

Land Cover Dynamics (from 1986 to 2015) and its Relation with Area Closure and Slope in Hita-Borkena Watershed, Northeastern Ethiopia

Alemayehu Assefa Ayele (✉ alemayehukelebe@gmail.com)

Wollo University <https://orcid.org/0000-0002-4470-7177>

Assefa Abegaz Yimer

Addis Ababa University

Simphiwe E. Mini

University of South Africa

Research

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Abstract

Background: Land cover dynamics take place as a result of the integration of both physical and man-made factors. This situation is common in Ethiopia and in the study watershed as well. The study was intended to assess the land cover dynamics through 1986 – 2015 and to identify its relation with slope and landscape restoration that incorporates area closure. The analysis was made based on the interpretation of satellite images.

Methods: Both ERDAS IMAGINE 9.1 and ARC GIS 10.3 software were employed in order to generate land cover maps of the study area from satellite images. Also, slope map of the study area was processed from DEM of Ethiopia.

Results: The study found out that forestlands and shrublands shrunk through 1986 – 2015, grasslands expanded mainly due to the implementation of landscape restoration including area closure since 2001. Cropland expanded remarkably. Similarly, the coverage of bareland and settlement also increased.

Conclusions: Based on the results of the study, it is concluded that similar restoration activities shall be implemented in similar environments in Ethiopia to keep the natural resources, and the vegetation cover of Hita-Borkena watershed shall be improved.

Background

Land, a crucial natural resource, supports life and various related activities. Land cover changes are one of the causes for the changes of ecosystem (George et al. 2016). Such changes are resulted due to the intermingling effects between human and natural processes at different scales (John et al. 2013). As reported by George et al. (2016), land cover changes are the consequences of high population pressure and rural-urban migration. Awoniran et al. (2014), on the other hand, showed that those changes are caused as a result of escalating human-induced pressure on the landscape.

A regular monitoring and evaluation of land cover changes is important for understanding the consequences of those changes (Giri et al. 2005 cited in Hassan et al. 2016). Those changes can lead to negative outcomes in the physical environment if they are not managed appropriately. In relation to this, Belay (2002) reported that land cover changes could negatively impact the environment and might also cause depletion and decline in productivity.

The integration of Geographic Information System (GIS) and Remote Sensing technologies assists to identify the list of land cover types, their changes in time and also transitions (Awoniran et al. 2014; George et al. 2016; Hassan et al. 2016; Menale et al. 2016; Mohammed, 2011). Assessing land cover changes using those technologies is also important in devising natural resources management strategies and in environmental planning as well as monitoring (Mohammed, 2011). Moreover, it is also essential for taking actions related to environmental restoration and different development agenda as well as for education purpose (Gete & Hurni 2001). This practice is more useful in developing countries where other data sources are mostly scanty (Kebrom & Hedlund 2000). Hence, this study is executed with the notion that the above-mentioned essences of assessing land cover changes will be achieved.

The study area, Hita-Borkena watershed, is found in Kalu district, South Wollo Zone, Amhara region, northeastern Ethiopia. It is one of the areas in the district which doesn't receive sufficient amount of rainfall and is among the

severely degraded parts of Ethiopia. Several efforts have been made by district's office of agriculture being in combination with WFP's (World Food Program's) MERET (Managing Environmental Resources to Enable Transitions to More Sustainable Livelihoods) project to restore the area and thereby benefit the residents (Kalu District Agriculture Office 2013).

Thus, the objectives of this study were to analyze land cover dynamics in 1986, 2001, and 2015; to compare the land cover conditions in the three periods; to evaluate how much the landscape restoration affected the land cover conditions of the study area; to examine the relations among land cover dynamics, slope and area closure. A combination of GIS and remote sensing technologies were used for achieving these objectives.

Materials And Methods

The Study Area

Hita-Borkena watershed is found in the southern part of Kalu district, South Wollo Zone of Amhara National Regional State of Ethiopia. It is located between $10^{\circ}55'10''$ – $10^{\circ}59'4''$ N and between $39^{\circ}44'53''$ – $39^{\circ}47'30''$ E (Fig. 1). Its total area is 20.94 square km. Its elevation ranges from 1471–2096 meter above sea level (m asl).

The mean annual temperature for the years 2000–2011 was 21.6°C (Kombolcha Meteorology Station 2013). The study area enjoys two rainy seasons: *Kiremt* (main rainy season usually exist between July and September) and *Belg* (small rainfall occurs mainly in March and April). The mean annual rainfall for the years 2000–2011 was 1069.47 mm (Fig. 2).

The study watershed is mainly covered by volcanic rocks formed during Tertiary period of Cenozoic era. The rocks are composed of Oligo-Miocene Trap basalts and are with faults and fractures (Abbate et al. 2014; Mengesha et al. 1996).

The study area consists of three main soil types: Cambisols, Regosols and Vertisols. Cambisols are the most dominant soil types covering 87.3% of the area of the watershed. The study watershed is part of the Awash River basin. It is mainly drained by Borkena River and also by a smaller stream called Hita.

The dominant vegetation types include different acacia species and *Euclea racemosa* (locally called "*Dedeho*"). Agriculture is the main economic base of the residents of the study watershed. People in the watershed practice a mixed farming system with high emphasis on cereal crops (Gete et al. 2014). Because of MERET project, different conservation measures including area closure have been implemented in this watershed since 2001/2. These measures were established with the intention of restoring the degraded environment and improving farmers' livelihood (Kalu District Agriculture Office, 2013).

Analysis Of Land Cover Dynamics

In order to analyze the land cover dynamics of the study watershed, cloud-free three satellite images was downloaded from the website of United States Geological Survey (USGS) named <http://glovis.usgs.gov>. The three images were Landsat TM (Thematic Mapper) of 1986 with 30 meters resolution, Landsat ETM+ (Enhanced Thematic Mapper Plus) of 2001 with 30 meters resolution, and Landsat ETM + of 2015 with 30 meters resolution.

The three years are selected on the basis of the period of implementation of MERET project in the study area. The year 1986 is selected because it is 15 years before the implementation of the project in the study watershed. The year 2001 is selected because it is the time when the project had begun. The year 2015 is selected because it is 14 years after the implementation of the project. Hence, using these reference years, it is possible to see the impact of the project on the land cover conditions of the study watershed.

The satellite images were clipped to fit the size of the study area. The images were radiometrically and geometrically corrected, and were georeferenced to Transverse Mercator geographic projection using WGS84 as a datum (Belay 2002; Messay 2011). Then, unsupervised classification was done to identify major land cover classes depending on their reflectance properties. Field visits and observations were made so as to collect ground truths, i.e. to identify the major land cover classes.

Incorporating data obtained from field visits and observations, supervised classification was made to produce three separate land cover maps for the three reference years. Such process led to the identification of six major land cover classes: forestland, shrubland, grassland, cropland, settlement and bareland. Accuracy assessment (Messay 2011) was calculated for the 2015 land cover map. The overall accuracy was 86.57% with a Kappa coefficient of 0.84. Furthermore, the producer's and user's accuracies were also calculated. The calculations were made using the following formulas taken from Congalton and Green (2009):

$$\text{Overall accuracy} = \frac{\sum_{i=1}^K n_{ii}}{n} \quad \text{Producer's accuracy} = \frac{n_{ii}}{n_{+i}}$$

$$\text{User's accuracy} = \frac{n_{ii}}{n_{+i}}$$

Where n = total number of points (sample)

k = number of categories (1, 2, 3, ..., k)

n_{ii} = correctly mapped point for each land cover type (diagonal values usually bold type)

n_{i+} = number of map data points for each land cover type (row total)

n_{+i} = number of ground data points for each land cover type (column total)

The area covered by each land cover class in each year was determined. The change of each land cover class in the two time intervals: 1986–2001 and 2001–2015 was computed. In doing such analysis, graph and tables were used. These all processes were conducted by integrating ERDAS IMAGINE 9.1 and ArcGIS 10.3 software.

In order to analyze the link between land cover dynamics and slope, first a slope map was produced from the DEM (Digital Elevation Model) of Ethiopia by surface analysis using spatial analyst tool of ArcGIS and then the slope map was classified into three classes based on Aklilu (2006): gentle slope (0–12%), mid slope (12–36%) and steep slope (> 36%). The area of each land cover type on each slope class for the three land cover maps was calculated using overlay analysis. To assess the relation between slope and area closure, the area of Forestland, Grassland and Shrubland (F-G-S) was aggregated for each slope class in the reference years. Also, emphasis was made on the improvement of vegetation on mid and steep slopes since area closures are located on such slopes.

Results And Discussion

Accuracy of the Land Cover Classification

The error matrix for the land cover map of 2015 revealed that the overall accuracy is 86.57% with a kappa coefficient of 0.84 (Table 1). These accuracy values indicate that it is possible to undergo analysis since they fulfill the accuracy level demanded from land cover maps, which are derived from satellite imageries (Anderson et al. 1976 cited in Berakhi et al. 2015).

Table 1
Error Matrix Generated from the 2015 Land Cover Map of the Study Area and the Reference Data

Classified data	Reference data						Row total	User's accuracy*
	Forestland	Shrubland	Grassland	Cropland	Settlement	Bare land		
Forestland	39	4	–	–	–	–	43	91
Shrubland	6	50	2	–	–	1	59	85
Grass land	5	1	49	–	1	3	59	83
Cropland	–	2	7	77	6	6	98	79
Settlement	–	–	–	–	46	–	46	100
Bareland	–	–	–	3	–	42	45	93
Column total	50	57	58	80	53	52	350	–
Producer's accuracy**	78	88	84	96	87	81	–	–
Overall accuracy (summation of the diagonal land covers/ summation of column or row totals): 86.57%, and Kappa coefficient: 0.84 (see the methodology section for details)								
* Diagonal value of a land cover (bold)/row total of the same land cover								
** Diagonal value of a land cover (bold)/ column total of the same land cover								

Description Of Land Cover Types

Six major land cover types were identified from 1986, 2001, and 2015 satellite images of Hita-Borkena watershed. These include barelands, croplands, forestlands, grasslands, settlements and shrublands. This does mean that these land cover types are the only ones in the watershed. There are rather other types like gullies, Borkena River and smaller streams, and main asphalt road that connect Addis Ababa to Kombolcha-Dessie-Woldia-Mekelle, but their spatial coverage is insignificant compared to the major ones. The description of the major land cover types is given in Table 2.

Table 2
Description of Land Cover Types in Hita-Borkena Watershed

Land cover types	Descriptions
Forestlands	Areas devoted for the growth of relatively taller trees that form closed or nearly closed canopy (70–100%) (Alemayehu et al. 2016), are mostly dominated by acacia species.
Shrublands	Areas that contain shrubs and thorny bushes and are less in density than forestlands. They include a bush canopy (> 50%) which is mixed with some trees and that of grass cover (< 50%). They are non-herbaceous species whose branches begin from the base of their stem and are usually < 5 meters in height (Alemayehu et al. 2016; Belay 2002). The dominant plant species in this category in the study area is <i>Euclea racemosa</i> (locally called "Dedeho")
Grasslands	Non-woody areas dominated by grasses with no or few shrubs (Messay 2011) and are used for communal grazing by the residents of the watershed.
Croplands	Land used for the growth of seasonal and perennial crops, which are mostly grown by rainfall and sometimes by traditional irrigation means. The source of irrigation water is mostly Borkena river.
Settlements	These are referring to both rural and urban settlements. Those located in rural areas can be of clustered or scattered dwelling units. Urban settlements are those with better road and social service facilities than the rural counterparts.
Barelands	Parcels of land mostly covered with no or little plant cover and contain exposed rocks. They are indicators of high rate of degradation in the given area.

Trends Of Land Cover Dynamics

The study found that forestland and shrubland diminished during the analysis period. The available forest was mainly deforested between 2001 and 2015 that give rise to the clearing of forest that covers 110.3 ha, i.e. 50% of the forest cover in 1986. The decreasing trends of forestland and shrubland, and increasing trends of cropland, bareland and settlement in the study watershed happened due to population pressure.

Table 3
Land Cover Changes in Hita-Borkena Watershed in 1986, 2001 and 2015

Land cover type	Land cover changes					
	1986		2001		2015	
	Ha	%	ha	%	ha	%
Forestland	220.6	10.5	135.9	6.5	25.6	1.2
Shrubland	774.0	37.0	441.8	21.1	285.4	13.6
Grassland	254.4	12.2	234.8	11.2	298.9	14.3
Cropland	766.5	36.6	1143.7	54.6	1315.2	62.8
Settlement	35.7	1.7	59.4	2.8	78.6	3.8
Bareland	42.6	2.0	78.1	3.7	90.0	4.3
Total	2093.8	100	2093.8	100	2093.8	100

Grassland exhibited a unique trend over the 29-analysis period (Table 4). Its coverage increased by 17.5% from 1986 to 2015. This happened due to the fact that cut-and-carry system has begun to be implemented in the study watershed after 2001. The result of this study is different from Gete & Hurni (2001), Messay (2011), Mohammed (2011) and Belay (2002). The first three authors found out that grassland show a decreasing trend over their respective analysis periods. On the other hand, Belay (2002) revealed that grassland followed an increasing trend in Derekolli catchment between 1957 and 2000 due to the shrinking and modification of shrubland.

Table 4
Trends of land cover changes in Hita-Borkena Watershed in different periods

Land cover type	Area dynamics of each land cover type					
	1986–2001		2001–2015		1986–2015	
	ha	%	ha	%	ha	%
Forestland	-84.7	-38.4	-110.3	-81.2	-195.0	-88.4
Shrubland	-332.2	-42.9	-156.4	-35.4	-488.6	-63.1
Grassland	-19.6	-7.7	64.1	27.3	44.5	17.5
Cropland	377.2	49.2	171.5	15.0	548.7	71.6
Settlement	23.7	66.4	19.2	32.3	42.9	120.2
Bareland	35.5	83.3	11.9	15.2	47.4	111.3
Total	0.0	0.0	0.0	0.0	0.0	0.0

Cropland showed an increasing trend between 1986 and 2015 (Table 4). This result is in agreement with most studies (for example, Aklilu 2006; Belay 2002; Gete & Hurni 2001; Kebrom & Hedlund 2000; Menale et al. 2016; Messay 2011 among others). Figure 4 also displays the expansion of cropland to the steepy slope in the study watershed.

Like the results given by Aklilu (2006) and Menale et al. (2006), the present study witnessed that settlement recorded an increasing tendency between 1986 and 2015 unlike forestland and shrubland. Bareland, which is mostly an overgrazed land containing rock outcrops (Woldeamlak 2002), exhibited an increasing trend alarmingly between 1986 and 2015 (Table 4). This implies that there has been a threat of land degradation (Gete & Hurni, 2001; Menale et al. 2016) in the study watershed. Though it recorded a rapid rate since 1986, the rate after the implementation of landscape restoration including area closure (i.e. after 2001) is relatively slower. However, Mr. Ali, who has been working as an agricultural expert in the study area for a long period of time, witnessed that the interest of the community to conserve the watershed relatively declined immediately after MERET project had stopped in 2012 (personal communication, 2015). The recent railway construction that connects Wollo to Afar passing through the watershed is disturbing the watershed and is contributing to the increase in area coverage of bareland. The researcher also observed that more care is being given for hillsides where area closures are found, but some farmers are letting their animals to graze freely at the foot of the hill (Fig. 5)

Transition Between Land Cover Types

As mentioned above, forestland declined massively in Hita-Borkena watershed between 1986 and 2015. It converted significantly into shrubland, followed by cropland, between 1986 and 2001 and into shrubland, followed by grassland, between 2001 and 2015. Considering the conversion of other land cover types into forestland, the conversion from shrubland into forestland was the most important one during the two periods: 1986–2001 and 2001–2015 (Tables 5 and 6).

In a similar fashion with forestland, shrubland coverage in the watershed decreased extensively. It changed to cropland, followed by grassland in 1986–2015 and 2001–2015. There was of course conversion of other land cover types into shrubland. The main conversions took place between forestland to shrubland and grassland to shrubland during the aforementioned periods (Tables 3, 4 and 5).

In the first year of the analysis period, grassland covered 12.2% of the total area of the watershed. Due to the prohibition of free grazing, though some violations still exist, its coverage increased to 14.3% in 2015 unlike other land cover types. It mainly transformed into cropland, followed by shrubland during the periods between 1986–2001 and 2001–2015. On the other hand, it gained 114.6 and 106.6 ha from shrubland and between 1986–2001 and 2001–2015, respectively. Larger area of bareland was relatively transformed into grassland during the second period than the first one (Tables 5 and 6).

Cropland has been occupying huge portion of the watershed compared to other land cover types. It changed to shrubland, followed by grassland, between 1986 and 2001 and to grassland, followed by shrubland, between 2001 and 2015. It gained larger area from shrubland and grassland in both periods compared to the area it lost (Tables 5 and 6). This is confirmed by Aklilu (2006). Besides, Mohammed (2011) found out that conversion of grassland, forestland and shrubland gave rise to the expansion of cultivated land.

Bareland gained more area through 1986–2015. It expanded at the expense of mainly cropland, grassland and shrubland between 1986 and 2015. It completely lost to cropland, followed by shrubland and grassland, in both periods: 1986–2001 and 2001–2015 (Tables 5 and 6). As indicated by Aklilu (2006), bareland transformed into cropland, plantations and grazing land during the period between 1957 and 2000.

In response to the increased population in Hita-Borkena watershed, rural and urban settlement greatly expanded through the analysis period. It converted into cropland, followed by bareland, between 1986 and 2001 and into cropland, followed by shrubland, between 2001 and 2015. The area it gained was greater than the corresponding area it lost in the two periods. It gained land from grassland, followed by cropland and from cropland, followed by shrubland, in 1986–2001 and 2001–2015, respectively (Tables 5 and 6). Similarly, Kebrom & Hedlund (2000) revealed that rural settlements transformed into cultivated areas, remaining open areas, shrublands and other land cover classes in 1958–1986. The same authors noted that conversion of other land cover categories into rural settlements constituted more than 50%.

Table 5
Land cover change matrix in Hita-Borkena watershed between 1986 and 2001

From land cover type in 1986								
To land cover type in 2001	Land cover type	Forestland	Shrubland	Grassland	Cropland	Bareland	Settlement	Total
		ha	ha	ha	ha	Ha	Ha	ha
	Forestland	81.1	52.6	0.0	2.2	0.0	0.0	135.9
	Shrubland	86.1	254.7	19.3	73.6	4.8	3.2	441.8
	Grassland	5.4	114.6	45.3	63.0	3.6	2.9	234.8
	Cropland	46.6	328.6	154.1	573.2	34.2	7.0	1143.7
	Settlement	1.1	10.6	17.8	13.6	0.0	16.4	59.4
	Bareland	0.2	12.8	18.0	41.0	0.0	6.2	78.1
	Total	220.6	774.0	254.4	766.5	42.6	35.7	2093.8

Table 6
Land cover change matrix in Hita-Borkena watershed between 2001 and 2015

From land cover type in 2001								
To land cover type in 2015	Land cover type	Forestland	Shrubland	Grassland	Cropland	Bareland	Settlement	Total
		ha	ha	ha	ha	Ha	ha	ha
	Forestland	11.6	6.5	0.1	5.6	0.0	1.8	25.6
	Shrubland	72.5	94.0	32.6	61.9	13.6	10.7	285.4
	Grassland	30.6	106.6	58.3	84.2	10.3	8.9	298.9
	Cropland	20.1	204.0	126.7	920.2	22.7	21.5	1315.2
	Settlement	1.1	19.1	12.5	29.7	0.0	16.2	78.6
	Bareland	0.0	11.6	4.6	42.0	31.5	0.3	90.0
	Total	135.9	441.8	234.8	1143.7	78.1	59.4	2093.8

Link Among Land Cover Dynamics, Slope And Area Closure

Attempts were made to see the association among land cover dynamics, slope and area closure in Hita-Borkena watershed, northeastern Ethiopia. The study watershed was classified into 3 slope classes, i.e. gentle slope (0–12%), mid slope (12–36%) and steep slope (> 36%), based on Akiilu (2006).

As can be seen in Fig. 6a, cropland was the major land cover type on the gentle slopes in the watershed. On the other hand, forestland, grassland and shrubland shrank down on the same slopes through 1986–2015.

Though the mid slopes in the watershed were dominated by cropland, grassland showed an increasing trend in the analysis period (Fig. 6b) mainly due to area closure. However, due emphasis should also have been given to forestland and shrub-land. This is because the watershed could be protected not only by grassland but also by forestland, shrubland and different SWC measures. In relation to grazing land, Aklilu (2006) identified that it is mostly located on gentle and mid slopes of Beressa watershed, Ethiopia.

In 1986 and 2001, unlike gentle and mid slopes, steep slopes in the watershed predominantly contained shrubland. In 2015, three land cover types: cropland, grassland and shrubland, were dominating the watershed (Fig. 6c). Grassland's coverage on the steep slopes significantly increased as a result of the presence of area closure in the watershed under consideration, but forestland on the same slope class drastically decreased. This implies that there was negligence of tree planting and high rate of deforestation in the study area. In line with this, Gete & Hurni (2001) noted that 90% of the forestland on the steep slopes in Dembecha area, northwestern highlands of Ethiopia had deforested between 1957 and 1982.

Comparisons were made in order to show how the amount of vegetation including forests, grasses and shrubs in combination and cropland on gentle, mid and steep slopes changed in the watershed between 1986 and 2015.

As revealed in Fig. 7a, cropland showed a considerable increase in the gentle slope throughout the analysis period for the reason that such slope is favorable for crop production. On the other hand, forestland, grassland and shrubland (F-G-S) in combination exhibited opposite trend.

In 1986, F-G-S on mid slopes covered almost 30% of the area of the watershed while cropland constituted only 11%. F-G-S on the same slopes declined to 18 and 14% in 2001 and 2015, respectively, whereas there was the corresponding rise in the size of cropland in the indicated years (Fig. 7b). Though not possible to resume the vegetation cover in 1986, the present F-G-S has been conserved as a result of the restoration project that incorporates area closure in the study watershed.

Conclusions

This study using GIS and remote sensing technologies confirmed that the major land cover types of the study watershed have undergone changes through 1986–2015. Forestland received a significant shrinkage throughout the analysis period, which implies that serious deforestation took place in the indicated years. The same trend, though the rate is relatively minimal, is followed by shrubland that could happen because of the fact that the shrinking of forest leave pressure on shrubs. Unlike the earlier land cover types, grassland decreased trend between 1986 and 2001, but it enjoyed an increasing trend through 2001–2015 due to MERET project that incorporates area closure. The project was introduced in the watershed in 2001.

Cropland expanded at the expense of mainly shrubland and grassland. Bareland and settlement have also expanded throughout the analysis period, though the rate is different from cropland. The area coverage of bareland was being tackled by MERET project especially after 2001. However, low participation of local people after MERET project, i.e. 2012, and recent railway construction are now mainly contributing to the expansion of bareland. As it is also true in other areas of the world, settlement has got an increasing trend in the study watershed through 1986–2015 because of population pressure.

In this study, it is witnessed that cropland was the main land cover type on gentle slope (0–12%) throughout the analysis period. Here, it is mandatory to acknowledge the contribution of area closure for the increasing trend of

grassland on both mid (12–36%) and steep (> 36%) slopes between 2001 and 2015. F-G-S was found to be higher in coverage compared to cropland on steep slope through 1986–2015. The overall coverage of F-G-S is, however, decreasing. This calls for the coordinated efforts of local people, local, zonal, regional and federal concerned offices, and NGOs (Non-Governmental Organizations) improve the vegetation coverage of the study watershed.

Abbreviations

DEM: Digital Elevation Model; ETM+: Enhanced Thematic Mapper Plus; F-G-S: Forestland, Grassland and Shrubland; GIS: Geographic Information System; MERET: Managing Environmental Resources to Enable Transitions to More Sustainable Livelihoods; NGOs: Non-Governmental Organizations; TM: Thematic Mapper; USGS: United States Geological Survey; WFP's: World Food Program's

Declarations

Availability of Data and Materials

Not Applicable.

Ethics Approval and Consent to Participate

Not Applicable.

Consent for Publication

Not Applicable.

Competing Interests

The authors declare no competing interest.

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Authors' Contributions

AAA analysed and interpreted the collected data and wrote the manuscript. AA significantly contributed in analysing and interpreting the data and writing the paper. SEM also gave feedback for the paper. All authors read and approved the final manuscript.

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Figures

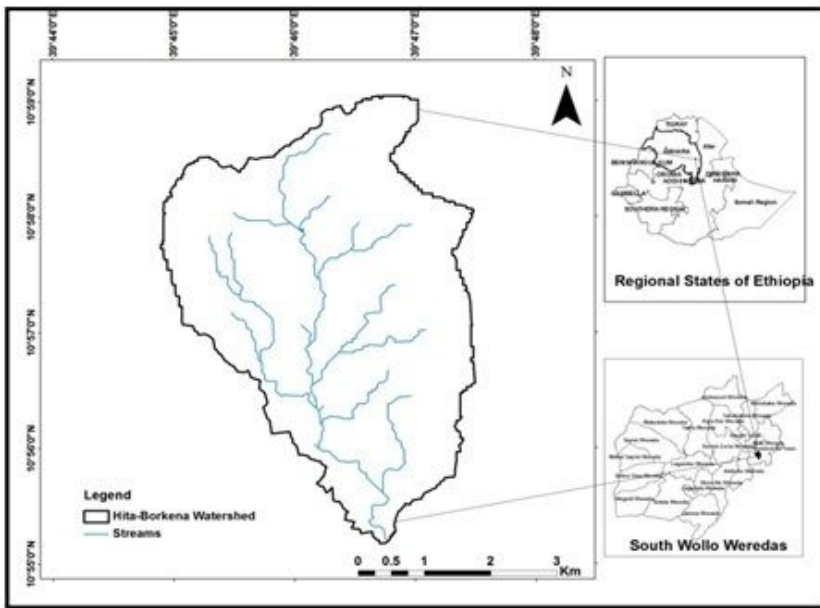


Figure 1

Location map of Hita-Borkena watershed, northeastern Ethiopia

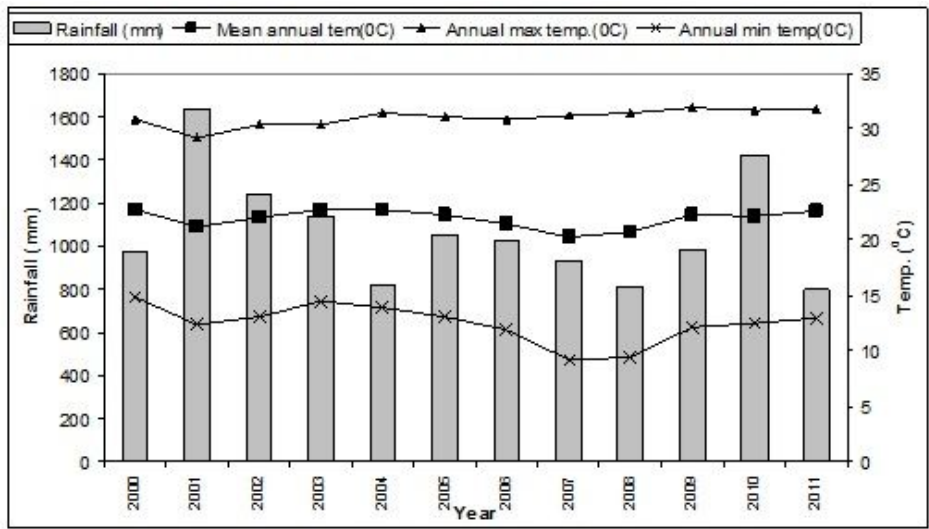
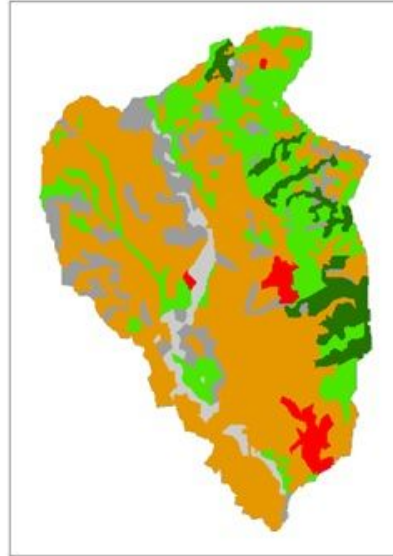
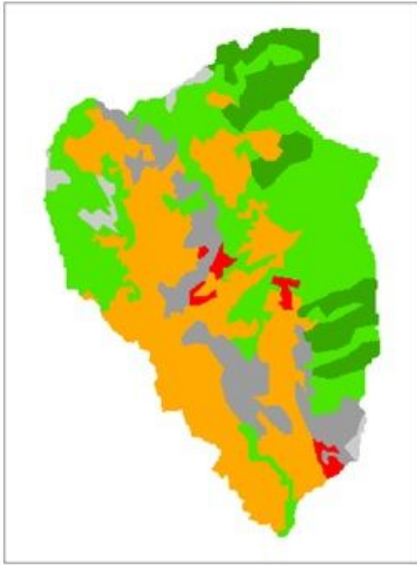


Figure 2

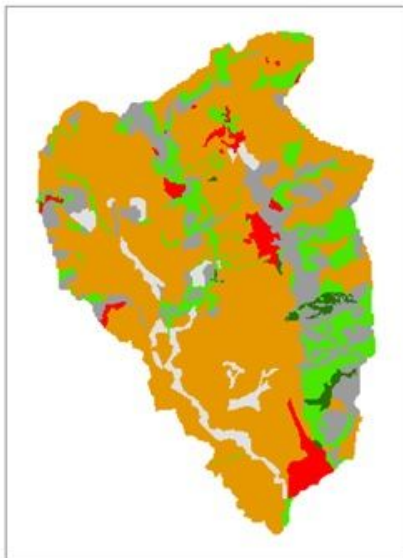
Mean annual temperature and total annual rainfall of the study watershed (2000-2011)

1986

2001



2015



Legend

-  Cropland
-  Shrubland
-  Settlement
-  Bareland
-  Grassland
-  Forestland

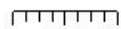

0 860 1.720 Kilometers

Figure 3

Land cover maps of Hita-Borkena watershed, northeastern Ethiopia



Figure 4

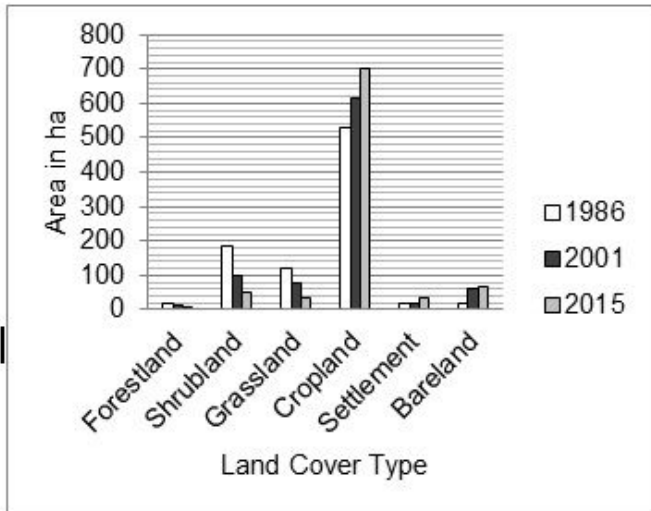
Expansion of cropland to sloppy bushland in Hita-Borkena watershed, 2015 (Photo by the Author)



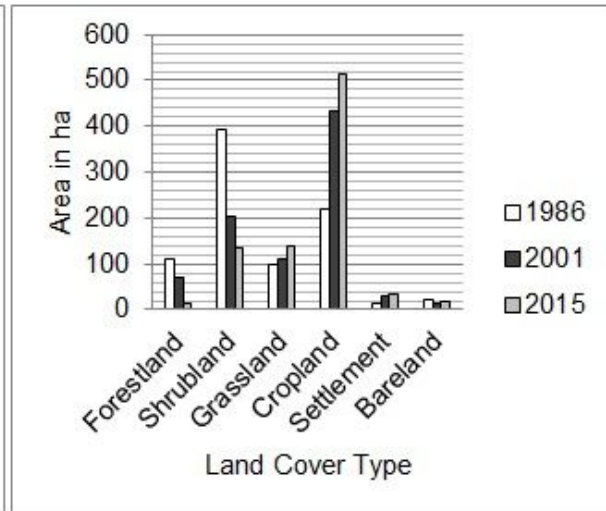
Figure 5

Overgrazed Grassland in Hita-Borkena watershed, 2015 (photo by the Author)

a) On gentle slope (0 – 12 %)



b) On mid slope (12 – 36 %)



c) On steep slope (> 36 %)

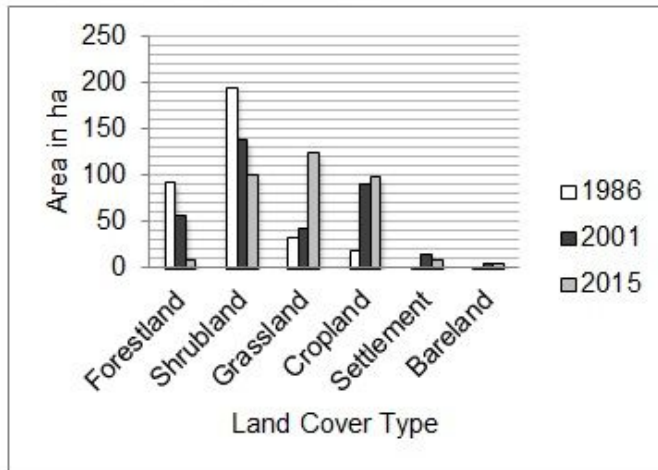
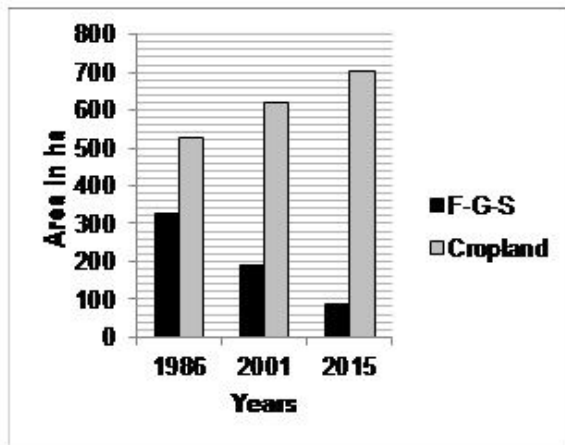


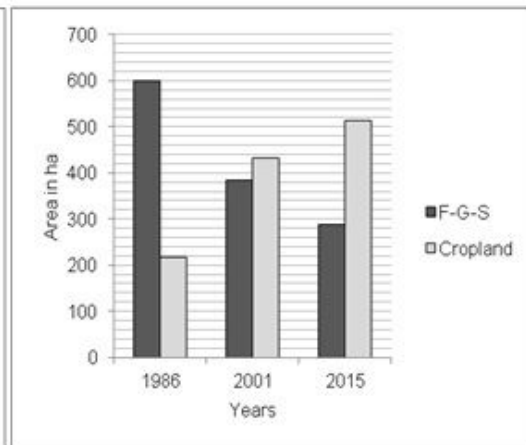
Figure 6

Link between land cover dynamics and slope in Hita-Borkena watershed, northeastern Ethiopia

a) On gentle slope (0 – 12 %)



b) On mid slope (12 – 36 %)



c) On steep slope (>36 %)

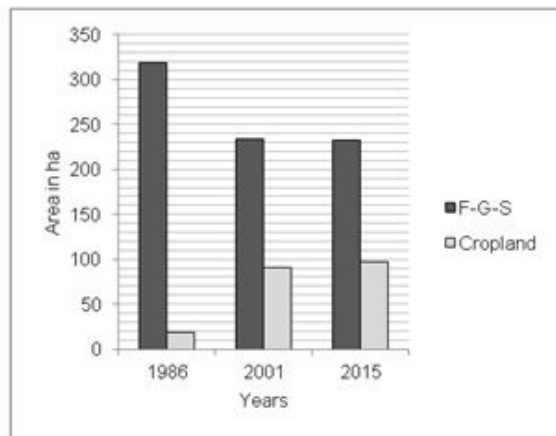


Fig. 7 Combined vegetation cover (Forestland-Grassland-Shrubland/F-G-S) against cropland on gentle, mid and steep slopes in Hita-Borkena watershed, northeastern Ethiopia in 1986, 2001 and 2015

Figure 7

Combined vegetation cover (Forestland-Grassland-Shrubland/F-G-S) against cropland on gentle, mid and steep slopes in Hita-Borkena watershed, northeastern Ethiopia in 1986, 2001 and 2015