> 500	0	0	0.1

Soil Type

Soil Code	Livestock	Crop	Forest
CM	0.9	0.9	1
VR	1	0.7	0.7
LV	0.6	0.5	0.7
LP	0.2	0.1	0.6
CM	0.9	0.9	1
PH	0.8	0.8	0.8
FL	0.6	0.6	0.5
WATER	0	0	0

Irrigation influence

River / Lake

Distance (m)	Weight (%)
200	1
500	0.9
1000	0.8
2000	0.7
3000	0.6
5000	0.5
>5000	0

Water for Livestock

River / Lake	
Distance (m)	**Weight (%)**
500	1
1000	0.9
2000	0.8
3000	0.7
4000	0.6
6000	0.5
8000	0.4
10000	0.3
12000	0.2
>12000	0.1

Annex 3. Analysis Matrix

Crop Vs. Livestock

Livestock	Crop				
	S1 = 0.8-1.0	**S2 = 0.6-0.8**	**S3 = 0.4-0.6**	**N1 = 0.2-0.4**	**N2 = 0-0.2**
S1 = 0.8-1.0	C	C	L	L	L
S2 = 0.6-0.8	C	C	L	L	L
S3 = 0.4-0.6	C	C	C	F	F
N1 = 0.2-0.4	C	C	C	F	F
N2 = 0-0.2	C	C	C	F	F

Crop Vs Forest

Forest	Crop				
	S1 = 0.8-1.0	**S2 = 0.6-0.8**	**S3 = 0.4-0.6**	**N1 = 0.2-0.4**	**N2 = 0-0.2**
S1 = 0.8-1.0	C	C	F	F	F
S2 = 0.6-0.8	C	C	F	F	F
S3 = 0.4-0.6	C	C	C	F	F
N1 = 0.2-0.4	C	C	C	F	F
N2 = 0-0.2	C	C	C	F	F

Livestock Vs. Forest

Forest	Livestock				
	S1 = 0.8-1.0	**S2 = 0.6-0.8**	**S3 = 0.4-0.6**	**N1 = 0.2-0.4**	**N2 = 0-0.2**
S1 = 0.8-1.0	L	L	F	F	F
S2 = 0.6-0.8	L	L	F	F	F
S3 = 0.4-0.6	L	L	F	F	F
N1 = 0.2-0.4	L	L	L	F	F
N2 = 0-0.2	L	L	L	F	F

C = Crop, L = Livestock, F = Forest

Annex 4. Dry matter Content of Different Land Uses

Land Use	Type	Dry matter (Kg/Ha)	AREA (%)	Total Dry Matter (Kg/Ha)
Cultivated crop	Maize	6516	2	130.32
	Teff	3295	50	1647.5
	Wheat	3624	30	1087.2
	Barley	0	0	0
	Sorghum	4234	6	254.04
	Lentil	780	2	15.6
	Haricot bean	2068	2	41.36
	Field pea	1110	4	44.4
	Other	?	4	0
	Sub-Total			**3220.42**
	Sugarcane		1	
Grass	Grass	3506		**3506**
Tree and Shrubs	Tree	1505		**1505**

Annex 5. Data Sources and Software used in the study

Data Sources

1.FAO Soil Classification
2. NASA Shuttle Radar Topographic Model (SRTM) 90m. http://www.srtm.csi.cgiar.org
3. WBISPP. Woody Biomass Inventory and Strategic Planning project in Ethiopia.
4. World Climate.
5. Bureau of Agriculture of the Adaa Woreda for Livestock Population

Software

1. ArcGIS 9.0X. ESRI