Assessment of forest cover change and its environmental impacts: The case of Gumara-Maksegnit watershed of North Gondar Zone, Ethiopia

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Abstract

This study evaluated changes in forest cover in the Gumara-Maksegnit watershed, northwestern part of Ethiopia. The trend of forest cover both in time and space was investigated from 1986 to 2007 using remote sensing images and Geographical Information System (GIS). Two sets of satellite images; Landsat (1986 and 1999) and SPOT (2007) were acquired and supervised classification was used to categorize the land cover types. The overall accuracy and the Kappa value of classification were 91% and 86%, respectively. Change detection was undertaken to know the dynamic trend of forest cover in the area. The findings showed a decreasing trend in the area of forest cover over the last 21 years. In all the periods considered, the area under forest declined by 1056.25 ha (18.92%) from the base year (1986). The annual clearance of forest cover in the first years (1986-1999), in the second years (1999-2007), and over all the periods (1986-2007) were 48.04 ha, 95.69 ha, and 50.3 ha respectively. Agricultural expansion was the major driving force behind the changes. As a result of deforestation, the local people are mainly facing loss of important tree/shrub species (biodiversity) and drying of rivers and streams in the area.

Key words: Change, forest, GIS, Landsat, SPOT, remote sensing, supervised classification.

Introduction

Ethiopia has large number of species of flora and fauna in general and forest resources in particular with a significant rate of endemism. Ethiopian forest cover once was 40% of the country's land area and with the inclusion of the savanna woodlands (EEPFE, 2008). FAO (2006) estimated 11.9% of the country's land mass is covered with forests (0.13 million Km^2) and is at an alarming rate of deforestation (at 1.1% annually).

Reduction in forest cover results in soil erosion, reduced capacity for watershed protection, reduced capacity for carbon sequestration, biodiversity threatening, deterioration and instability of ecosystems and shortage of various wood and non-wood forest products and services. Before putting something to the ground to reverse the existing degradation, the first step should be mapping the current situation of the area.

Some researches on natural resources mapping have been conducted in the Amhara Region (Solomon, 1994 and 2005; Kebrom and Hedlund, 2000; Gete and Hurni, 2001; Belay, 2002; Woldeamlak, 2002; Girmay, 2003; Selamyihun, 2004; Birru, 2007; Hussien, 2009; Menale *et al.,* 2011), but there is significant variation in the level of analysis performed and purpose and output of the studies.

It is hoped that this study will provide information for decision makers and development practitioners about the magnitude and dimensions of long term forest cover changes, its drivers and impacts in the study area and surrounding.

Problem Statement

The ecology and environment of the Gumara-Maksegnit watershed has changed due to the sharper conflict between human and nature. IFAD/EPLAUA (2007) stated that most of the forests in the watershed are destroyed except some remnants of vegetation types of scattered trees left in the farm fields, churchyards, open forest along the streams and inaccessible areas. The natural vegetation cover of the watershed has been depleted. As a result, the natural resource base has been depleted to a greater extent due to inappropriate land use, soil erosion, reduction in the vegetation cover, biodiversity loss, and associated substantial reduction in the desired services including soil and water conservation and sustainable flow of water to the downstream. These problems are related either directly or indirectly to the total reduction of vegetation/forest cover and its composition (biodiversity) of the study area. Yonas *et al.* (2010) has also reported that small-scale farmer's productivity is constrained by small and fragmented land holdings, harsh climatic conditions, and other related factors. Therefore, it is crucial to answer the following questions: What was the spatial pattern of forest cover of the watershed in the past? What is the current status forest cover? What are the main causative factors for the change of forest cover over time? And what are the socioeconomic impacts of these forest cover changes?

Material and methods

The study area

The study was conducted in the Gumara-Maksegnit watershed located at about 45 km southwest of Gondar town and 695 Km from Addis Ababa, the capital of Ethiopia. It is located between 12^0 11’ 24” and 12^0 39’ 00” latitude and 37^0 22’ 48” and 37^0 36’ 00” longitude. The watershed drains into the Gumara-Maksegnit River, which ultimately reaches to Lake Tana (Fig 1).

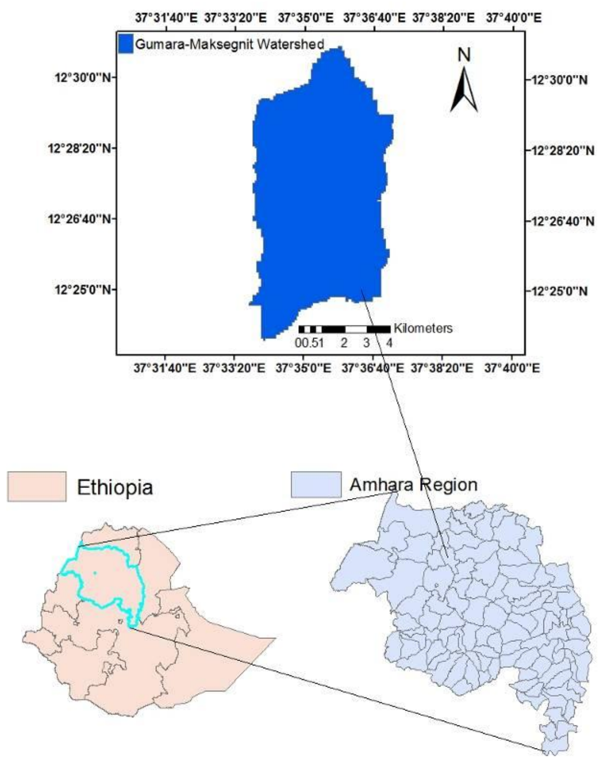

Figure 1. The study area

The study area is characterized by a unimodal rainfall distribution with mean annual rainfall of 1052 mm. The mean monthly minimum and maximum temperatures are 13.3 °C and 28.5 °C, respectively (Yonas *et al.*, 2010). The total area of the Gumara-maksegnit watershed is about 5600 ha. The topography situation of the area ranges from gentle slope to very steep slope. The altitude ranges from 1912 to 2848 m above sea level. The soils are red soil (Nitosol) 21%, black soil (Vertisol) 43%, and brown and other types (Gleysol and Leptsol) 36% of the study area. Vegetation of the study area is part of the evergreen dry afromontane forests that dominate the highlands of Ethiopia (Demel, 1996). The dominant tree species is *Olea africana*. Other large tree species are *Albizia gummifera, Ficus spp and Euphorbia species* (mainly in the natural forest). In areas of clearings and gaps, *Croton macrostachys* is the frequent species (Chaffey, 1979, ILDP, 2002 and Yonas *et al.*, 2010). The major crops include sorghum, teff, garlic, shallot, faba bean, lentil, bread wheat, chickpea, field pea, linseed, finger millet, barley and maize. Teff, sorghum and chickpea are the main staple crops in the study area (Yonas *et al.*, 2010).

Data collection and analysis

Data type and software used

Satelite images and analysis tools included in Table 1 were used to analyze the forest cover change in the watershed.

Table 1. Data type and software used.

Data types and software used	Description
Landsat	p170r055 Landsat TM 1986 and ETM+ 1999 with 28.5m spatial resolution,
SPOT	SPOT 2007 (spatial resolution =10m, (Scene ID = 4 133-325 07-10-08 08:21:42 1 I, Date = 2007-10-08 08:21:42, Instrument = HRVIR 1 and Number of spectral bands = 4)
DEM (Digital Elevation Model)	ASTER DEM (pg-BR1A0000-2007020401_003_012, 90m spatial resolution)
ERDAS	ERDAS version 9.1 used for image analysis
ArcGIS	ArcGIS version 9.3 used for image analysis
SPSS	SPSS version 16 used for socioeconomic data analysis

Socio-economic data

Questionnaires were developed and interviewes carried out to gather the necessary information. Households were selected from three kebeles (Chenchaye degola, Denzaze and

Jayera). All of the interviewees were farmers living in the watershed. In each Kebele, 30 interviewees were selected and a total of 90 respondents were interviewed. The overall content of the questionnaire mainly focused on knowledge of people in the watershed related to the trend of forest cover change and their experiences due to the changes of the forest resources. The questionnaire included personal and demographic data, crop production, vegetation data emphasizing on the forest resources, its changing trend, its associated environmental problems and solutions. Quantitative and qualitative data were co-analyzed in order to allow identification of causative factors. The analysis of the socioeconomic data was carried out using SPSS software version 16 (SPSS, 2007).

Different methods and techniques were used to measure and analyze spatial and non-spatial data. Landsat and SPOT satellite images of 1986, 1999 and 2007 were analyzed to identify forest cover change in the Gumara-Maksegnit watershed. A topographic unit such as altitude was extracted by using ASTER DEM and the aforementioned images. Field observations and/or Global Positioning System (GPS) points were collected from December to March 2011 to make reference information for image analysis and accuracy assessment. Socioeconomic data were also collected through questionnaires and informal communication to identify the pressures causing forest cover change and its impact on the environment.

Data acquisition and classification of forest cover

Field observations were performed to understand the features of different land cover (LC) classes. A total of 234 GPS points were collected. The number of GPS points for cropland, forest, and grassland were 60, 94 and 15, respectively. In addition, the remaining 65 GPS data were used for accuracy assessment. With some modifications, the land cover categorization was attained based on Hurni and Ludi (2000), Amsalu *et al.* (2007), Birru (2007), Hussien (2009) and Menale *et al.* (2011).

Forest/open shrub land: Refers to those areas covered with trees, shrub, bushes and some grasses. There exists variation in vegetation between dense shrub/bush lands with an estimated cover of >50% and open shrub/bush lands with less than 50% cover. The latter are not bare at all, but being degraded from competing use of grazing, cultivation, and deforestation as some of the degraded shrub/bush lands serve for grazing purposes (Birru, 2007). Red brown to bright red in the Landsat image (4, 3, 2 band combination) (Menale *et al.*, 2011) and SPOT image (1, 2, 3 band combination).

Cropland: Cultivated and fallow lands have a characteristic pattern, for example sharp edges between fields. Dark to grey and brown color in the Landsat image (4, 3, 2 band combination), unless the land lies fallow (Hurni and Ludi, 2000) and (Amsalu *et al.*, 2007) and SPOT image (1, 2, 3 band combination).

Grassland/Pasture /Bare land: Land under permanent and intensive grazing and bare land (land surface features devoid of vegetation) (Hussien, 2009). Homogeneous and have no pattern compared to agricultural land. Bright to white color in the Landsat image (4, 3, 2 band combination) (Hurni and Ludi, 2000) and SPOT image (1, 2, 3 band combination).

Analysis of images

Images obtained and used were Landsat TM 1986, Landsat ETM 1999 and SPOT 2007. These periods were considered based on the availability of satellite images. The projection was Universal Transverse Mercator (UTM). Before any analysis, resampling of spatial resolution of all images to 28.5 m X 28.5 m was done. Digital Elevation Model having a spatial resolution of 90 m was accessed to generate altitudinal classes. Representative Areas of Interests (AOIs) were selected as training for LC classification. The AOIs are selected based on the knowledge of the area obtained from field work, visual interpretation of the images and using GPS points. The number of sample AOIs for cropland, forest and grassland were 118, 62, and 53, respectively. A total of 233 AOIs were used for classification.

Based on the field survey data, an error matrix was generated to compare the real LC type versus the automated classification output. Overall accuracy of the classification, producer´s and user´s accuracy and kappa coefficient were calculated from the error matrix.

Forest cover change detection was done for 1986 to 1999, 1999 to 2007 and 1986 to 2007 using functions in the ERDAS Imagine software version 9.1. Four classes were assigned for the map produced after two images were overlaid to produce the change detection. The classes were no class (a place which is devoid of forests between two times under interest or cropland and grasslands), no change (a place where it is under forest in both times under study), new forest (a place where it was covered with non forest land covers during the first study period but forests emerged or replaced the previous land covers in the second time of the study period) and deforestation (places where there was a forest land in the base year, whereas lost its cover in the subsequent periods). Altitude was categorized into five classes to identify forest cover change in each level of category. Those class ranges were extracted in "if conditional modeler" by combining DEM and each year's change detection result. Then the model generated the amount of forest cover change at each level of altitudinal ranges. The altitudinal ranges were categorized into five classes with an interval of 200 m. The categories were: below 2000 m, 2000-2200 m, 2200- 2400 m, 2400-2600 m, and above 2600 m a.s.l.

Results and discussion

Land cover conditions of Gumara–Maksegnit watershed

To group land covers into different classes, classification categories were made based on reference information, structure/pattern and spectral signature. Three LC maps were produced for visual display of different LC categories for the three periods (Figure 2).

Forest cover share for the specific study years of 1986, 1999 and 2007 were 31.6%, 25.5% and 22.2%, respectively. Cropland covers 38.7%, 62.6% and 76.1% in 1986, 1999 and 2007, respectively. Grassland shared 29.7%, 11.8% and 1.8% in 1986, 1999 and 2007, respectively.

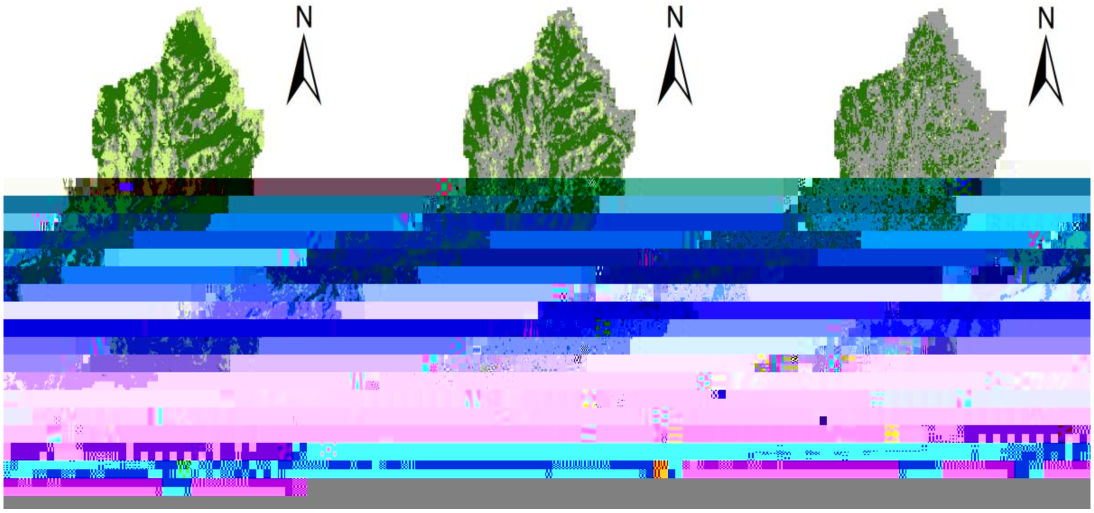

Figure 2. Land cover classification over study period.

Accuracy assessment

Sixty five GPS points were used for verification of the land cover classes generated. The general kappa index obtained is 0.86, which explains that the classification process is avoiding 86% of the errors that a completely random classification would generate. The overall accuracy of the field data versus automated classification result is 91% which is more than the acceptable range in such kind of classifications. And the producer's and user's accuracy are presented in Table 2.

Table 2. Error Matrix.

	Field data				
Classification	Forest	Agriculture	Grassland	Row total	User's accuracy
Forest	25	1	0	26	0.96
Agriculture	0	23	4	27	0.85
Grassland	0	1	11	12	0.92
Column total	25	25	15	65	
Producer's accuracy	1	0.92	0.73		

Forest cover change detection

Spatial and temporal forest cover change in the watershed was investigated. There was a decreasing trend of forest cover between the first (1986 and 1999) and the second (1999 and

2007) periods, and for the whole study period (1986 to 2007). The area under the forest cover was 1764.5 ha (31.6% of the watershed) in 1986 found declined to 1425.0 ha (25.5% of the watershed) and to 1239.19 ha (22.2% of the watershed) in 1999 and 2007, respectively. The greatest deforestation took place between 1999 and 2007. The size of forest cleared between 1999 and 2007 is 765.55 ha or 13.71% of the watershed. The annual clearance of forest covers in the first, second and the whole period were considerable and was estimated 48.0 ha, 95.7 ha and 50.3 ha, respectively. However, few newly emerged forests were also found. This is due to plantation in farmlands, farm boundaries, gullies and homesteads. The field observation revealed that most of the emerging forests are plantation covered by Eucalyptus species. Farmers have great interest for Eucalyptus because of its fast growth habit which enables to fulfil the wood demand of the farmers and as cash income generation along side with the main farm activities. Regeneration of the natural forests situated in remote and inaccessible (steep terrain) areas also contributed these increments. The change detection of forest cover was categorized as no class (land covered by crop and grassland), new forest, deforested land and forest areas that have no change in the last two decades (Table 3).

Table 3. Forest cover change (ha).

Class	1986 to 1999	1999 to 2007	1986 to 2007
No class	3534.91	3591.61	3300.90
No change	1140.40	659.47	708.20
New forest cover	284.61	567.36	518.62
Deforested	624.05	765.55	1056.25
Total	5583.98	5583.98	5583.98

Analysis of forest cover across altitudinal ranges

The natural distribution of forests is sensitive to altitude due to the physiological requirement. The distribution of land area to the different altitude classes in the watershed is shown in Table 4.

Table 4. Distribution of land areas in different altitudes (DEM of the watershed).

Altitude (m.a.s.l.)	Area (ha)	%
Below 2000	730.38	13.08
2000 – 2200	1458.88	26.13
2200 – 2400	2375.51	42.54
2400 – 2600	607.08	10.87
Above 2600	412.14	7.38
Total	5583.98	100

Between 2200 and 2400 m a.s.l. elevation category, for the first study period (1986 and 1999) the amount of deforestation was 16.0% while the amount of newly emerged forests was 10.5% (Figure 3).

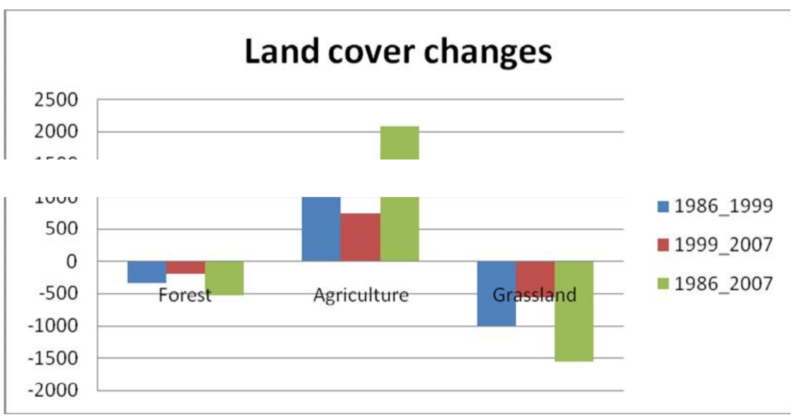

Figure 3. Land cover change

For the second period (1999 and 2007) of the study the amount of deforestation and newly emerged forests were 24.6% and 13.2%, respectively. And for the whole study period these amount are estimated to be 30.2% and 13.1%, respectively.

In all the periods, deforestation and new forests were concentrated in altitudinal range between 2000–2200 and 2200–2400 m a.s.l. This is because, in these higher altitudes agricultural and grazing (which is "no class" in the graph) activities are very limited due to its inaccessibility and physical unsuitability of the land to agricultural practice as can be seen in the result. Agricultural and grazing activities are concentrated up to 2200 m a.s.l altitude. Large areas of newly planted forests (153.6 ha first period, 240.4 ha second period and 233.6 ha whole period) were observed in between 2200–2400 m altitudinal ranges in all the studied periods. The reason behind this was that it predominates (68.67%) the watershed and as a result there is a high population intervention to this altitudinal range. The field observation also confirmed that plantations which are new forests like Eucalyptus woodlots were concentrated around homesteads and farmlands. In addition, large areas of deforestation (237.0 ha, 358.4 ha and 440.2 ha in various periods) were observed within the elevation category of 2200-2400 m a.s.l. altitudinal ranges. This is due to clearance of forests by the people starting from their surrounding up to the tolerable distances for different purpose.

Socioeconomic data

The total population of the 90 sample households was 369, of which 194 (52.57%) were male and 175 (47.43%) female. The average family size for all surveyed households was 4.1 with a range of 2 to 11. Average agricultural land holding of farmers is 1.32 ha. Only 3.25% of the interviewees have more than 2.5 ha. A large proportion of the surveyed households (91.6%) indicated that area under cultivation has decreased from time to time due to giving the resource to their children. While the remaining (8.4%) responded that there was no change. Ninety two percent of the respondents have put population growth as a first rationale for cultivation area decline in the households.

Drivers of forest cover change

The majority of interviewees (97.8%) confirmed that forest cover of the watershed has declined for the last decades. While the remaining 2.2% of them said there was no change on its extent. The major cause identified by 83.3% of respondents in the study was expansion of agricultural fields with the expense of forest lands and grasslands. The LC change detection result also showed the changes in LC types from 1986 to 2007 period. Agricultural land cover increased by 24% from 1986 to 1999, 13% from 1999 to 2007 and 37% for the whole study period with the expenses of forest and grassland land covers. Conversely, forest cover has declined 6% from 1986 to 1999, 3% during 1999 to 2007 and 9% during 1986 to 2007. The highest reduction occurred during the time between 1986 and 1999. As it has been observed during field observation, the remaining forests were due to difficulty to cultivate and inaccessibility for other use of the forests. Moreover, 11.1% and 3.3% of the respondents reported that the loose institutional setup and fuel wood collection contributed as a second and third causes of deforestation, respectively. About 98% of the farmers responded that government institutions have little or no influence despite the forest policy is in place.

Impact of forest cover change on the environment

The interviewees raised many problems that occurred as a result of deforestation in the watershed. Among the problems raised; lack of fire wood, construction timber scarcity, shortage of fodder, increased soil erosion and water flooding, drying out of springs and rivers, species extinction and productivity reduction were some of them. Sixty-nine percent of the respondents reported that the main problem in the study area occurred due to deforestation is drying of water bodies like ground water, springs and rivers. About 17% of them indicated soil erosion due to water as the main environmental problem, whereas 9% of them have raised fire wood scarcity as a major problem. Others prioritized scarcity of fodder (2.2%), lack of construction timber (2.2%) and species extinction (1.1%) as a primary problem of the watershed. The respondents identified a list of trees/shrubs species (Table 5) as disappeared due to deforestation in which the farmers had been extracting one or more benefits from these trees.

Table 5. Disappeared plant species from the Gumara-Maksegnit Watershed.

Vernonia amygdalina (Grawa)	*Psydrax schimperiana* (Seged)	Shonet
Schefflera abyssinica (Geteme)	*Delonix regia* (Kachona)	Yellew
Rhus glutinosa (Embus)	*Carissa ed ulis* (Agam)	Enkoy
Combretum molle (Abalo)	Euphorbia spp (Enketitif)	Kechem
Ziziphus spina-christi (Gaba)	Tekere	Kunbel
Syzygium guineense (Dokima)	Duduna	Dimetot
Juniperus procera (Tid)	Ayiderkie	Wonbella
Entada abyssinica (Kontir)	Afer	Chocho
Podocarpus falcatus (Zigiba)	Dingay seber	Tenbelel
Acacia albida (Girar)	Awera	Kimo

In addition to the impacts mentioned earlier, farmers in the watershed also raised productivity reduction and gully formation as other major problems due to deforestation. Ninety percent of the respondents asserted productivity reduction on their farmlands while 6% and 4% of the respondents replied as there has not been any change in productivity and increase in production through time, respectively. For the solutions farmers given to combat the problem of loss of productivity, 48% of the respondents looked for additional land through different mechanisms (e.g renting, buying, etc). Forty three percent of the respondents tried to increase the fertility of their farmland by using fertilizers as a solution for productivity reduction. Two percent of the respondents used to fallow their old farms as a solution for the productivity reduction occurred on their farmlands. The rest 7% of the respondents didn't take any action because there was no reduction of productivity.

Conclusion and recommendations

Using Landsat TM 1986 and ETM 1999 and SPOT 2007 datasets, forest cover change of the Gumara-Maksegnit watershed was analyzed. Drivers for the observed change and deforestation consequences over the environment were also identified by analyzing the knowledge of the farmers by surveying and focus group discussion.

The quantitative evidence of forest cover dynamics showed the substantial decline of forest cover since 1986. Therefore, it was the agricultural expansion which was accountable for the decline of the forest cover in the watershed. So, due to such deforestation, the local people have faced so many environmental problems such as loss of biodiversity, drying of streams and water bodies, etc. However, the leading problem was found to be the deterioration of the water bodies in the watershed.

Satellite derived topographic unit, such as altitude which is supposed to influence the growth of trees were extracted to examine the topographic unit of the study site. The mid elevation category of the watershed area is the dominating natural condition to the distribution of forest cover and agricultural land expansion in the watershed. And large areas of deforestation and newly emerging forests were observed in this altitudinal ranges.

Deforestation mainly as a result of agricultural expansion is a serious problem in the study area; it requires the decision of the government with top priority to come to an understanding with the communities to undertake afforestation, close the forest areas from animals and human beings and utilize sustainably, establish arboretum to conserve the biodiversity and prevent further expansion of cultivation lands through different mechanisms. Besides it would be important for farmers to be engaged in different off farm activities so as to reduce the pressure over forest resources. Making a local forest as a source of income generation by incorporating economically useful trees could make the resource sustainable. Further studies on policy and detailed socioeconomic issues should be undertaken to understand the human forest interaction and bringing options to reverse the current deforestation. Further study is required to quantify the reported species extinction and underlying factors responsible for the problem. Introduction of modern energy sources like kerosene as well as the introduction of fuel wood saving stoves has to be given priority consideration.

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