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Research Application Summary

Spatio-temporal dynamics of land use and land cover changes, and woodlot expansion in northwestern Ethiopian Highlands

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Abstract

Rapid land use land cover (LULC) change is one of the fundamental environmental problems in Ethiopia in general and, especially in the highlands of Ethiopia. This study was aimed to understand the trends, magnitudes, and drivers of LULC changes in three Districts of the northwestern Ethiopian Highlands, namely (Guna Begemidir, North Mecha, and Fagta Lekoma) with high expansion and management of woodlots during 1987 to 2020 periods. The study employed a hybrid classification technique to group the images into LULC classes. The results indicated that woodlots as plantation forests increased from 2.5% in 2009 to 19.4% in 2020 in Fagta Lekoma District. An increment of plantation forest from almost none to 33% was also observed in North Mecha District during 1987-2020. In the case of Guna Begemidir District, coverage of plantation forest increased from 0.32% in 2009 to 7.9% in 2020. Overall classification accuracy of 80.19, 84.49, 81.79%, and a Kapa coefficient of 0.75, 0.81, and 0.78 for Fagta Lekoma, North Mecha, and Guna Begemidir Districts, respectively, were attained. The landscapes of the study areas have shown remarkable changes across spatial and temporal differences. The main drivers of the changes in the LULC were associated with the shift of livelihood dependence and demand for various ecosystem services. The LULC changes in the study areas have implications for enhancing forest-based ecosystem services. A continuous study on the risks, trade-offs and synergies of ecosystem services in the LULC changes is needed to scrutinize the impact of the land use and land cover changes and design optimum land management strategies in the study areas.

Keywords: Drivers, ecosystem service, Ethiopia, image classification, plantation forest

Résumé

Le changement rapide de l'utilisation et de la couverture des terres (LULC) est l'un des problèmes environnementaux fondamentaux en Éthiopie en général et, en particulier, dans les hautes terres de l'Éthiopie. Cette étude avait pour but de comprendre les tendances, l'ampleur et les facteurs de changement de l'occupation des sols dans trois districts des hauts plateaux du nord-ouest de l'Éthiopie, à savoir Guna Begemidir, North Mecha et Fagta Lekoma, qui ont connu une forte expansion et une bonne gestion des terres boisées entre 1987 et 2020. L'étude a utilisé une technique de classification hybride pour regrouper les images en classes de LULC. Les résultats indiquent que les bois en tant que forêts de plantation ont augmenté de 2,5% en 2009 à 19,4% en 2020 dans le district de Fagta Lekoma. Une augmentation de la forêt de plantation de presque zero à 33% a également été observée dans le district de North Mecha au cours de la période 1987-2020. Dans le cas du district de Guna Begemidir, la couverture de la forêt de plantation est passée de 0,32% en 2009 à 7,9% en 2020. La précision globale de la classification a atteint 80,19, 84,49, 81,79 % et un coefficient Kapa de 0,75, 0,81 et 0,78 pour les districts de Fagta Lekoma, North Mecha et Guna Begemidir, respectivement. Les paysages des zones étudées ont montré des changements remarquables à travers les différences spatiales et temporelles. Les principaux moteurs des changements de LULC sont associés à l'évolution de la dépendance des moyens de subsistance et à la demande de divers services écosystémiques. Les changements de LULC dans les zones étudiées ont des implications pour l'amélioration des services écosystémiques basés sur la forêt. Une étude continue sur les risques, les compromis et les synergies des services écosystémiques dans les changements de LULC est nécessaire pour examiner l'impact des changements d'utilisation et de couverture des terres et concevoir des stratégies optimales de gestion des terres dans les zones étudiées.

Mots-clés : Drivers, service écosystémique, Ethiopie, classification d'image, forêt de plantation

Background

The world environment is in a dynamic state of changes due to natural and anthropogenic activities. In the process of environmental dynamics, land is the major focus among all forms of changes (Belayneh *et al.,* 2018). The hasty use and destructive human dependence on various ecosystems services (ESs) combined with frequently unrestricted demands for ESs has exerted heavy pressure on natural resources. Globally, crop and pasture lands have been expanding at the expense of forest cover during 1970 to 2005 (Lambin and Geist, 2003; FAO, 2015). Global deforestation was estimated at 129 million ha during 1990-2005 (FAO, 2015). In the stated time, the highest rate of annual forest loss was observed in Africa (e.g., Nigeria 4.5% and Zimbabwe 2%), followed by Latin America (Paraguay1.9%), and Asia (Myanmar 1.7%) (FAO, 2015) indicating more severe problem of deforestation in the tropics, particularly in Sub-Saharan Africa (MEA, 2005; FAO, 2015).

Due to diversified land forms, agro-ecologies, cultural and socio-economic settings, the scale, rates, directions, and drivers of LULC changes reported by different scholars at global and local level are not uniform. Land cover and land use change has been reported to be global challenge. For instance, in the Upper Manyame Sub-Catchment, Zimbabwe forest cover decreased (9.4%), cropland increased (9.5%) in the years 1999-2020 (Zvobgo and Tsoka, 2021). A study by (Hu *et al.,* 2019) in Guangxi, China reported both deforestation by (0.76%) and forest cover increment due to afforestation (0.58%) in the years 1999-2017. (Rawat and Manish, 2015), reported an increase of vegetation and built-up land by (3.51%) and 3.55% respectively while agriculture, barren land, and water body have decreased by 1.52%, 5.46%, and 0.08% respectively during the last two decades in district Almora, Uttarakhand, India.

Existing studies in Ethiopia also show diverse evidences. For example, an increase of cultivated land (22.5 %) while a decline of forest (45%), shrub land (41.5 %) and grassland (36.1 %) cover during period of 1985 to 2015 in Andassa Watershed in the Blue Nile Basin were reported by Gashaw *et al.* (2017). A rapid reduction in woodland area (54%) and forest cover (99%) during 1973-2013 in the Central Rift Valley of Ethiopia (Mesfin *et al.,* 2020). Bewket and Abebe (2013), reported decrease (64%) forest and shrub grassland (6%), while grassland and cropland increased by 7 and 21% respectively during 1957-2001 in a highland watershed, Ethiopia. The work of Zerga *et al.* (2021) in the Western Gurage Watersheds, showed similar trend i.e. forest cover declined by 18.9% during 1987-2001 but increased by 34.1% during 2001-2017. (Minta *et al.,* 2018), also reported a decline of forest land (73%), woodland (100%) and pastureland (67%) while an increase of cultivated land (170%), eucalyptus plantation land (13,674%) and settlement (172%) for a period of 1957-2014 in the central Ethiopian highland. Negasa *et al.* (2016), also reported a massive increase of Eucalyptus plantation (1420%), and an increase of cultivated land (64.6%), but grassland decreased by (33.3%) during 1976-2015 in Meja Watershed, Ethiopia. Other reports also showed an increase of forest cover (1.2%) per year and a decrease of cropland (1%) per year for the period 1995 to 2015 (Wondie and Mekuria, 2019); an increase of forest lands (256 %), built-up areas (100 %) and grassland (96 %) for the period of 2003–2017 in Fagta Lekoma District (Belayneh *et al.,* 2018); an increase of forest (120%) cover in Gilgel Abbay and a decrease of forest (24.1 %) in Birr between 1957 and 2001 (Gebrehiwot and Bishop, 2014).

The above mentioned contrasting reports demonstrate that the magnitude, direction, and drivers of LULC change varies, in spatial difference and temporal series, and the need for further understanding through research for specific case studies at relevant spatial and temporal scales with a standard definition of land use types. Unlike the previous studies that reported the overall LULC change at a specific watershed without considering woodlot expansion, this study focused on comparison of cases across spatial, agro-ecology, and intervention differences by employing standard definition of forest types. This paper presents findings of the study undertaken on comparative analyses on the trends, magnitudes and drivers of LULC changes in three Districts (Guna- Begemidir, North-Mecha, Fagta Lekoma) with high expansion and management of woodlots during 1987-2020.

Methodology

Image preprocessing and classification. Four Landsat images for the periods 1987, 1998, 2009 and 2020 were downloaded from the United States Geological Survey database (https://earthexplorer.usgs.gov, accessed during the months December to January, 2021). The years of study were selected based on the response of Key Informants (KIs) on the LULC change and expansion of woodlots in the study areas. Image classifications of the Landsat images were undertaken using hybrid classification technique, which combines both unsupervised and supervised classification technique (Gebrehiwot and Bishop, 2014; Gashaw *et al.,* 2017).

A total of 527 GPS points were collected from the different LULC classes and used for the supervised classification. The resulting samples were imported to the ERDAS Imagine and the signature files were generated. Using signature editor of unsupervised classes, a pixel-based supervised classification with Maximum Likelihood Classification (MLC) algorithm (Gebrehiwot and Bishop, 2014; Gashaw *et al.,* 2017) was undertaken using the ground truth points collected from each LULC category. Image classifications of the historical LULC periods (i.e., 1987, 1998 and 2009) were undertaken through collecting training data from the corresponding Google

Earth Images (Gashaw *et al.,* 2017). Moreover, geo-linking techniques were also undertaken in classifying the earlier images. ERDAS Imagine 2015 and Arc GIS 10.7 software were used for image classification and mapping works, respectively.

Accuracy assessment. Accuracy assessment was carried out to understand the representation of the classified images on the ground (Gashaw *et al.,* 2017; Mosammam *et al.,* 2017). A total of 1002 reference points were used for the accuracy assessment of the 2020 classified images of the three Districts. About 10% of the GPS points which were utilized for image classifications were used for accuracy assessment while the remaining reference points were collected from the field. Then, the accuracy of each of the LULC classification was computed following the methods described by Lillesand *et al.*
(2004).

Analyses of land use land cover changes and transitions. Change analysis is needed to demonstrate patterns of changes and make useful decisions. After the image classification, comparisons among the subsequent time periods were made to illustrate the changes between periods (Gashaw *et al.,* 2017). The land cover changes were detected by comparing the 1987 image values with the corresponding values from 2020. Moreover, percent and rate of changes (Gashaw *et al.,* 2017; Hassen and Assen, 2018) were computed to demonstrate the magnitude of the changes experienced between the periods using equations 1 and 2, respectively.

$$\text{Percent of change} = \left(\frac{X-Y}{Y}\right)*100 \quad (1)$$

$$\text{Rate of change } (\text{ha}\,\text{yr}^{-1}) = \left(\frac{X-Y}{Z}\right) \quad (2)$$

Where, X =area of LULC (ha) in time 2, Y =area of LULC (ha) in time 1 and Z =time interval between X and Y in years.

LULC transitions from one category to another are common phenomena in many LULC studies (Gashaw *et al.,* 2017). The LULC transitions undertaken between subsequent LULC periods were evaluated in Terr Set Geospatial Monitoring and Modeling System Software, Version 18.31, which provides the LULC changes that have taken place in each LULC class.

Results and Discussion

Accuracy of the classification process. According to (Monserud, 1990), Kappa values between 0.70 and 0.85 are generally rated as very good indicators of the classified image in representing the ground truths. In the present study, an overall accuracy of above 80% and a Kapa coefficient of higher than 0.75 were achieved for the three study Districts. Hence, the classified images can be used for further applications.

Land use and land cover changes. Land use land cover transitions constitute the replacement of one class by the other, and it is commonly observed in various LULC change studies Gashaw *et al.,* 2017; Minta *et al.,* 2018; Hu *et al.,* 2019; Wondie and Mekuria, 2019; Zvobgo and Tsoka, 2021). Demand for ecosystem services has been a key determinant for LULC changes in Ethiopia in general and, especially, in the northwestern highlands. The ways, magnitude, direction, and intensity of LULC changes vary across different landscapes and over the course of time.

This study revealed the dynamics of LULC change across spatial differences over temporal sequences. The direction of change observed for some land uses in the three study sites is not always uniform over the study period considered. For example, cropland showed an increment from 26.8 to 35.4%, 38.1 to 53.6%, and 41.7 to 47.8% during 1987-1998 in Guna Begemidir, North Mecha, and Fagta Lekoma Districts, respectively (Table 1). The possible reason for the expansion of cropland during the stated time is high demand of food products associated with the increasing population pressure. However, during 2009 and 2020 cropland has been diminishing to 32.4 and 29.9%, 38.6 and 34.9%, 41.6 and 40% in Guna Begemidir, North Mecha, and Fagta Lekoma, respectively (Table1). The observed decline in cropland area coverage during the latter time is caused by the existing trend of tree planting activities mainly on croplands which is in line with work of Belayneh et al. (2018) and Wondie and Mekuria (2019).

The highest decline in grazing land, with 50.8%, was observed at a rate of 439.4 ha yr^{-1} during 2009-2020 in Guna Begemidir District is in line with the work of Wondie and Mekuria (2019). On the other hand, the increase in plantation forest by 7.6 % in Guna Begemidir, by 32.8% in North Mecha and by 16.9 % in Fagta Lekoma Districts during 2009-2020 clearly shows variation in

Table 1. Land use and land cover change in during 1987-2020 in the three study Districts

Guna Begemidir LULC class	1987		1998		2009		2020	
	Area (ha)	Proportion (%)	Area (ha)	Proportion (%)	Area (ha)	Proportion (%)	Area (ha)	Proportion (%)
Bush land	10,901	21.8	12,395	24.8	4,930	9.9	13,044	26.1
Cropland	13,415	26.8	17,705	35.4	16,205	32.4	14,919	29.9
Degraded land	14,688	29.4	14,630	29.3	15,089	30.2	7,924	15.9
Grazing land	7,942	15.9	2,823	5.6	9,523	19.1	4,690	9.4
Natural forest	2,875	5.8	2,265	4.5	1,987	4.0	2,715	5.4
Plantation forest					158	0.3	3,954	7.9
Settlement area	152	0.3	156	0.3	2081	4.2	2,726	5.5
Water body								
Total	49,973	100	49,974	100	49,973	100	49,972	100
North Mecha								
LULC class	1987		1998		2009		2020	
Bush land	37993	32.4	32187	27.4	26529	22.6	9026	7.7
Cropland	44654	38.1	62826	53.6	45236	38.6	40970	34.9
Grazing land	27656	23.6	18985	16.2	29659	25.3	14473	12.3

Plantation forest	-	-	-	-	269	0.2	38748	33.0
Settlement area	168	0.1	287	0.2	13628	11.6	12344	10.5
Water body	6829	5.8	3016	2.6	1980	1.7	1740	1.5
Total	117301	100	117301	100	117301	100	117301	100
Fagta Lekoma								
LULC class	1987		1998		2009		2020	
Bush land	13393	22.8	4053	6.9	16866	28.7	5370	9.1
Cropland	24497	41.7	28131	47.8	24438	41.6	23500	40.0
Grazing land	17246	29.3	16862	28.7	6283	10.7	5925	10.1
Natural forest	3572	6.1	2820	4.8	3660	6.2	6481	11.0
Plantation forest	-	-	-	-	1486	2.5	11390	19.4
Settlement area	93	0.2	6935	11.8	6068	10.3	6135	10.4
Total	58801	100	58801	100	58801	100	58801	100

strategies of their land management. The trend in conversion of other land uses to plantation forest is in line with several studies (Gebrehiwot and Bishop, 2014; Rawat and Manish, 2015; Negasa *et al.,* 2016; Zerga *et al.,* 2021). Highest expansion of woodlot observed in North Mecha in relation to the other two Districts is supported by the KIs' view which indicated high involvement of the local communities in tree planting and woodlot management. The proportion of non-adopters (farmers not planting tree) in Guna Begemidir Districts as perceived by KIs was higher than the other two Districts. This is supports the result of image analysis. The likely reason for the lower expansion of woodlots observed in Guna Begemidir could be associated with the difference in the perception of the local communities on the comparative benefits of woodlots than other land uses and the agro-ecological variation that may affect the productivity of woodlots, which, in turn, could affect the economic benefits of the woodlots.

The rapid expansion of woodlots during the last 11 years of the study period at the expense of the other land uses (grazing land, cultivated land and degraded land) shows the switch of the livelihood dependence of communities on forest ecosystem services in the study areas , as it is in central and northwestern Ethiopia (Negasa *et al.,* 2016; Wondie and Mekuria, 2019; Belayneh *et al.,* 2020; Zerga *et al.,* 2021).

The decline of area covered by degraded land, by almost half, (from 30.2% in 2009 to 15.9% in 2020) at a rate of 651.4 $hayr^{-1}$ in Guna Begemidir District indicates its replacement by expansion of woodlot besides cropland and grazing land. The coverage of natural forest increased during 2009-2020 from 6.2 to 11% in Fagta Lekoma and from 4 to 5.4% in Guna Begemidir Districts is in contrast with some previous studies (Bewket and

Abebe, 2013; Gebrehiwot and Bishop, 2014; Gashaw *et al.,* 2017; Minta *et al.,* 2018; Hu *et al.,* 2019; Mesfin *et al.,* 2020; Zvobgo and Tsoka, 2021). The contrasting result of the present study with the previous studies in different parts of Ethiopia and other countries could be related to the differences in the definition of forest used, spatial difference between the studies and differences in the study period considered. In addition, less dependency of communities on natural forest due to increased supply of wood products from woodlots and enhanced natural regeneration on previously degraded natural forests have contributed to the area coverage.

The increment of settlement area in the study sites, at a rate of 85.8, 369, and 183.1 ha yr^{-1}, in Guna Begemidir, North Mecha, and Fagta Lekoma, respectively, during the entire study period replacing other land uses (bushland, grazing land and cultivated land) is also justified by the population growth and the construction of additional houses in towns, as the number of better-off farmers coming from rural villages is increasing. This previous studies (Gashaw *et al.,* 2017; Wondie and Mekuria, 2019; Belayneh *et al.,* 2020; Zerga *et al.,* 2021) also support this finding.

Drivers of land use and land cover changes. As it was reported in previous studies (Bewket and Abebe, 2013; Gebrehiwot and Bishop, 2014; Gashaw *et al.,* 2017; Minta *et al.,* 2018; Sahle and Yeshitela, 2018; Belay and Mengistu, 2019; Belayneh *et al.,* 2020; Zerga *et al.,* 2021; Zvobgo and Tsoka, 2021; Bufebo and Elias, 2021) population growth is the main driver for LULC changes. In the present study, population growth coupled with the dynamics of livelihood dependence on various ecosystem services caused LULC changes in different ways. The increase in population pressure obviously results in demand for various ecosystem services (food products, wood products, soil and water conservation, income, soil fertility enhancement and other services). To fulfill the stated demands, the community has been forced to change the land use and land cover in a non-uniform magnitude, and direction over temporal changes. During the earlier years of the present study (1987-1998), high livelihood dependence on agriculture caused expansion of cultivated land by replacing bushland, natural forest and grazing land in the study areas. The high demand for food products by the growing population pressure was found to be the major driver for LULC changes observed in the study areas. This is in line with work of others (Bewket and Abebe, 2013; Gashaw *et al.,* 2017; Minta *et al.,* 2018; Sahle and Yeshitela, 2018; Belay and Mengistu, 2019; Belayneh *et al.,* 2020; Zerga *et al.,* 2021).

The other driver reported by KIs includes land degradation that reduced crop productivity, caused severe food insecurity, and shortage of wood products. As a result, in the later years (2009-2020), despite the continued increasing population pressure and the escalated demands for various ecosystem services, the community in the study Districts conceived new innovations, popularly referred to as "woodlot management", to satisfy their demands and reduce further depletion of land resources. This was also supported by the report of (Belayneh *et al.,* 2018; Minta *et al.,* 2018; Zerga *et al.*, 2021). As reported by KI, farmers in the study areas have been attracted to woodlot management due to several socio-economic benefits including wood products for house construction, fuel wood and employment opportunities. The main source of energy for the local people is derived from biomass (fuel-wood, crop residue and cattle dung). Currently, the higher share of energy source is supplied from the woodlots. Employment opportunity is the other important social benefit of woodlots.

As it is noted by KIs, many people are engaged in harvesting, processing and transporting of woodlot products indicating woodlot management as household livelihood strategies is the highest among other strategies. As a result, households consider woodlots as a form of security against any unforeseen financial risk and as money deposited in a bank (live bank account). Most of the KIs highly appreciated the economic impact of woodlots not only for the household high return, but also due to their lower establishment and management cost than croplands. The KI view is supported by several work (Belayneh *et al.,* 2018; Minta *et al.,* 2018; Zerga *et al.,* 2021).

Conclusions

The landscapes of the study areas have shown remarkable changes across spatial difference and over the course of time. The main driver of the changes in the LULC is basically associated with the shift in livelihood dependence and demand for the various ecosystem services. During the study period (2009-2020), rapid expansion of woodlots was observed at the expense of grazing land, cultivated land and degraded land. The rate of woodlot expansion is highest in North Mecha followed by Fagta Lekoma and Guna Begemidir Districts. Farmers in the study areas have been attracted to woodlot management due to its comparative socio-economic and environmental benefits. In the process of land use conversion and replacement, the local communities are carefully evaluating the cost-benefit of the two land uses (cropland and woodlots). The present study showed that the comparative socio-economic and environmental benefits largely influenced LULC changes. The LULC changes in the study areas have implications on enhancing forest-based ecosystem services. The rapid expansion of woodlots in the study areas could also have various risks, such as scarcity of food and livestock products, possible seasonal price decline of wood products as well as lack of steady cash flow associated with the long-term investment of woodlots. Therefore, a comprehensive study on the risks, trade-offs and synergies of ecosystem services of the land use changes is needed to scrutinize the impact of the LULC changes and design optimum land management strategies in the study areas.

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