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Analysis of Land Use Land Cover Dynamics and Driving Factors in Desa'a Forest in Northern Ethiopia

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ABSTRACT

Understanding the dynamic of land use/land cover (LULC) can assist relevant authorities in implementing them along with management options for natural forests like Desa'a forest in Northern Ethiopia. It is worth mentioning that no comprehensive study has been done so far on the overall change of LULC within the surrounding of Desa'a forest areas. This study aimed at analyzing the LULC changes and driving factors in Desa'a forest through Landsat images (i.e., 1973 (MSS), 1986 (TM), and 2015 (OLI)) and maximum likelihood supervised classification. Post classification pixel to pixel comparison was also performed to detect changes from year to year. Finally, focus group discussions were made to identify the LULC change drivers and support the computer-based classifications accuracy. Results demonstrated that both dense (54.11%) and open forest (28.48%) in 1973 covered almost 83% of the total forest area while only 17% was covered by grasslands (10%), farmland (3%), and bare land (4%). This is despite the fact that woody vegetation covered only 39% of the total forest reserve in 2015. During the study period, almost 54,000 ha of grasslands and open and dense forests have been converted to either bare land or farmland, of which 48,163 ha were previously open dense forests. Continuing with such a trend will lead to more severe deforestation and it is necessary to identify and modify the driving variables in Desa'a forest. The results also showed that fire, agricultural expansion, grazing and browsing effect, drought, extraction of wood, and lack of government attention are the major deforestation driver in Desa'a forest. The results of this study can provide a practical perspective for land use planners to manage LULC changes, reduce greenhouse gases, and enhance the biodiversity conservation in the region. In addition, the findings of the current study could provide a perfect source for calculations and choosing the best policy-making decisions to protect and manage plans for Desa'a forest.

1. Introduction

Forest resources, mainly natural forests, are increasingly becoming scarce due to immense pressure from anthropogenic activities (FAO, 2010a, 2010b; Starr et al., 2019; Bhandari and Bijlwan, 2020). Tropical forests which contribute to most of the carbon stored in the earth (Gibbs et al., 2007; Lewis et al., 2015) have been under immense increasing pressure (Kayhko et al., 2011; Dar et al., 2019; Pendrill et al., 2019 and Jayathilake et al., 2020). Deforestation and clearing forests for different purposes such as agricultural expansion, charcoal making, fuelwood,

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timber production, fire, and construction are the major problems in almost all countries (Darkoh, 1998; Wilkie and Gerrand, 2010; de Mûelenaere et al., 2014). It is very worrying that forests around the world were cleared about 8.9 and 7.3 million ha per year in the 1990s and 2000s, respectively (Wilkie and Gerrand, 2010). As can be noted from these figures, the net loss change in these ecosystems is impressive and shows a declining pattern. The main reason for the pattern is forest planting, landscape restoration, and natural expansion of forests (Kayhko et al., 2011; Birhane et al., 2019 and Bhandari and Bijlwan, 2020). For instance, the report from global forest resource assessment showed that the forested area covered 30% in 2000 (FAO, 2001), 30% in 2005 (FAO, 2005), and 31% in 2010 (FAO, 2010a, 2010b).

The fundamental purpose of land use planning is to ensure that local and urban areas develop sustainably. Land use planning is an "outcome of all activities and decisions related to guiding the allocation and use of land in patterns that enable development of the way of life of the people" (Chigbu and Kalashyan, 2015). Understanding the extent of land use planning could facilitate the feasibility and performance of the plans, leading to subsequent preparation for the improvement of the plans and the planning process. Ethiopia is a sub-Saharan African country that makes concerted efforts to ensure sustainable land use through land use planning and safeguards land tenure rights (Tesema Bulti and Dinsa Sori, 2017). Such goals, however, are difficult to attain because of the rapid changes in land use that occur in most parts of the world. Even where land use planning is carried out, it focuses on improving the conditions of the land in place of people's living conditions. Therefore, evaluation hypotheses need to be chosen depending on the essence of land use plans in order to obtain proper outcomes using specific plans. In Ethiopia, the use of land-to-people or farm-to-land relationships to facilitate better living conditions for people remains a missing factor in local development (Alemayehu, 2016; Chigbu et al., 2019). There is a similar situation in Ethiopia where improvements are being observed in the vegetative cover due to the wide use of exclosure management techniques (Mengistu et al., 2005; Yami et al., 2006; Birhane et al., 2007; Yayneshet et al., 2009; Nyssen et al., 2009; Vilímek et al., 2010; Birhane and Meles, 2014; Steger et al., 2017), but the pressure on the natural forests remains uncontrolled (Badege, 2001; Feyera and Demel, 2001; Aerts et al., 2006). In Tigray region (Northern Ethiopia), there are only two big remnant natural forests identified as national priority forest areas and important birdlife hot spots, i.e., Desa'a and Hugumburda Girat Kahisu (BLI, 2001).

Desa'a is one of the driest Afromontane forest ecosystems of Ethiopia (Friis, 1992) and is under tremendous anthropogenic pressure (Zenebe, 1999; Aynekulu et al., 2012) and natural diebacks (Aynekulu et al., 2012), resulting in contraction of the forest and expansion of agricultural and bare lands. Though the forest area is officially reported to cover more than 120,000 ha, large tracts of land are found covered by agricultural land, bare land, and grazing lands. However, some studies showed clear indicators of hazards to the forest. Threats such as degradation of the most important key species of the ecosystem, e.g., *Juniperus procera* and *Olea europaea* subsp. cuspidata (Aynekulu, 2011; Hishe et al., 2015a), and lowland species, mostly shrub species, e.g., *Cadia purpurea*, are replacing the upland species, mostly the trees (Khan and Hanjra, 2008), such as the olive and juniper tree. Deforestation is a common practice in the forest where lots of wood is extracted for commercial and domestic uses (Pendrill et al., 2019). Such deforestation scenarios have clear implications on the health of the environment through the loss of nature balance and continuum, carbon dioxide emission, and loss of other ecosystem services (Gibbs, 2007; FAO, 2010a, 2010b). However, no meaningful efforts are made to quantify the actual forest coverage and loss over time for proper management setting up and amendments. Besides, while forests are an important resource mitigating climate change (Lasanta et al., 2016; Gibbs et al., 2007; Gimmi et al., 2010), no actual measurements are made to quantify the potential of carbon storage and loss due to deforestation in this big forest.

According to the report from the Federal Democratic Republic of Ethiopia (2011), more than 85% of the greenhouse gas emissions come from agriculture and forestry, of which 50% are from conversion of forests to agriculture lands. At a time of climate change crisis and demand for green growth strategies, Ethiopia has developed a policy framework and viable plan to achieve a green economy by minimizing or avoiding the effect of climate change on the nation's economy. The goal of such plans is to reduce greenhouse gas emissions to 65% by 2030. In the business as a usual scenario, by 2030, the need for wood as fuel consumption will grow by 65% leading to a clearance of 22 million tons of biomass.

If the nation intends to achieve its planned goal, the loss of huge forest reserves such as Desa'a makes the road to this goal very difficult. Therefore, studying the status and trend of land use land cover (LULC) changes (especially in forest and agricultural lands) in general is timely so that concerned bodies should have information on the actual situation for prescribing appropriate mitigation measures. However, several studies are already conducted on possible silvicultural options to enhance the restoration process (Filer et al., 2009; Giday, 2013; Haarsma and Qiu, 2017), the effects of dieback (common symptoms of a disease, especially of woody plants) on forests (Aynekulu et al., 2012), and the socio-economic influences on the deforestation (Hishe et al., 2015b). Nonetheless, to the best of our knowledge, no comprehensive study has been done so far on the overall change of LULC within the surrounding of Deas'a forest areas. Given the importance and necessity of LULC change monitoring, we have addressed the issue for the first time in this study. Conducting such studies is very important for land use policymakers and environmentalists to provide them with the basis on how to conserve and enhance forest coverage in such environmentally degraded forests.

More specifically, given the intense process of land degradation and deforestation in Desa'a forests, this study was conducted with the following specific objectives: i) monitoring LULC changes in a 42-year time period (1973-2015), ii) systematic assessing of gains and losses of the forest reserve using remote sensing data, and iii) determining the green economy plans of the nation carbon dynamics affected by LULC changes. The most important hypothesis of this research is that whether severe deforestation has been occurred in Desa'a forests (during 1973-2015) and if satellite data and field surveys will be able to monitor and identify driving variables of the deforestation. Linked to the study objectives and hypothesis, this study attempts to answer the following questions: What are the major driving variables of land degradation and deforestation in Desa'a forests? To what extent do the results of this study affect the green economy transition in Ethiopia?

2. Methodology

2.1. Description of the study area

Desa'a is located at the eastern border of the Tigray Zone and west border of the Afar regions, geographically, between the latitude of 13°20′-14°10′N and longitude of 39°32′-39°55′E (Fig. 1). It is one of the two Dry Afromontane forest remnants (Friis, 1992) which are declared as National Forest Priority Area. Desa'a, with an area about 105172 ha, provides a buffer zone between the hot lowlands of Afar region and highlands of Tigray with an altitude ranging from 900 m a.s.l at the lower limit to about 3000 m a.s.l at the plateau and with an average annual temperature ranging from 14 °C to 25 °C and average annual rainfall oscillating between 700 and 1100 mm. The vegetation is of diversified species (Aynekulu et al., 2012), dominated by juniper and olive trees (Friis, 1992). The soil is shallow in inclined surfaces and deep and fertile in the valley bottoms (BLI, 2007). The dominant soil types in the study areas are Lepthosols, Cambisols, Vertisols, Regosols, and Arenosols.

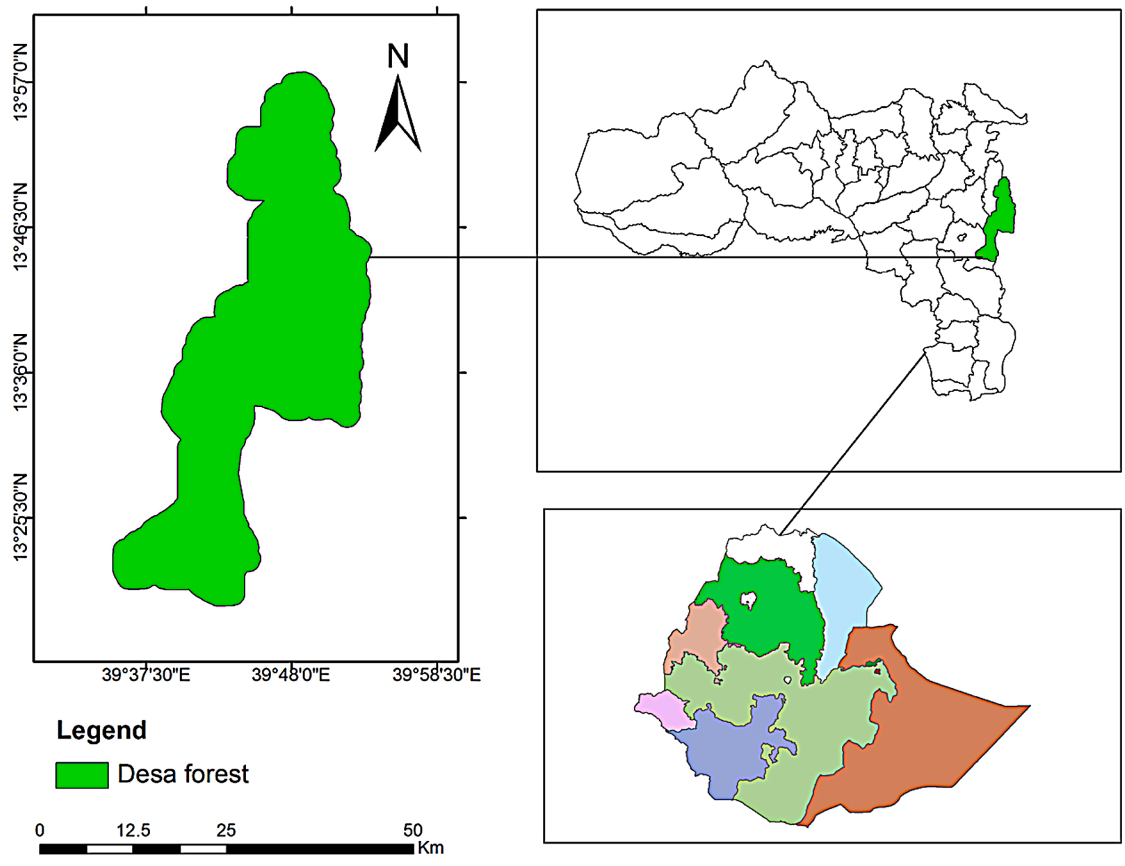

Fig. 1. The Geographical Location of the study area, Desa'a Natural Forest.

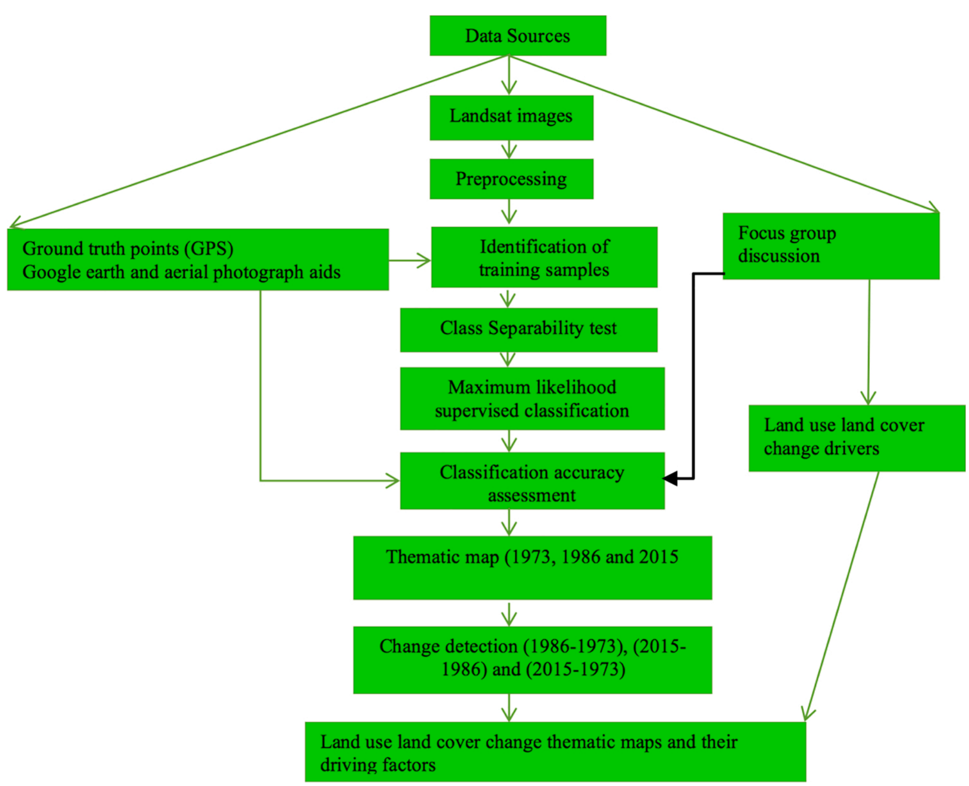

Fig. 2. Methodological work flows.

2.2. Data collection and analysis

2.2.1. Data sources and data pre-processing

Satellite remote sensing data were applied to generate the LULC maps of the study area in a 42-year period of time (1973-2015). In this regard, Landsat satellite images, i.e., MSS (1973), TM (1986), and OLI (2015), were downloaded from the Earth Explorer website (https://earthexplorer.usgs.gov/). Afterward, pre-processing and classification processes on the images were performed. Fig. 2 shows the methodology flowchart, and more descriptions are given in the following sections.

Change detection using multi-temporal images is very difficult without adjustments for radiometric differences among the images used, regardless of whether the images are from similar sensors or different sources. This is because the performances of sensors depreciate and atmospheric and physical components synergy differ over time. The differences in spatial resolution between images are equally important. In order to make an efficient LULC comparison, the images need to have similar spatial resolution and radiometric calibration (Mas, 1999). This study used multiple pre-possessing methods, i.e., geometric, radiometric, and atmospheric corrections. In this way, the MSS Landsat imagery of 1973 was upgraded to 30 m × 30 m spatial resolution using the nearest neighbor resampling technique. Then, the geometric correction of all the studied images was made by in-field control points. In the next step, FLAASH (Fast Line of Sight Atmospheric Analysis Hypercube) has been used to modify the differences in radiometric properties. These differences have been caused by an atmospheric effect on the brightness of the image, the adjacency effect (pixel mixing due to scattering of the surface reflection radiance), and the effect of haze (Matthew et al., 2000). Finally, the radiometric correction has been done by converting the raw DN (digital number) to reflectance values.

2.2.2. Signature development and Separability test

Following image pre-processing, ground control GPS points were collected for each of the identified LULC types, namely dense forest, open forest, grassland, farmland, and bare land. LULC definitions were based on recommendations from FAO (2001). According to the recommendation of Congalton (1991), 250 ground truth points at minimum and 350 ground control points (GCPs) were collected for classification purposes. By displaying these 350 point shape files over the pre-processed images in Erdas Imagine viewer, signatures for each LULC were developed (Hord, 1982) using the polygon AOI tool.

To check whether the created signature was distinct from each other and can be used as separable features in the supervised classification, separability tests using the transformed divergence test (Jensen, 1996) were run for the entire signature. According to Jensen (1996), this tool is more efficient in identifying separable signatures and has a range between 0 and 2000 values. A value of zero is an indication of complete inseparability, and 2000 is an indication of complete separability. Jensen (1996) has identified values between 1700 and 1900 as fairly separable and above 1900 as highly separable.

Results of the transformed divergence separability test for the signatures developed indicated that they are almost completely separable with values above 1950.

2.2.3. Images classification and accuracy assessment

Five types of LULC, i.e., dense forest, open forest, grassland, farmland, and bare land were identified in the study area, based on the spectral responses of the Landsat images and field observation features. Supervised image classification was performed using the Maximum Likelihood classification algorithm, one of the most popular and widely used image classification techniques (Chen and Stow, 2002). The GCPs were distributed focusing on the objective of the research. Thus, 60 GCPs for dense forest and open forest and 30 GCPs for grasslands, cultivated land, and bare land were collected and accuracy assessment was completed by ERDAS imagine version 10.

Classifications were carried out using signatures drawn from 350 training sample points distributed from secondary data sources and field survey for each of the established LULC classes. The accuracy evaluation was carried out using the remaining 210 sample points which were not used to develop signatures. Confusion matrix was obtained and the accuracies of producers and consumers and the Kappa statistics were determined from the error matrix. It should be noted that error matrix was created to compare reference data and classification results and to generate the overall accuracy and Kappa coefficient tables. The Kappa statistic considers the off-diagonal elements of the error matrix and represents the possibility of an agreement between reference data and classification results occurring by chance (Bogoliubova and Tymków, 2014).

2.2.4. Focus group discussion

To identify the drivers of LULC change and support the computer based accuracy assessment, focus group discussions were held with 12 elder people (aged above 60 years) so that more accurate information could be extracted since 1973 about the conditions and trends of the forest dynamics (Fig. 2). Focus group discussion was chosen over other statistical population representatives to explore the long-term factors that have been governing the land cover land use change dynamics (Nyumba et al., 2017). This situation could be challenging as there is a possibility that the remedial opportunities for discussion could be missed because the evaluation of the most important factors belongs to the long-term memory.

The overall methods used are summarized in Fig. 2. This figure presents the combination of the quantitative and qualitative methods used in classifying historical images, assessing the accuracy of the classified historical images and the main factors that controlled land use dynamics in the last four decades.

3. Results

3.1. Accuracy assessment of LULC maps

Accuracy assessment was done using the confusion matrix to compare the classification results of 2015 with ground truth collected by Google Earth. User and producer accuracy results are presented for each LULC in a matrix along with the Kappa coefficient (Congalton and Green, 1999). To see the accuracy of the LULC classification, 210 ground control points were taken representing five LULC types identified in the area. Accordingly, the results showed that the classification has been achieved with high accuracy of 91% and the Kappa coefficient of 0.89. Overlaying of the classified imageries with Google Earth was also rendered to further refine results where the contribution was noticeable. Historical image classification was attempted using aerial photographs.

3.2. LULC change analysis

Following the multi-temporal image analysis, while the total vegetated land (woody vegetation) in 1973 covered almost 83% of the total forest, only 17% of the forest reserve area was covered by other LCLU types (grasslands, farmland, and bare land have covered 10%, 3%, and 4% percent, respectively) (Table 1). The situation in 1986 was very different as opposed to 1973. The woody vegetated land covered 57% of the forest (Table 1) in 1986. All other LULCs, however, showed positive changes in their cover extent. Dramatic increment has been observed in farmland and bare land which covered 11.8 and 14% of the total forest area in 1986, respectively. The remaining 16% was grasslands. The degradation and clearance of the forest continued to be so severe that the woody vegetation has covered only 39% of the total forest reserve in 2015. In contrast, the non-vegetative land continued to increase, and by 2015, farmland and bare lands had doubled their spatial coverage since 1986 and by more than eightfold since 1973. As represented in Table1, grassland, farmland, and bare land shared around 5%, 27%, and 29% of the forest priority area in 2015, respectively, a total of 60%. Among the

Table 1
The area of the Desa'a LULC during 1973, 1986, and 2015 (in hectares)

	LULC of Desa'a forest in 1973, 1986, and 2015					
LULC type	1973	Percentage	1986	Percentage	2015	Percentage
Dense Forest	56909	54.11	32081	30.50	12110.84	11.52
Open Forest	29948	28.48	28418	27.02	26583.47	25.28
Grass Land	10814	10.28	17532	16.67	5063.947	4.81
Farm Land	3560	3.38	12393	11.78	30090.32	28.61
Bare Land	3941	3.75	14748	14.02	31323.42	29.78
Total	105172	100	105172	100	105172	100

possible reasons for such a rapid decline of the forest might be the low administrative control and conflicts of interests between the lowland pastoralist of the Afar land and the agriculturalists of the highlands of Tigray (Zenebe, 1999; Hishe et al., 2015b). A similar rapid LULC change trend was recorded in the Northern Afar where farmland and bushland have significantly increased at the expense of woodlands and grassland (Tsegaye et al., 2010). In contrast with the present results, Reygadas et al. (2019) reported a slight process of degradation. Their results showed that 52% of forests had positive trends of vegetation change (i.e., increasing LAI), 37% remained unchanged, and 11% exhibited some levels of forest degradation in central Mexico.

The LULC in Desa'a forest has shown different change trends at different times (Table 2). Between 1973 and 1986, the forest area showed decrement of both open and dense forest by 5% and 44%, respectively; whereas grassland, farmland, and bare lands have shown positive increment. This is mainly due to the accidental drought occurrence in 1985 which has increased the dependency of the local community on the forest for sustaining human and livestock needs (Zenebe, 1999). Between 1973 and 1986, the decrement rate was almost 3.4% or 1909 ha a year, which was so fast that it has resulted in expansion of large areas of bare land and farmland. However, after the drought had ceased, little improvement was observed in the rate of forest area declination which was lowered to 3.2% or 1536 ha a year. Overall, in the last 42 years, most of the forest (48163 ha) areas, including both open and dense forests, have been converted to either farmland or bare land. Dense and open forests covered 82% of the forest area in 1973; however, most of them have already been destroyed and only 36% of the total area remained. On the contrary, the other land uses such as grasslands, farmlands, and bare lands only covered 18%, of which 10% were grasslands in 1973, which now are covering more than 64%, of which the farm and bare lands are the dominant (greater than 58%).

Between 1973 and 1986, while grasslands and cultivated and bare lands have shown positive changes by 248% and 273%, respectively (Table 2), dense and open forest lands decreased by 44% and 5%, respectively. The degradation and forest disappearance continued severely and more than 60% of the forests are covered by non-forest LULC types (Tables 1 and 2). Of the total area, 48.000 ha that used to be covered by forests in 1973 are now destroyed and replaced largely by

Table 2
LULC changes for 42 years (negative sign shows decrement in cover)

	LULC change of Desa'a forest in 1973, 1986, and 2015					
LULC type	1986-1973	% change	2015-1986	% change	2015-1973	% change
Dense Forest	−24828	−44	−19970	−62	−44798	−79
Open Forest	−1530	−5	−1835	−6	−3365	−11
Grass Land	6718	62	−12468	−71	−5750	−53
Farm Land	8833	248	17697	143	26530	745
Bare Land	10807	274	16575	112	27382	695

farm and bare lands (Tables 1 and 2). Tekle and Hedlund (2000) have documented the rapid declination of shrub (69%) and forest (31%) coverage within 28 years (1958-1986) in Southern Wello, Amhara region. Therefore, such rapid delineation in the coverage of forest and shrubs is a common phenomenon in almost all regions of Ethiopia (Fig. 3). In addition, Kindu et al. (2013a, 2013b) and Girmay et al. (2010) recorded a rapid decline in vegetation cover and additional land cover in Munessa-Shashemene and Gum Selassa, respectively. Hailemariam et al. (2016) have found a loss of 123,751 ha of forest cover due to the expansion of agriculture and urban settlements in the Bale Mountain Eco-Region of Ethiopia from 1985 to 2015. The expansion of the agricultural and urban settlements was found to be a significant driver of LULC transition.

4. Discussion

4.1. Causes of forest deforestation and degradation

During the discussion with the elders of the *Tabias* within and around Desa'a forest, the following causes (i.e., forest fire, agricultural expansion, grazing and browsing effect, drought, extraction of wood, and lack of government attention) were mentioned as the main drivers of LULC, mainly vegetation change, over time.

4.1.1. Forest fire

Fire is one of the most challenging hazards in the world's forests (Matin et al., 2017; Velizarova et al., 2019; Mohammed et al., 2019) and has been occurring periodically in the study area. However, the beginning of all losses in this forest is a devastating fire set ablaze in 1970 which eradicated most forest species in the lower altitude to the east lasting for more than 10 consecutive days. Since then, the dominant species of the forest, i.e., *Olea europaea* and *Juniperus procera*, failed to come back, while fast colonizing species, e.g., *Cadia pupurea, Calpurnia aurea,* and *Tarchonanthus camphoratus,* used the opportunity and suppressed the regeneration of the dominant species with the aid of human & animal intrusion. During the visit to the stated portion of the forest, it was clearly seen that the fire was immense and those huge stumps of *Olea europaea* and *Juniperus procera* were left burned and overtaken by the growth of different shrub species.

4.1.2. Agricultural expansion

Agricultural expansion is among the main driver variables in deforestation. It was mentioned that both illegal expansion of agriculture and legal distribution of land at the periphery of the forest with remnant standing trees are the main causes of deforestation. For instance, conversion of mixed tree-grazing land to subsistence agriculture can lead to deforestation. Results from the change detection analysis support this result where a significant amount of open forest is converted to agricultural land. Similar results are all around the globe where agricultural expansion causes huge amounts of deforestation (Acheampong et al., 2019; FAO, 2010a, 2010b; Pichon et al., 2001; Reardon and Barrett, 2001; Fisher et al., 2011; Mirzaei et al., 2019)

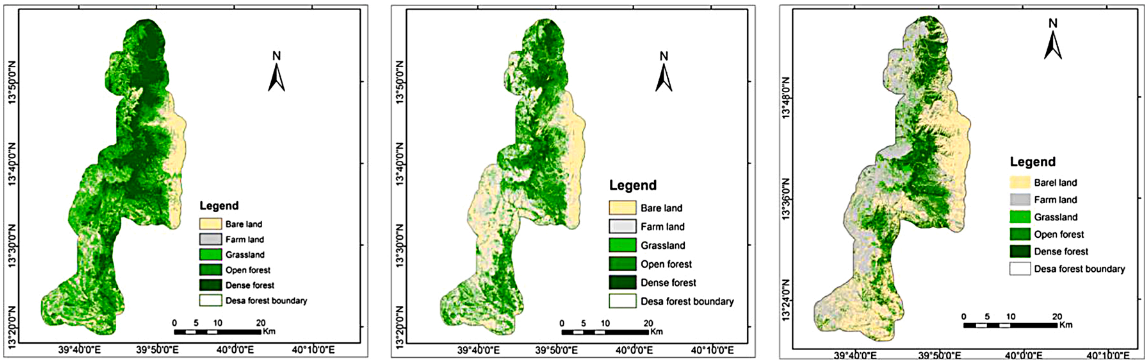

Fig. 3. Land use land cover status of Desa'a forest, 1973, 1986 and 2015 from left to right.

4.1.3. Grazing and browsing effect

Animal grazing, which hindered forest succession by eradicating the emerging seedlings and browsing especially olive trees (including large young biomass of olive). This process led to the deforestation process next to the devastating fire occurred in 1970. The rainy season is very short and grazing lands outside the forest are scarce. Therefore, animals from Afar and the upper highlands of Tigray are kept inside the forest for longer times using the grasslands in the forest and palatable trees and shrub species for browsing animals like camel and cut and carry systems for grazing animals. Due to this fact, there had been repeated disagreement resulting in bloody use conflict between the Afar and Tigray prospects which made forest management difficult. Their different livelihood systems, agriculturalists in Tigray, and pastoralists in Afar brought difficulties in introducing certain forest management interventions.

4.1.4. Drought

Among the listed factors of forest decline, drought was described as the third cause and the only natural process (factor) mentioned by the group members. While drought was a repetitive phenomenon in the study area in particular and the region in general. The drought phenomenon that occurred in 1985 was very serious and caused huge loss of biodiversity. Furthermore, declination of rainfall over years has increased the dependency of the local population and their livestock on the forest. This has resulted in the retreat of the forest. During the drought period, a lot of branches of different palatable species were cut to feed animals due to the lack of grass growth. This might be explained also by the researcher's observation on the periphery of the forest, in close proximity to settlements, where standing big trees are left only with regrown small branches or completely branchless which may indicate that such activities are still valid.

4.1.5. Extraction of wood

As per the discussion results show, extraction of wood for domestic and commercial use, predominantly from residents and also sometimes from illegal merchants, is also another serious problem. Most of the time, well performing trees are primarily felled which affects the reproduction process of the growing population. These well performing vigorous and healthy plant individuals are responsible for perpetuating plant communities by serving as mother trees for natural regeneration (Whisenant, 1999). The severe logging of active tree species seems to be the main driver of the huge decline in dense forestry which is obtained from the change detection results. On the other hand, the method of house construction was also mentioned as a factor aggravating deforestation through wasteful wood extraction. Because the resource is available, wasteful cutting and piling were reported as common phenomena in the study area (Zenebe, 1999). The group discussion members reported that wood mining was also excessive during the past and present governmental regimes due to military settlement in the forest. Forest stands were cleared for camp establishments and building military bases. Similar reports were documented by TFAP (1996) and Zenebe (1999).

4.1.6. Lack of government attention

In the same way, all the group members noticed that even though they do not like to be deprived of access to their forest, the lack of government attention, which is only now improving, is another indirect cause of the forest degradation. It was explained that there are forest guards, but they are only there for symbolical representation of the government. There is a saying, 'the forest cannot be kept safe with government forest guards.' This expression was explained by the fact that the forest guards have to lose their relationship with the local community they are living with. There are few checkpoints for vehicles that are used in the transportation of illegally logged wood. However, as the group discussion revealed, it is wood transportation by humans and animals which plays a crucial role in deforestation of Desa'a forest. For this type of illegal wood logging, the government has not designed appropriate mitigating measures and fully implemented already existing laws and regulations. There are legal frameworks and policy documents that are meant to regulate forests and forest products of the nation. Proclamation 199 4/94, for example, states that cutting the endangered species such as *Juniperus procera* is against the law (Anonymous, 2007). *Juniperus procera* is listed as threatened species by FAO (1975) which requires in-situ conservation so as to maintain the enormous benefits of the species to the ecosystem and community the species resides in. On top of that, utilizing any products from any state forests without permission is punishable by five years' imprisonment as well as a fine of 10,000 Birr (Anonymous, 2007). However, this species still remains under tremendous pressure (Demel, 1996; Aynekulu, 2011), and this was mentioned to be due to poor implementation of the available laws and regulations

As a final remark, Desa'a forest plays a crucial role in buffering the hot climate of the lowlands of Afar and the cold climate of Tigray highlands (Zenebe, 1999; Aynekulu et al., 2012). This sustains the ecosystem of the downstream Afar pastoralists and highlands ecosystem of Tigray providing all the resources needed for the livestock and also human demands. This forest now consists of mainly shrub growth, as well as shrublands converting to forest areas. Similarly, Asmamaw et al. (2011) reported that in the Gerado catchment in northeastern Ethiopia, forest land expanded at the expense of shrublands between 1985 and 2006. Such changes of shrubland to forest land are evident in various parts of the world as well. For example, Wu et al. (2007) stated that owing to afforestation in Beijing, China, shrublands were transformed into forest lands (Aynekulu et al., 2012). The ecosystem revolving around the services of the forest will be demolished and at the very minimum, the micro climate conditions will be changed. These leave the nearby pastoralist communities of Afar and agriculturalists communities of Tigray vulnerable to drought, land degradation, and, therefore, deteriorate land productivity that results in production decline and shortage of food.

4.2. Limitations of the study

This study has some limitations to the interpretation of our results. Firstly, we used the focus group discussion method to identify and prioritize driving variables of LULC changes in the study area. This method can be very qualitative and depends on the taste of the participants; some people may exaggerate in expressing their opinions. It may also involve respondents who have more power to express themselves and not allow other people to express their opinions. Second, our study was conducted over a 42-year period (1973-2015), and we considered three-time intervals (1973, 1986, and 2015) for mapping LULC. Changes may have occurred between these time intervals which might have been overlooked (especially between 1986-2015). Thus, to better understand the dynamics of LULC change, choosing more time intervals can overcome this limitation in future studies.

5. Conclusion

LULC change monitoring of forests is one of the most important management plans for the protection and improvement of these areas. Thus, LULC estimates are among the most essential information in any forest management practice. The obtained results support the hypothesis that degradation and forest disappearance have occurred severely, and more than 60% of the forest is covered by non-forest LULC types. This finding reveals that the present land management in Desa‘s forest is not sustainable. In this context, the most important findings and conclusions of the study are listed as follows:

ii) During the study period, almost 54,000 ha of grasslands and open and dense forests have been converted to either bare land or farmland, of which 48.,163 ha is open and dense forest. Continuing with such a trend will lead to more severe deforestation and it is necessary to identify and modify the driving variables in Desa'a forest.

iii) According to the elders of Tabias within and around Desa'a forest, forest fire, agricultural expansion, grazing and browsing effect, drought, extraction of wood, and lack of government attention were mentioned as the main drivers of LULC changes in the study area.

- Our results can provide a practical perspective for land use planners to manage LULC changes in the study areas with similar topographic and climate conditions. The results can also be used in environmental impact assessment to identify sensitive and vulnerable areas and revive them, and finally can be used to implement the REDD (Reducing Emissions from Deforestation and Forest Degradation) project with the goal of reducing greenhouse gases and biodiversity conservation. This research is vital to notify policymakers for further planning and intervention on the status and change of the LULC. The forest cover has also shown growth, so that forest management in the study region can be applied to other protected areas in a similar setting. Accordingly, we suggest conducting similar studies in other forest hotspots around the world. In future studies, to further monitor and analyze LULC changes, its driving variables can be determined by using statistical analysis (e.g., spatial regression). Furthermore, the LULC maps for the future should be predicted using artificial intelligence techniques (e.g., artificial neural network and support vector machine) or scenario development techniques (e.g., map overlays). Considering shorter time intervals and therefore analyzing more LULC maps can also be offered as a final recommendation in future studies. Below are a few recommendations based on the findings of our study: It is necessary to changes the policies and strategies for sustainable land use toward the combination of development with sustainable environmental management. Improved soil management is essential to maintain soil quality and improve the productivity of farmland, which in turn can help decrease deforestation and soil degradation.
- There is a need to raise the awareness of the benefits of a protected forest area and sustainable land use, in particular for farmers living in the vicinity of the Desa'a forest.
- Different stakeholders, such as the government, NGOs, and researchers, need to create knowledge to guide society on how to strengthen the social understanding in relation to inappropriate use of forest resources.

CRediT authorship contribution statement

Hadgu Hishe: Conceptualization, Data curation, Formal analysis, Writing - original draft. **Kidane Giday:** Conceptualization, Formal analysis, Methodology, Writing - original draft. **Jos Van Orshoven:** Formal analysis, Methodology, Supervision, Writing - original draft. **Bart Muys:** Formal analysis, Methodology, Supervision, Writing - original draft. **Fatemeh Taheri:** Formal analysis, Methodology, Writing - original draft. **Hossein Azadi:** Formal analysis, Methodology, Writing - original draft, Writing - review & editing. **Lei Feng:** Formal analysis, Writing - review & editing. **Omid Zamani:** Formal analysis, Writing - review & editing. **Mohsen Mirzaei:** Formal analysis, Writing - review & editing. **Frank Witlox:** Formal analysis, Writing - review & editing.

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