Trees, Forests and People 9 (2022) 100305

Contents lists available at ScienceDirect

Trees, Forests and People

journal homepage: www.sciencedirect.com/journal/trees-forests-and-people

Threats and management options of the green belt natural forest, northwest lowlands of Ethiopia

Gashachew Yeshineh [a], Mulatie Mekonnen [b,*], Gete Zeleke [c], Gizaw Desta [d]

[a] West Armachiho District Agricultural Office, northwest lowlands of Ethiopia, Ethiopia
[b] Bahir Dar University (BDU), College of Agriculture and Environmental Sciences (CAES)
[c] Director of the Water and Land Management Resource Center & Leader of NCCR - RP12 Landscape Transformation Research Project in Ethiopia
[d] Gizaw Desta, ICRISAT, NRM and Landscape Management, Research Manager, Ethiopia

ARTICLE INFO

Keywords:
Green belt natural forest
Re-settlement
Agricultural investment
Local bylaws

ABSTRACT

The natural forest located across central Africa from Gambia (West Africa) to Ethiopia (East Africa) is believed to break the expansion of the great Sahara Desert towards the southern and south eastern Africa, as a green belt. However, natural and anthropogenic factors are challenging the existence of the forest. Thus, this study was conducted to investigate the spatio-temporal dynamics, threats and sustainable management options of the green belt forest (GBF) located in Ethiopia. Satellite imagery was used to assess the GBF cover dynamics between the year 1980 and 2020 using ERDAS IMAGINE software. ArcGIS software was used for spatial analysis and mapping. Field observation, focus group discussions, and questionnaire based interview were used to collect the required data and SPSS software was used for analysis. The result showed that farmland increased from 32% (in 1980) to 52% (in 2020), whereas, the GBF cover decreased from 58% (in 1980) to 39% (in 2020), with the overall classification accuracy and kappa coefficient of 86% and 81%, respectively. Re-settlement, large-scale agricultural investment, charcoal production, fuel wood, and road construction were among the important threats causing the GBF reduction. Investors, settlers, migrants, residents and day-workers are agents of the GBF cover reduction. To minimize deforestation and sustainably use the GBF local bylaws, delineating and keeping the GBF from human interferences, building awareness, enrichment plantation, and alternative firewood sources were identified as management options. Therefore, to maintain the GBF and break the expansion of the Sahara Desert, governmental and non-governmental organization and the local community ought to apply the recommended GBF management options.

1. Introduction

Natural forest deterioration is a widespread and accelerating process, mainly driven by anthropogenic activities (Yismaw et al., 2014; Kimutai and Watanabe, 2016; Mekonnen et al., 2016; Abera et al. 2020), which signals the loss of the vital ecosystem services provided directly and indirectly to humans, including the supply of food, material goods and environmental regulation (Tigabu, 2016; Alemayehu, 2019). Deforestation is common in developing countries most of which are located in the tropics due to high human dependence on agriculture (Adu et al., 2012; FAO, 2016; Wondie et al., 2016). Globally, forest cover shrank by an annual average of 3.3 million ha between 2010 and 2015, with the most loss occurring within the tropics (FAO, 2016).

Agriculture based investment in most African countries is changing dense forest to open forest, and then to agricultural lands (FAO, 2016). According to FAO and UNEP (2020), Africa had the highest net loss of natural forest between 2010 and 2020 with an annual estimated loss of 3.94 million ha. Fuel wood consumption has declined or remained steady over time in most developed regions, but in sub-Saharan Africa, it continues to increase.

In Ethiopia agricultural encroachment into forest areas, to produce more food for the rapidly growing population is causing unprecedented changes on the natural forest, grassland, and wildlife (Adu et al., 2012; Tolessa et al., 2019). Unregulated land resources exploitation by the investors is also causing huge forest destruction, land degradation, and disruption of wildlife resources (Mekonnen et al., 2016; Hurni et al., 2010; Kasaro et al., 2019). Natural forest cover in Ethiopia is declining from time to time where farming and settlements are changing

* Corresponding author.
E-mail address: mulatiemekonneng@gmail.com (M. Mekonnen).

https://doi.org/10.1016/j.tfp.2022.100305
Received 4 May 2022; Received in revised form 15 July 2022; Accepted 16 July 2022
Available online 17 July 2022

landscapes for millennia with an immense increase in crop lands, largely at the expense of grass and forest lands (FAO, 2010; Mulugeta and Woldesemait, 2011; Walle et al., 2011).

The lowland belts of northwest Ethiopia, along Ethio-Sudan Border, is known for its natural forest cover, and mostly named as the green belt (Mekonnen et al., 2016). Ethiopians believe that this green belt could prevent the expansion of the great Sahara Desert towards Ethiopia, however, its cover is rapidly decreasing (Alemu et al., 2015; Mekonnen et al., 2016). In this study, part of the GBF extended from west Africa (Gambia) to East Africa (Ethiopia), located in the NW lowlands of Ethiopia along the Ethio-Sudan Border was considered for investigation. The reason was that the area is a major destination for re-settlement and large-scale agricultural investment for the past four decades. Investigating the natural forest cover changes, existing threats, and management options were the focuses of this study.

Knowledge on natural forest cover changes and its major threats, are essential to design forest management actions and make data-based decisions. Consequently, the objectives of this study in the northwest (NW) lowlands of Ethiopia where the GBF exists were to; (i) detect and quantify the GBF cover changes between 1980 and 2020, and (ii) identify the major threats and find out management options related to the GBF.

2. Material and methods

2.1. Descriptions of the study area

2.1.1. Location

The study was conducted in the northwest (NW) lowlands of Ethiopia located along the Ethio-Sudan border endowed with dense natural forest, which is believed as a green belt that could prevent the expansion of the great Sahara Desert towards Ethiopia. The study area is located between 11° 43′ 34″ to 13° 44′ 26″ N and 35° 15′ 10″ to 36° 47′ 50″ E, covers about 15,566 km^2, and comprises three districts Metema, Quara and West Armachiho, and one city administration (Genda Wuha) (Fig. 1).

2.1.2. Rainfall and temperature

The climate of the study area is characterized as a moist Kolla (Hurni, 1998). The mean annual rainfall ranged from 800 to 1,200 mm. About 80-90% of the rainfall falls in the main rainy season (locally called, *Kiremt*) which starts in June and extends to August, but is preceded and followed by two months of low and dispersed rainfall. The mean minimum and maximum temperatures of the area are 25 °C and 35 °C, respectively (Fig. 2).

2.1.3. Soils, geology and demography

Altitude of the study area (Metema, Quara and West Armachiho districts and Genda Wuha town administration) ranged from 550 to 1600 m above sea level. The soil in the flat areas along the Sudan border is dominantly Pellic Vertisol, whereas, Chromic and Orthic Luvisols are dominant in the hillsides (Berhanu et al., 2013a, 2013b). The geology of the area is characterized by a Precambrian basement overlain by a Paleozoic-Mesozoic Sedimentary succession capped by Tertiary volcanism (Sembroni et al., 2017). The total population is estimated at 401, 761 (204,534 males, and 197,227 females). Majority of the population had been settled by the government since 1990 with the re-settlement program.

2.1.4. Farming system and economy

Large part of the study area is occupied by large-scale farmer (investors) and small-scale farmers. The small-scale farmers' operate from 2 to 10 ha of land on average, but large-scale farmers (investors) operate from 11 to 1500 ha of land. The household economy depends on crop production, livestock rearing, trade, and non-timber forest production (like Gums and Resin). The area is suitable for livestock rearing because of livestock feed availability. The numbers of cattle in the study area are quite high. Gum, resin and honey are other sources of income to the people of the area.

The temperature and rainfall conditions are favorable for the production of different varieties of crops like sesame (*sesamum indicu),* cotton *(Gossypium Spp. L),* Sorghum *(Sorghum bicolor),* and peanut *(Arachis hypogea. L).* Onion (*allium cepa*), Tomato *(Lycopersicon esculentum. L)*, and Cabbage *(Brassica oleracea var. capitata)*, are common

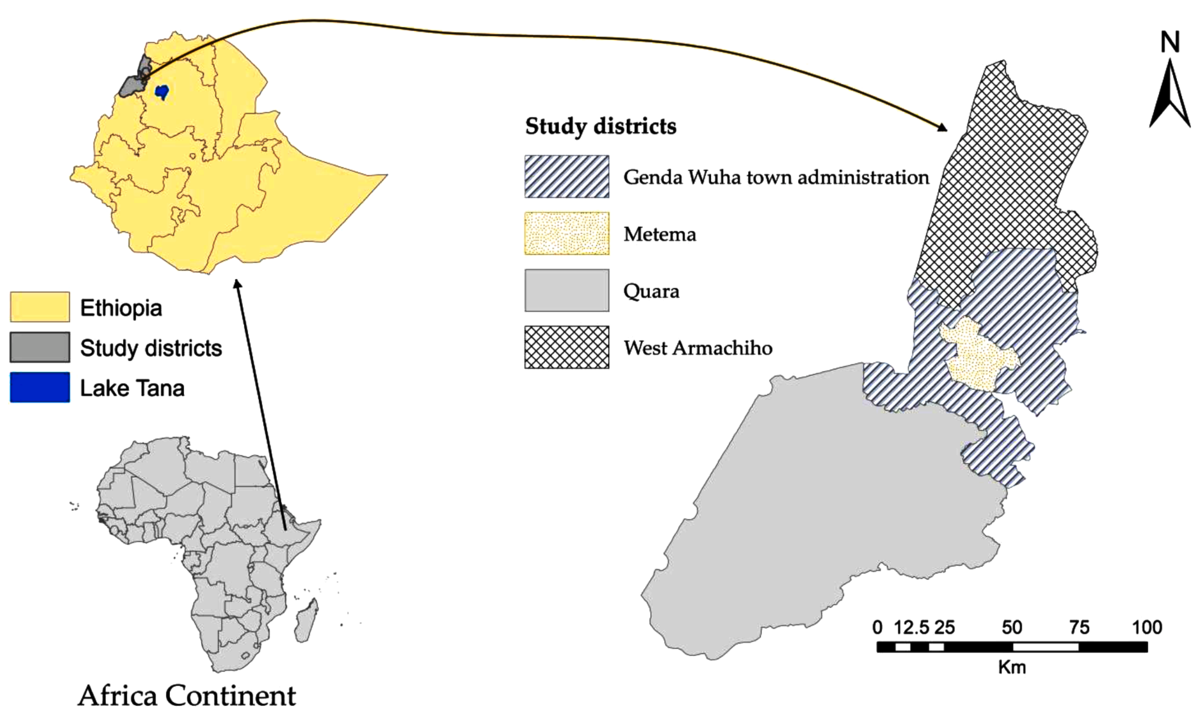

Fig. 1. Location map of Africa, Ethiopia and study districts (Metema, Quara and West Armachiho) and Genda Wuha town administration, in the NW lowlands of Ethiopia

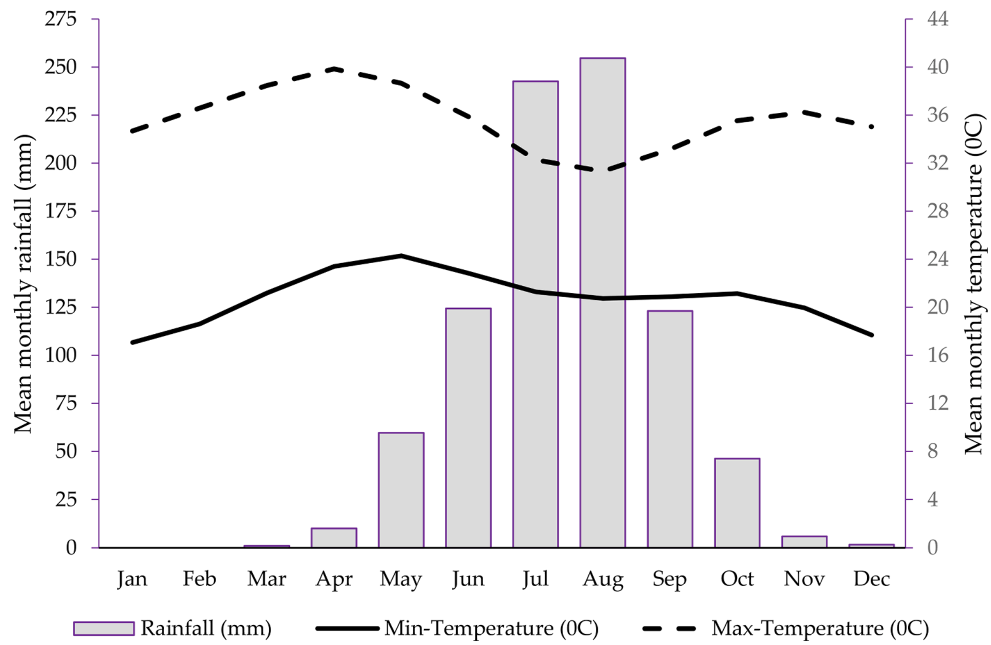

Fig. 2. Mean monthly rainfall and temperature of the NW lowlands of Ethiopia

vegetables in the study area.

2.1.5. Natural resource potentials

The study area is rich in natural rivers. Angereb, Guang, Jarema, Zemenemerike, Shinfa, Wodigemezo and Genda Wuha are among the major rivers. Hence, the area has huge potential for irrigation agriculture. The vegetation type of the study area is *Guinea Savanna* and *Combretum - Terminalia* woodland or deciduous dry forest with important woody plant species diversity. The dominant woody species in the area includes *Pterocarpus lucens, Acacia species, Boswellia paprifera, Ziziphus mucuronata and Sterculia setigera*.

2.2. Method of data collection

2.2.1. Biophysical data collection

Both primary and secondary data sources were used in this study. The primary data were obtained from field visits complemented with ground-truths. The field visit was mainly focused on observing and capturing data on the land use/covers (LULC) types, re-settlement, agricultural investments, and charcoal production. LULC was mapped through the interpretation and classification of Landsat Images with 30 m by 30 m resolution (Table 1). Landsat images of the study area for the years 1980; 2000; and 2020 were obtained free from the United States Geological Survey (USGS) Earth Explorer. The images were acquired for the period of February and March, because these months are clear sky months in the region that helps to reduce atmospheric and radiometric effects. Based on field visits and satellite image inspection, four major LULC types were identified such as agricultural land, forest land, grass land, and settlement (Table 2).

Table 1
Satellite images, sensors, acquisition date and spatial resolution

Years	Spacecraft	Sensor ID	Acquisition date	Path/ Row	Spatial resolution (m)
1980	Landsat 4-5	TM	16-02-1980	183/51	30
			16-02-1980	183/52	30
			08-02-1980	184/51	30
			08-02-1980	184/52	30
2000	Landsat 7	ETM^+	19-02-2000	170/51	30
			03-02-2000	170/52	30
			29-03-2000	171/51	30
			16-03-2000	171/52	30
2020	Landsat 8	OLI-TIRS	02-02-2020	170/51	30
			02-02-2020	170/52	30
			09-02-2020	171/51	30
			09-02-2020	171/52	30

Source; http://www.usgs.gov.et

2.2.2. Satellite image pre-processing

The LULC types were extracted from Landsat TM and ETM^+ images with the help of visual interpretation and different reflectance characteristics of the features. The Landsat images were enhanced before classification using histogram equalization in ERDAS Imagine software to improve the image quality and achieve better classification accuracy. Image enhancement and pre-processing such as georeferencing, resolution merges, and layer stacking and sub-setting were conducted to remove disturbance and radiometric variations. The satellite images were co-registered geometrically on the same datum and geographic coordinate system (WGS 1984, UTM zone 37) via ground control points collected in the field using a handheld global positioning system (GPS) having 2 m accuracy.

Landsat 4-5 and Landsat 7 have seven bands separately with different spatial and atmospheric resolutions. The bands that have high resolutions (2, 3, 4, 5 and 7) were selected combined and stacked using ERDAS Imagine software raster processing. Landsat 8 OLI-TIRS provides 11 bands separately with different resolutions. Other thermal and coastal bands were not used due to their low spatial and atmospheric

Table 2
Descriptions of LULC types identified in the study area

LULC type	Description of the LULC types
Agricultural land	Areas covered with perennial and annual crops
Forest land	Land covered with trees reaching about 5 m in height, a minimum of 0.5 ha in area, and a canopy cover of >10% without other land use
Grass land	Areas dominantly covered with grasses
Settlements	Urban areas and permanent residential areas

Source: Mekonnen et al. (2016); Othow et al. (2017)

resolutions.

Satellite images were composed in a false-colour combination of RGB 4 3 2 as band 4 represents the Near-Infrared and band 3 belongs to red and band 2 to green. This combination gives better visualization in identifying vegetation that looks red in 4 3 2 combinations. Whereas true colour composite is usually known by RGB 3 2 1 combination where band 3 reflects red colour, band 2 reflects green and band 1 reflects blue colour.

Image analysis was done using ERDAS Imagine software to obtain meaningful information from the acquired satellite images. Supervised image classification technique was employed and verified by field data. Images were classified through the maximum likelihood parametric decision rule with probability. Then the major land use types were classified and the raster data were converted into vector layer using conversion tool in the ArcGIS environment. After the pre-processing stage, post-classification analysis was carried out to calculate the area of each LULC and rate of cover change by using the following equations (Eqs. (1)–(3)) (Othow et al., 2017).

$$Area\ in\ (ha) = \frac{number\ of\ pixels * (cell\ resolution)^2}{10,000\ m^2} \quad (1)$$

$$Q = \frac{(A_2 - A_1)}{T} \quad (2)$$

$$Area\ in\ (\%) = \frac{Observed\ pixel\ size * 100}{Total\ number\ of\ pixels} \quad (3)$$

Where Q is rate of change; A_1 is area of the previous land-use class, A_2 is area of the recent land use class and T is number of years between A_1 and A_2. The conversion factor 10,000 m^2 is used to convert from square meter to hectare.

2.2.3. Accuracy assessment

Classified LULC maps from remotely sensed images may contain various types of errors. Accuracy assessment is a technique to investigate and verify such errors comparing with ground reality. The classified LULC types using supervised classification were cross-checked with the ground truth. For this purpose, 155 ground control points (GCPs) were collected (35 points from the settlement, 47 points from forestland, 35 points from grassland, and 38 points from agricultural land). Finally, the accuracy of the classified maps have been assessed and compared with GCP data using an error matrix. Elderly people were also used to get information about the past situations.

The error matrix is a square table with reference data in the columns and mapped data in the rows. The reference data is obtained from the field, which is considered to be correct, whereas, the mapped data is obtained through the classification of remotely sensed satellite imagery. The accuracy of the classification was assessed by using four performance assessment criteria: producer's accuracy (PA), user's accuracy (UA), overall accuracy (OA) and Kappa coefficient (K).

The overall accuracy was derived by dividing the total number of correctly classified classes of pixels by the total number of reference pixels. The overall accuracy provides the percentages of how correct the classified pixels are in the error matrix (Lung and Schaab, 2010). The user accuracy is computed dividing the number of correctly classified pixels in each class by the number of training set pixels used for that class (column). Producer accuracy is calculated dividing the number of correctly classified pixels in every class by the total number of pixels that were classified in that class (row) calculated (Lillesand et al., 2000). User's accuracy shows the percentage of the correctly classified pixels per land cover class while the producer accuracy provides the percentage of correctly classified pixels per reference class.

Kappa coefficient or statistics was applied as a measure of how well the remotely sensed classification agrees with reference data. This method also provides accurate information and its values always range between 0 and 1 (Congalton and Green, 2019). Kappa statistics is the best measurement that has been widely applied in many change detection methods where it reflects the actual agreement of the remotely sensed image with the agreement expected by chance in the reference data (Fung and Ledrew, 1988).

2.2.4. Change detection analysis

Change detection is defined as the process of identifying differences in the state of an object observing it across years (Singh, 1989). Land use/cover (LULC) change detection involves the use of multi-temporal datasets to identify areas of the LULC between different years of image acquisition. The pairs of classified thematic maps (1980; 2000; and 2020) were compared by applying the detection algorism. Change matrix was produced to understand the changing status and its rate of magnitude for the period of 1980-2000; 2000-2020 and 1980-2020. The magnitude and annual rate of change for each LULC type during each period were computed using Eq. (4).

$$ARC\ \left(km^2\ year^{-1}\right) = \left(\frac{A_f - A_i}{n}\right) \quad (4)$$

Where ARC is the annual rate of change; A_i is area (ha) at the initial time; A_f is area (ha) at the final time; and n is the number of years. The statistics of LULC change in general and forest cover change in particular, was computed and summarized to detect the nature of the changes based on the years 1980; 2000 and 2020 images.

2.2.5. Socioeconomic data

Socioeconomic data were used to identify the threats and management options of the green belt natural forest. Four districts (Quara, Metema, and West Armachiho) and one town administration (Genda Wuha) were selected purposefully as sampling areas. The major reasons were (i) the existence of natural forest believed as a green belt to break the expansion of the Sahara Desert towards Ethiopia, (ii) re-settlement from 1990 to 2010, (iii) and large-scale agricultural investments. Three villages from Quara district, three villages from Metema district, and three villages from West Armachiho district were further selected purposefully in addition to the Genda Wuha town administration. Totally 9 villages and one town administration were used for the socio-economic survey.

Questionnaire, interview and focus group discussions (FGD) were used to collect the socio-economic data. Community leaders, elderly people, district experts, and development agents who have firsthand knowledge about the area have been involved. Investors, settlers and migrants are also part of the socio-economic survey. Lists of the total population was obtained from the zonal office of agriculture, and divided in to smaller groups (investors, settlers, residents, and migrants). Then simple random sampling was done, and 160 interviewees were selected, in which agricultural investors' were 26, settlers 48, residents 66 and migrants 20. Moreover, 8 district experts, 5 development agents and 8 Kebele leaders were part of the FGD.

2.3. Statistical analysis

Change in the natural forest cover was analyzed using ArcGIS software. The collected demographic and socio-economic data were subjected to descriptive statistics such as average, percentage and frequencies, and supported by qualitative analysis. The data were analyzed using SPSS software and the results were presented in tables, graphs and charts. Fig. 3a below shows the general methodological flow chart of the study.

3. Results and discussions

3.1. Land use/cover (LULC) types

Fig. 3b shows the LULC types and distribution. Agricultural (farm)

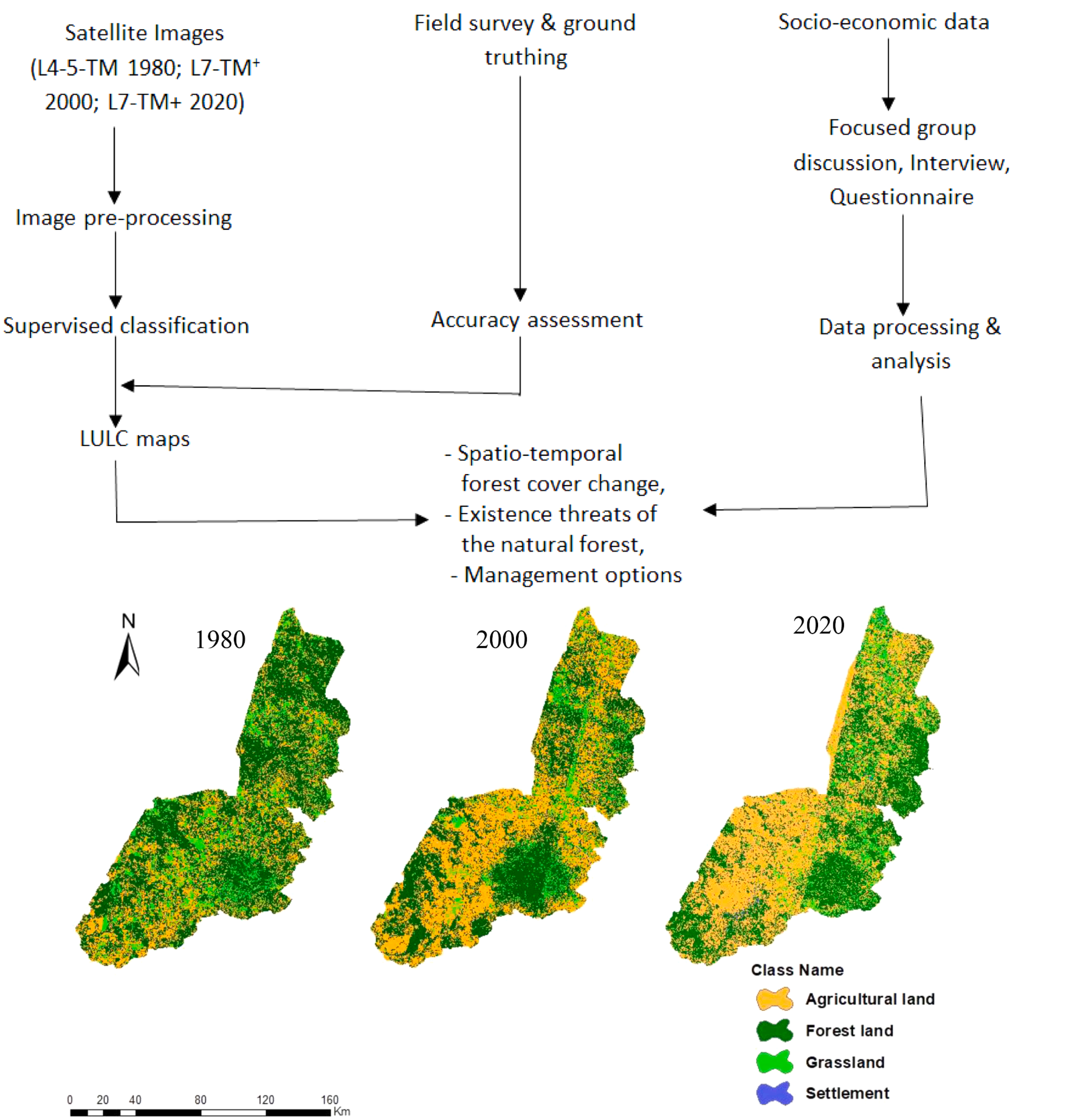

Fig. 3. (a) Methodological flow chart of the study (b). Map showing the LULC types of the study districts in the NW lowlands of Ethiopia

land, forest land, grass land and settlement were the major LULC types identified in the study area. Forest land cover (~58%) was the dominant LULC type in the reference year 1980, followed by agricultural land (~32%), grass land (~9.8%), and settlement (~0.2%). However, agricultural land cover (~52%) was the dominant LULC type in the year 2020, followed by forest land ~39%, grassland ~7.7% and settlement

Table 3
LULC change accuracy assessment error matrix of the year 2020

Class name	Settlement	Forest land	Grass and	Agriculture	Row total	Users accuracy
Settlement	***29***	1	3	2	35	82.86%
Forest land	1	***42***	1	2	46	91.30%
Grass land	2	1	***29***	1	33	87.88%
Agriculture	3	3	2	***33***	41	80.49%
Column Total	35	47	35	38	155	
Producers accuracy	82.86%	89.36%	82.86%	86.84%		
Overall classification accuracy						*85.81%*

1.1%.

3.2. Image classification accuracy

Table 3 shows an example accuracy assessment result of the year 2020 classification. The users' accuracy ranged from 80.49 to 91.30%, producers accuracy ranged from 82.86 to 89.36%, the Kappa coefficient and overall classification accuracy were found to be (81%), and 85.8%, respectively.

The bold and italic diagonal number in the error matrix shows the correctly classified referenced data for each LULC type, whereas the other values indicated the wrong classification. For instance, from the settlement land use about 29 reference data were correctly classified and six reference data were incorrectly classified. This means one forest land, two grass land and three agricultural land pixels were wrongly included in the settlement area category. From the forest land cover 42 reference data were correctly classified but one settlement area, one grass land, and three agricultural land pixels were wrongly included in the forest land category.

The maximum user's accuracy was obtained from forest land classification (91.30%), and the minimum was from agriculture/farm land classification (80.49%). According to Anderson (1976), the minimum overall classification accuracy value of an acceptable LULC classification is 85%. Based on the kappa coefficient levels outlined by McHugh (2012), a value $<$ 20% represents no agreement, a value between 21% and 39% represents a minimal agreement, a value between 40% and 59% represents a weak agreement, a value between 60% and 79% represents moderate, a value between 80% and 90% represents strong agreement, and a value above 90% represents almost prefect agreement. Hence, the overall accuracy (85.81%) and the kappa coefficient (81%) results of the classification indicated that there is a strong agreement between the reference data and the remotely sensed classified data.

3.3. LULC change extent and trends

Table 4 and Fig. 4 shows the extent and trends of the LULC changes. Between 1980 and 2000, forest and grass lands decreased by 14% and 1.5%, while agricultural/farm land and settlement areas increased by 15% and 0.2%, respectively. Between 1980 and 2020, forest and grass lands decreased by 18.7% and 2.2%, while agricultural land and settlement areas increased by 20% and 1%, respectively. In general, a continuous increasing trend was observed on agricultural land use/cover, and a continuous decreasing trend was observed on forest land use/cover. Grass land also showed a continuously decreasing trend. For the past 40 years, the agricultural land showed large increment but the forest land cover showed large decrement, which clearly shows that forest land cover is decreasing at the expense of agricultural land increment.

The major reasons for agricultural land increment and forest land decrement are re-settlement programs, agricultural investments, and charcoal production. Based on the information obtained from the households interview and focus group discussion, the expansion of agricultural land was mainly because of the large number of investors in the study area (927 investors) to produce high market value exportable crop like sesame (*sesamum indicu),* cotton *(Gossypium Spp. L),* Sorghum *(Sorghum bicolor),* and peanut *(Arachis hypogea. L)*. Settlers (because of the resettlement program) also had great contribution to the expansion of agricultural land because they are large in number and are cultivating wide areas to sustain their lives.

The result is in line with Adu et al. (2012); Mekonnen et al. (2016); Othow et al. (2017); Degife et al. (2018); Alemayehu (2019) and Abera et al. (2020) that natural forest cover is reducing at alarmingly fast rate in Ethiopia, especially in the lowlands where the remnant natural forest exists, due to agricultural investment, re-settlement and charcoal production.

3.4. LULC conversion: among LULC types

Table 5 shows LULC conversions among the different LULC types, which means conversion from one LULC type to another. Between 1980 and 2000, about 25.6 km^2 (0.17%), 646 km^2 (4.2%) and 4050 km^2 (26%) of the forest land was converted to settlement area, grass land and agricultural land, respectively. The forest land was mainly converted to agricultural land (26%) compared to other LULC conversions. The result is in line with Yismaw et al. (2014) that 65% of the forest area was converted to agricultural land in Banja district, NW highlands of Ethiopia.

On the other hand, about 5.4 km^2 (0.03%), 639.6 km^2 (4.11%) and 683 km^2 (4.4%) of the grass land changed to settlement, forest and agricultural lands, respectively. About 16.7 km^2 (0.11%), 1904 km^2 (12.23%) and 420 km^2 (2.7%) of the agricultural land was converted to settlement, forest and grass land, respectively.

3.5. Green belt forest (GBF) cover reduction

Table 6 shows the GBF cover reduction between 1980 and 2020. The negative values showed reduction in forest cover. The GBF cover was about 9030 km^2 (during 1980), 6868 km^2 (during 2000), and 6124 km^2 (during 2020). The annual reduction of the GBF cover between 1980 and 2000; 2000 and 2020; and 1908 and 2020 was 108 km^2, 37 km^2, and 72.7 km^2, respectively. The highest reduction of the GBF was between 1980 and 2000, which was due to the Ethiopian government re-settlement program between 1990 and 2010, in addition to agricultural investments. About 60% of the interviewed households also described that GBF reduction was because of 83102 settlers between 1990 and 2010, and the large number of investors cultivating commercial crop. The result is in line with many study findings, for instance, Mekonnen et al. (2016, 2021), Othow et al. (2017); Wassie (2020), and Worku et al. (2021) that forest cover distraction was mainly because of immigrants, re-settlement programs, and large-scale agricultural investment in Ethiopia.

3.6. Deriving causes of the GBF cover reduction

In the NW lowlands of Ethiopia, along Ethio-Sudan Border, the native remnant natural forest resource that is believed to protect the expansion of the Sahara Desert towards Ethiopia in particular, and the horn of Africa in general, is declining from time to time. In three decades (between 1980 and 2020), about 19% of the natural forest was cleared. About 98% of the households interviewed, who have firsthand know-

Table 4
Spatial extent and temporal trends of LULC changes in the NW lowlands of Ethiopia

LULC type	1980		2000		2020	
	Area (km^2)	Area (%)	Area (km^2)	Area (%)	Area (km^2)	Area (%)
Settlement	27.92	0.18	51.41	0.33	171.63	1.10
Forest land	9030.23	58.01	6868.37	44.12	6123.95	39.34
Grass land	1545.31	9.93	1286.97	8.27	1201.16	7.72
Agriculture	4962.71	31.88	7359.42	47.28	8069.43	51.84
Total	15,566.17	100.00	15,566.17	100.00	15,566.17	100.00

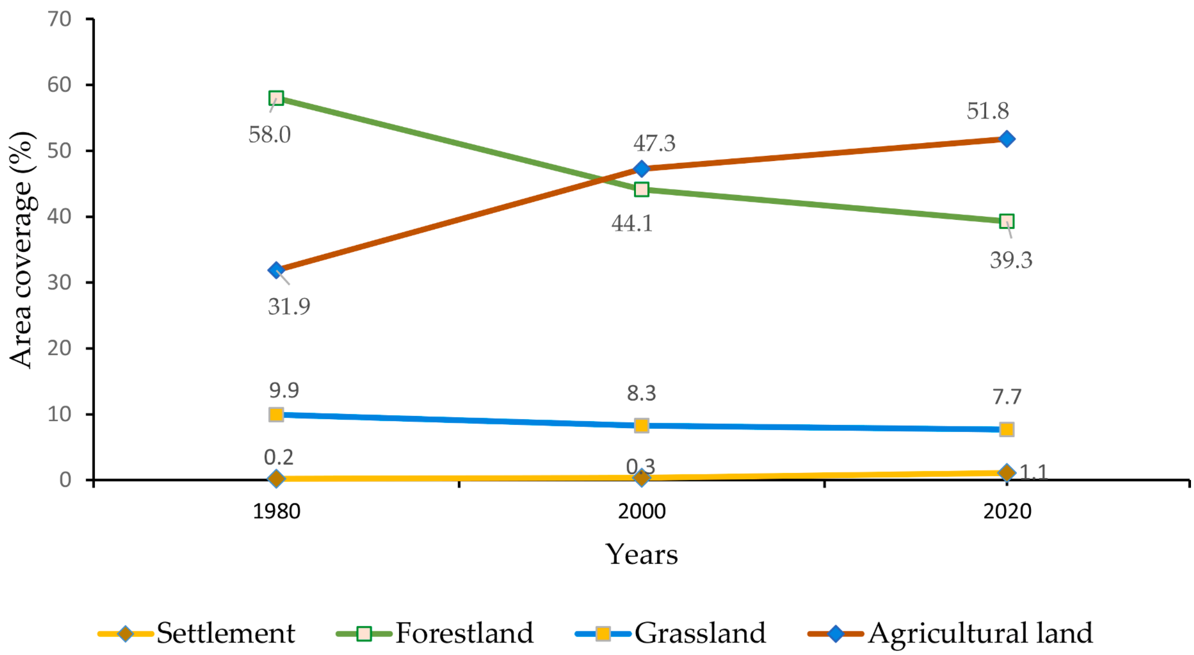

Fig. 4. LULC change trends in the NW lowlands of Ethiopia

Table 5
LULC change from one LULC type to another, between 1980 and 2020, in the NW lowlands of Ethiopia

Changed from	Changed to	1980-2000		2000-2020		1980-2020	
		Area (Km^2)	Area (%)	Area (Km^2)	Area (%)	Area (Km^2)	Area (%)
Settlement	Settlement	0.24	0.00	2.31	0.01	0.65	0.004
	Forest land	7.57	0.05	16.08	0.10	5.76	0.037
	Grass land	3.72	0.02	18.79	0.12	1.93	0.012
	Agriculture	9.96	0.06	10.81	0.07	13.16	0.085
Forest land	Settlement	25.64	0.16	59.64	0.38	105.50	0.678
	Forest land	4315.02	27.72	3275.12	21.04	3710.18	23.835
	Grassland	646.11	4.15	309.98	1.99	682.52	4.385
	Agriculture	4050.43	26.02	3227.08	20.73	4538.42	29.156
Grassland	Settlement	5.42	0.03	27.92	0.18	24.64	0.158
	Forest land	639.61	4.11	427.26	2.74	551.11	3.540
	Grass land	216.96	1.39	240.00	1.54	139.71	0.898
	Agriculture	683.22	4.39	591.81	3.80	829.84	5.331
Agriculture	Settlement	16.66	0.11	94.27	0.61	53.31	0.342
	Forest land	1904.37	12.23	2409.28	15.48	1859.74	11.947
	Grass land	419.85	2.70	666.30	4.28	410.78	2.639
	Agriculture	2621.37	16.84	4189.52	26.91	2638.92	16.953
Total Area (Km^2)		15,566.17	100.00	15,566.17	100.00	15,566.17	100.000

Table 6
Green belt forest cover reduction in the NW lowlands of Ethiopia

Years	Forest cover (km^2)	Forest cover (%)	Average annual rate of reduction (km^2)		
			1980-2000	2000-2020	1980-2020
1980	9030.23	58.00	-108.09	-37.08	-72.66
2000	6868.37	44.12			
2020	6123.95	39.34			

how about the area, mentioned that large-scale agricultural investment and re-settlement programs were the major causes of the GBF cover reduction. Both investors and settlers are encroaching to the remnant natural forest in search of additional crop land to produce the high market value sesame, cotton, and soya bean crops.

Forest fire was found to be another major cause of the GBF cover reduction. Although the high temperature as a natural factor has a great contribution for the forest fire, anthropogenic factors like purposefully burning the forest to get cultivated lands, and wild-honey harvesting using fire-smoke are important causes. Forest fire is not only causing reduction in forest cover but also causing loss wildlife and plant species.

Charcoal production is the other important cause for deforestation because it is an important source of income for farmers', next to crop cultivation. Many trees cut per year for charcoal production. Gum and resin production, fuel wood, and road construction were also mentioned as minor causes for the GBF cover reduction. In general, agricultural investment, charcoal production, re-settlement, and forest fire were found as major causes of the GBF cover reduction in the NW lowlands of Ethiopia. The result is in line with different researchers' reports on the negative impacts of agricultural investment, re-settlement, charcoal production, forest fire, etc. on natural forest resources in Ethiopia (Walle 2011; Adu et al., 2012; Alemu et al., 2015; Mekonnen et al., 2016; Tigabu, 2016; Othow et al., 2017; Alemayehu, 2019; Wassie et al., 2020).

3.7. Agents of the GBF cover reduction

The households' interview and focused group discussion result showed that about 33%; 27%; 22%; 15% and 3% of the GBF cover reduction was due to investors, settlers (re-settlement), migrants, residents and day-workers, respectively. Respondents witnessed that investors (large-scale farmers) were the main agents of the forest cover reduction or deforestation. There are 927 investors in the area owning from 11 to 1500 ha of farmlands. Primarily investors' destruct the natural forest and then grow crops. For instance, investors are illegally producing charcoal by cutting and burning massive live trees. On average investors are producing about 50,000 quintals of charcoal annually. Investors remove the tree together with its roots that bans the native forest species from regeneration, and misbalancing the natural ecosystem. The results agree with Adu et al. (2012); Eshetu (2014); Degifie et al. (2018), and Kasaro et al. (2019) that large-scale agricultural investment is one of main agents of the natural forest loss.

Due to the Ethiopian government re-settlement program about 83,000 households were settled in the study area (between 1990 and 2010). On average each settler household has 2.5 ha farmland for crop production. Most of the settlers produce charcoal that was estimated as five quintals (500 kg) per year per settler. Hence, settlers were found to be the second key forest destructing agents in the study area.

Migrants are the people who are residing in the area temporarily and have no permanent lands provided by the government legally. Most of the migrants get land through rental system from land owners or resident for specific years that would be for one year or more. These migrants came from the different parts of the country, Ethiopia. About 22% of the respondents indicated that migrants were the third-ranked agents of deforestation. Most of the migrants lack a sense of ownership about the importance of the forest resource. Based on the information from the respondents, district experts and development agents about 20 - 30 ha of GBF is cleared by migrants annually.

Residents' (farmers who permanently settled in the area) and day-workers contribution in deforestation was found to be low compared with the above discussed agents. Even though the residents' contribution was small, they participate in burning the forest during farm clearing. Day-workers contribute the occurrence of forest fire by throwing a piece of cigarettes with fire to the grassed area which was adjacent to the forest land (Fig. 5).

3.8. Sustainable management options of the GBF

Identification of effective forest management options is one of the basic issues to the sustainable use the rapidly declining forest resources. Fig. 6 below shows the GBF management options identified and recommended by households.

(i) Bylaws, the local community bylaw were recognized as the most effective management option. Local bylaws are community cultural, social, religious, etc. bylaws owned by the local community. For instance; preserving seed source trees inside the forest; preserving native trees inside farmlands as an agroforestry system; planting endangered tree species around churches (in Ethiopia, no one cut trees planted around the Orthodox Tewhido Church). Nearly endangered, remnant tree species are mainly found around the Orthodox Tewhido Church. Hence identifying the local bylaws, documenting and supporting with judicial issues is one important option for preserving and conserving the forest resources. (ii) Delineating and keeping the GBF from human interferences was identified as the second most important management option. Delineating and keeping the GBF is also important to enhance native trees regeneration from the soil seed bank. Since the area has sufficient moisture content during the summer season, the forest species of the area regenerate easily within short period of time. By nature, the study area was rich in a diversity of plant species, which needs only one or two years of ex-closure to regenerate naturally. (iii) Building awareness (mental reshaping) was identified as the third important management option. Within and around the GBF area, different societies have been settled coming from different parts of the country without deep knowledge and sense of ownership about the importance of the forest resource. Therefore, creating awareness about the importance of the conserving forest resource and the negative impacts of deforestation is an important management option. (iv) Soil and water conservation and enrichment plantation, were identified as the 4th and 5th management options, respectively. Finally, institutional integration is crucial to sustainably protect and manage the natural forest resources, for instance, Ministry of Agriculture, Ministry of Environment, Forest and Climate Change, and Ethiopian Wildlife Conservation Authority.

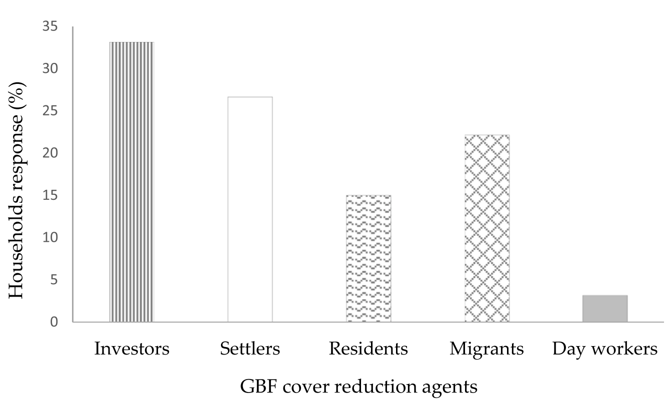

Fig. 5. Agents of the GBF cover reduction in the NW lowlands of Ethiopia

Sustainable Development Goal (SDG) 12 reads natural resources must be managed better to ensuring sustainable consumption and production patterns, and SDG 15 reads protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, halt and reverse land degradation, and halt biodiversity loss. Forests cover more than 30 percent of the Earth's surface, but 7 million hectares of forests are being lost every year while the persistent degradation of drylands has led to the desertification of close to 4 billion hectares. Halting deforestation and restoring the use of terrestrial ecosystems is necessary to reduce the loss of natural habitats and biodiversity. Therefore, conserving the native forests in the northwest lowlands of Ethiopia and sustainably managing it help to attain the 2030 United Nations Sustainable Development Goals (UN-SDGs). In general, since deforestation is one of the major factors that lead to land degradation, ecosystem loss, desertification, etc., sustainable forest protection and management is not an optional but an obligatory.

4. Conclusion

This study analyzed the spatio-temporal land use/cover (LULC) dynamics in general and the green belt forest (GBF) covers reduction in particular for the past four decades, and identified the threats and management options of the GBF, in the northwest lowlands of Ethiopia. The GBF is believed to hinder the expansion of the great Sahara Desert towards Ethiopia in particular, and eastern Africa in general. The results showed that the area has undergone substantial LULC changes, and GBF cover reduction. A large decrease in GBF cover (~2,906 km^2) and grassland (~334 km^2), and a large increase in settlement areas (144 km^2) and cultivated lands (3,106 km^2) have taken place during the study periods (1980–2020). Agricultural investment, re-settlement, charcoal production, road construction, fuel wood collection and house construction were found as the important causes of GBF cover reduction. Such causes were facilitated by different agents like large-scale farmers (investors), settlers, migrants, residents, day-workers etc. To minimize deforestation and sustainably use the GBF, forest management options like local bylaws, delineating and keeping the GBF from human interferences, building awareness, enrichment plantation and alternative firewood sources were identified as management options by the

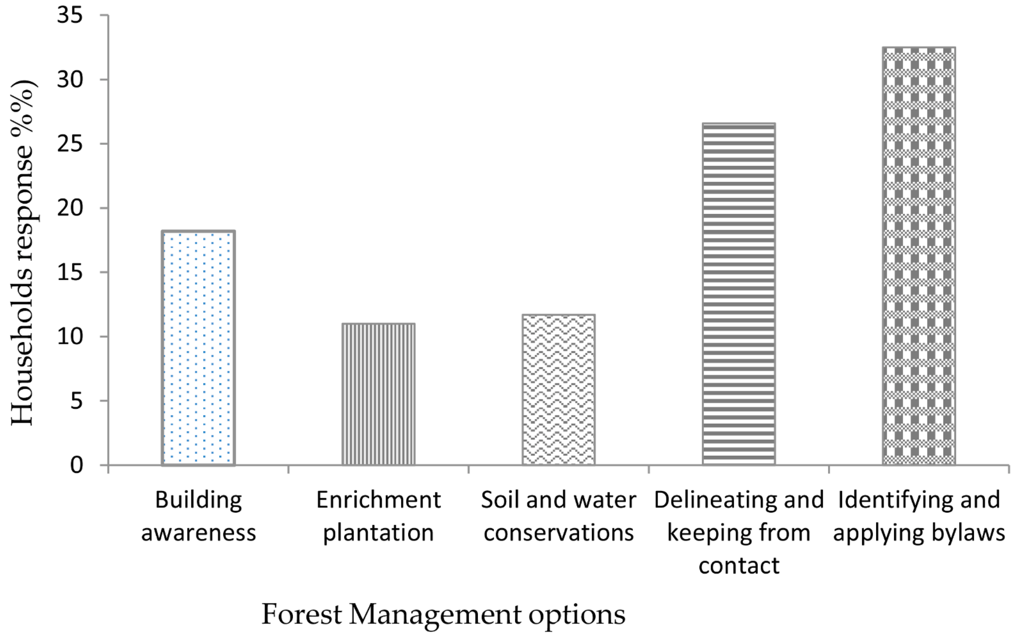

Fig. 6. GBF management options identified by households in the NW lowlands of Ethiopia

indigenous people living long years in the area. Therefore, to maintain the GBF resource and break the expansion of the Sahara Desert, governmental and non-governmental organization and the local community ought to apply the recommended GBF management options.

Author contributions

Gashachew Yeshineh: Conceptualization, data collection, data Analysis, visualization. Mulatie Mekonnen: Conceptualization, methodology, data curation, result interpretation, writing and editing, supervision. Gete Zeleke: Conceptualization, writing, review and editing. Gizaw Desta: Conceptualization, review and editing, and writing. All authors read and approved the final manuscript.

Declaration of Competing Interest

The authors declare that they have no known financial interests of personal relationships that could have appeared to affect the work reported in this work.

Acknowledgments

The authors would like to thank the farmers, district experts and development agents of the study area for their assistance during the field work and socio-economic data collection. We would also extend our thanks to Bahir Dar University (BDU), College of Agriculture and Environmental Sciences (CAES) in facilitating the research. Comments from anonymous reviewers are highly appreciated.

References

Abera, A., Yirgu, T., Uncha, A., 2020. Impact of resettlement scheme on vegetation cover and its implications on conservation in Chewaka district of Ethiopia. Environ. Syst. Res. 9 (2), 1–17. https://doi.org/10.1186/s40068-020-00164-7.
Adu, G., Marbuah, G., Mensah, J.T., 2012. Contribution of agriculture to deforestation in the tropics: a theoretical investigation. Afric. Rev. Econ. Finance 3 (2), 1–12.
Almayehu, O., 2019. The causes, consequences and remedies of deforestation in Ethiopia. J. Degrad. Min. Lands Manag. 6 (3), 1747.
Alemu, B., Garedew, A., Eshetu, Z., Kassa, H., 2015. Land use and land cover changes and associated driving forces in north western lowlands of Ethiopia. Int. Res. J. Agric. Sci. Soil Sci. 5 (1), 28–44. http://www.interesjournals.org/IRJAS.
Anderson, J.R., 1976. A Land Use and Land Cover Classification System for Use with Remote Sensor Data, 964. US Government Printing Office, Washington DC, WA. https://doi.org/10.3133/pp964.
Berhanu, B., Melesse, Assefa M., Seleshi, Y., 2013a. GIS-based hydrological zones and soil geo-database of Ethiopia. Catena 104, 21–31. https://doi.org/10.1016/j.catena.2012.12.007.
Berhanu, Y., Negatu, L., Beyene, B., Angassa, A., 2013b. Influence of resettlement on pastoral land use and local livelihoods in southwest Ethiopia. Trop. Subtropic. Agroecosyst. 16 (1), 103–117.
Congalton, R.G., Green, K., 2019. Assessing the Accuracy of Remotely Sensed Data: Principles and Practices. CRC press.
Degife, A., Zabel, F., Mauser, W., 2018. Assessing land use and land cover changes and agricultural farmland expansions in Gambella Region, Ethiopia, using Landsat 5 and Sentinel 2a multispectral data. Heliyon, 4 (11), e00919. https://doi.org/10.1016/j.heliyon.2018.e00919.
Eshetu, A.A., 2014. Forest resource management systems in Ethiopia: Historical perspective. Int. J. Biodivers. Conserv. 6 (2), 121–131.
FAO, and UNEP., 2020. The State of the World's Forests 2020. Forests, biodiversity and people, Rome. https://doi.org/10.4060/ca8642en.
FAO, 2010. Global Forest Resource Assessment. FAO Forestry paper 163, Main Report, Rome, Italy.
FAO, 2016. State of the World's Forests 2016: Forests and Agriculture: Land-Use Challenges and Opportunities. Rome.
Fung, T., LeDrew, E., 1988. For change detection using various accuracy. Photogramm. Eng. Remote Sens. 54 (10), 1449–1454.
Hurni, H., 1998. Agroecological belts of Ethiopia. soil conservation research program in Ethiopia. Research Report. Centre for Development and Environment, University of Bern, Switzerland in association with the Ministry of Agriculture, Addis Ababa, Ethiopia, pp. 1-43.
Hurni, H., Abate, S., Bantider, A., Debele, B., Ludi, E., Portner, B., Zeleke, G., 2010. Land degradation and sustainable land management in the highlands of Ethiopia. Glob. Change Sustain. Dev. https://doi.org/10.13140/2.1.3976.5449.
Kasaro, D., Phiri, E., Nyambe, I., 2019. Deforestation impact on ecosystem services in Kamfinsa sub-catchment of Kafue River Basin in Zambia. Afr. J. Environ. Sci. Technol. 11 (4), 33–45.
Kimutai, D.K., Watanabe, T, 2016. Forest-cover change and participatory forest management of the lembus forest, Kenya. Environments. 3 (3), 20.
Lillesand, T.M., Kiefer, R., Chipman, J., 2000. Remote Sensing and Image Interpretation, 6th edn. John Wiley and Sons. Inc. New York.
Lung, T., Schaab, G., 2010. A comparative assessment of land cover dynamics of three protected forest areas in tropical eastern Africa. Environ. Monit. Assess. 161 (1), 531–548.
McHugh, M.L., 2012. Interrater reliability: the kappa statistic. Biochem. Med. 22 (3), 276–282.
Mekonnen, M., Sewunet, T., Gebeyeh, M., Azene, B., Melesse, A.M., 2016. GIS and remote sensing-based forest resource assessment, quantification and mapping in Amhara Region. In: Melesse, AM, Abtew, W (Eds.), Landscape Dynamics, Soil and Hydrological Processes in Varied Climate. Springer Geography, Springer, Switzerland, pp. 9–29.
Mekonnen, M., Worku, T., Yitaferu, B., Cerdà, A., Keesstra, S.D., 2021. Economics of agroforestry land use system, upper blue nile basin, northwest Ethiopia. Agrofor. Syst. https://doi.org/10.1007/s10457-021-00612-y.

Mulugeta, M., Woldesemait, B., 2011. The impact of resettlement schemes on land-use/land-cover changes in Ethiopia: a case study from Nonno resettlement sites, central Ethiopia. J. Sustain. Dev. Africa 13 (2), 269–293.
Othow, O.O., Gebre, S.L., Gemeda, D.O., 2017. Analyzing the rate of land use and land cover change and determining the causes of forest cover change in Gog district, Gambella regional state, Ethiopia. J. Remote Sens. GIS 6 (4), 2–13.
Sembroni, A., Molin, P., ramis, F., Abebe, B., 2017. Geology of the Tekeze River basin (Northern Ethiopia). J. Maps 13 (2), 621–631. https://doi.org/10.1080/17445647.2017.1351907.
Singh, A., 1989. Review article digital change detection techniques using remotely-sensed data. Int. J. Remote Sens. 10 (6), 989–1003.
Tigabu, D.G., 2016. Deforestation in Ethiopia: causes, impacts and remedy. IJEDR 4 (2), 204–209.
Tolessa, T., Dechassa, C., Simane, B., Alamerew, B., Kidane, M., 2019. Land use/land cover dynamics in response to various driving forces in Didessa sub-basin, Ethiopia. GeoJournal. 85, 747–760. https://doi.org/10.1007/s10708-019-09990-4, 2020.
Walle, T., Rangsipaht, S., Chanprasert, W., 2011. Natural resource conservation practices of resettlers in the new resettlement areas of Amhara region, Ethiopia. Kasetsart J. Soc. Sci.. 32 (2), 297–307.
Wondie, M., Schneider, W., Katzensteiner, K., Mansberger, R., Teketay, D., 2016. Modelling the dynamics of landscape transformations and population growth in the highlands of Ethiopia using remote-sensing data. Int. J. Remote Sens. 37 (23), 5647–5667.
Worku, T., Mekonnen, M., Yitaferu, B., Cerdà, A., 2021. Conversion of Crop land use to Plantation land use, northwest Ethiopia. Trees Forest. People 3. https://doi.org/10.1016/j.tfp.2020.100044.
Wassie, S.B., 2020. Natural resource degradation tendencies in Ethiopia: a review. Environ. Syst. Res. 9 (1), 1–29.
Yismaw, A., Gedif, B., Addisu, S., Zewudu, F., 2014. Forest cover change detection using remote sensing and GIS in Banja district, Amhara region, Ethiopia. Int. J. Environ. Monit. Anal. 2 (6), 354–360.