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PARTICIPATORY FOREST MANAGEMENT AND ITS IMPACT ON NATURAL FOREST DYNAMICS IN NORTHWEST ETHIOPIA

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ABSTRACT

This study evaluates the impact of a participatory forest management (PFM) program on forest structure and cover change in the *Guangua Elala* Natural Forest, Ethiopia. A comparison of current vegetation data with baseline information collected by *Guangua* Woreda agricultural experts was conducted to assess structural and coverage changes. Vegetation data were gathered from 44 plots, each measuring 20 m × 20 m, to capture tree and shrub density, height, and diameter distributions. Additionally, cloud-free Landsat-7 and Landsat-8 images from 2012 and 2021 were analyzed to determine forest cover change over time. Data analysis included computation of vegetation metrics such as stem density, height, and diameter classes, with t-tests applied to compare these variables before and after PFM implementation. Results indicate that the forest displays a healthy, inverted 'J' shape population structure, which signifies robust regeneration with higher densities in lower diameter and height classes. Forest and shrub land cover expanded slightly after the PFM program, with increases of 0.69 % and 0.27 %, respectively. This suggests that PFM positively impacts both the structural health and coverage of the forest by promoting regeneration and conserving existing cover. Overall, this study concludes that PFM contributes to the stability and improvement of forest ecosystems in the region. Expanding PFM initiatives to neighboring forests could further enhance forest conservation and provide sustainable benefits to local communities. This research underscores the effectiveness of participatory approaches in managing forest resources for both ecological and social benefits.

Keywords: Participatory Forest Management (PFM), Forest Structure, Forest Cover Change, Guangua Elala Natural Forest, Land Use Land Cover (LULC) Change, Community-based Forest Management, Ethiopia

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INTRODUCTION

The structural characteristics of species population patterns (SPP) have been instrumental in understanding the ecological niches of various species, detecting spatial heterogeneity, and studying the temporal dynamics and regeneration patterns of understory vegetation (Gairola *et al*., 2014). SPP is defined as the arrangement of individuals within a population across arbitrarily defined diameter height classes (Afua, 2011). Analyzing stand structure is key to understanding forest ecosystems and biodiversity (Su *et al*., 2010), and assessing species composition, structure, and regeneration status is essential for the effective conservation and management of forest resources (Teketay, 2005). Many forests, particularly those with limited disturbances, exhibit a reverse J-shaped diameter class distribution, which suggests a stable population structure (Gebeyehu *et al*., 2019b). For example, studies in the Bonga forest have shown that participatory forest management (PFM) areas have a greater proportion of seedlings and saplings, indicating enhanced reproduction and regeneration compared to non-PFM areas (Gobeze *et al*., 2009). Similarly, research in the Komto forest highlighted a population structure with a positively skewed distribution (inverted J-curve), suggesting high regeneration due to effective management practices (Gurmessa *et al*., 2012).

High-resolution remote sensing data have become valuable for forest cover mapping and monitoring, playing a central role in sustainable forest management over the past two decades (Badesso *et al*., 2020; Hishe *et al*., 2021). In Ethiopia, forest cover change studies have focused on deforestation, afforestation, agricultural expansion, and natural forest degradation (Alemayehu, 2015). Historical records indicate that forest coverage has drastically declined—from approximately 30 percent in the late 19th century to a mere 3.56 percent, with an annual deforestation rate estimated at 140,000 hectares (Bessie *et al*., 2016). Various studies underscore that agricultural expansion and land-use changes have led to the extensive loss of natural vegetation, including forests and shrublands (Badesso et al., 2020; Berhanu *et al*., 1998; Berhane, 2007; Gete & Hurni, 2001). For instance, the dense forest area in Duguna Fango, Southern Ethiopia, decreased from 5,966.46 hectares in 2000 to 1,857.51 hectares in 2018, with over 4,100 hectares converted to other land uses (Badesso *et al*., 2020). Conversely, under PFM, forest areas in Ethiopia have shown a positive trend; forest cover in PFM areas increased by 1.5 % in two years, while government-managed forests nearby decreased by 3 % due to illegal logging and deforestation (Takahashi & Todo, 2012).

In Kenya, forest cover under PFM decreased at an annual rate of 0.4 % between1985–2002 and 0.2 % from 2002–2015, highlighting challenges in sustaining conservation efforts (Kimutai & Watanabe, 2016). Changes in forest cover, especially in response to population growth, over-cultivation, and overgrazing, have been prevalent in Ethiopia, with demands on land and natural resources challenging sustainable management practices (Badesso *et al*., 2020; Alemayehu, 2015). However, in the Western Highlands of Ethiopia, forest loss has slowed due to growing awareness of ecosystem services and an expansion of plantation forestry, primarily Eucalyptus and *Acacia species* (Alemneh *et al*., 2019).

Monitoring forest cover and assessing its changes are essential for evaluating the impacts of management strategies. Satellite remote sensing has proven effective in mapping land-cover changes over time, offering insights into forest-cover dynamics (Kimutai & Watanabe, 2016). This study will assess the impacts of PFM on forest conditions, with a particular focus on woody species structure and forest cover changes, by comparing forest conditions before (BPFM) and after (APFM) the introduction of PFM in Guangua Elala, Awi Zone, northwestern Ethiopia.

MATERIALS AND METHODS

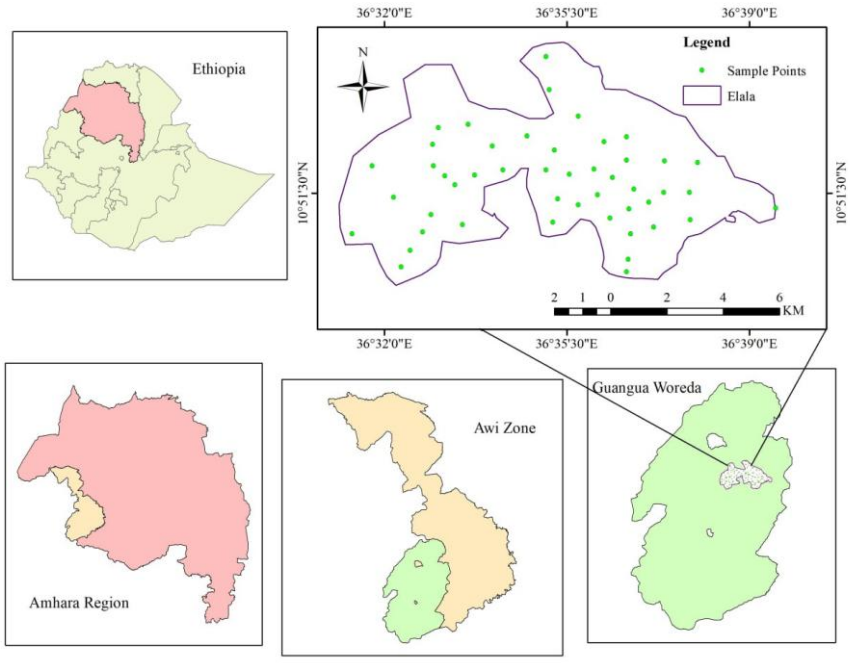
Description of the Study Area

The study was conducted in the Guangu Elala natural forest, located in the Awi Zone of the Amhara National Regional State, northwestern Ethiopia. The site spans 4,494 hectares and is geographically positioned between latitudes 10°48' N and 10°54' N, and longitudes 36°33' E and 36°39' E. The altitude ranges from 1,799 to 2,284 meters above sea level. The nearest major town, Chagni, is situated approximately 16 km from the forest.

Guangu Elala lies within the Weyna Dega agro-climatic zone, characterized by average temperatures ranging from 22°C to 32°C and an annual rainfall of 1,300 to 1,800 mm (Berhanu, 2017). The area's topography varies from mild to steep slopes, including river valleys, hills, and small to medium-sized mountains. About 60 % of the area has slopes ranging from 0 to 25 %, while steeper slopes above 25 % account for the remainder. Flatlands and steep slopes make up approximately 7 % of the area. Numerous perennial rivers and small streams traverse the district, contributing to its hydrological diversity (Gebeyehu *et al*., 2019b).

The soil in the study area is primarily derived from volcanic parent material. It is predominantly reddish-brown, well-drained, and varies from medium to heavy in texture. This soil composition supports diverse vegetation and plays a crucial role in the forest's ecology.

Fig. 1: Location map of the study area.



The study area is characterized by diverse geological formations, primarily composed of Precambrian rocks, along with late Tertiary volcanic formations in certain areas. Soils in this region are classified into five main textural classes, predominantly clay and clay loam, with

smaller areas classified as silty clay loam, silt loam, or sandy clay loam (Gebeyehu *et al*., 2019a).

The natural vegetation faces considerable pressure due to rapid population growth over recent decades. Many indigenous tree species have been cleared for agriculture, fuelwood, construction, and charcoal production (Gebeyehu *et al*., 2019b). Eucalyptus plantations are common, often planted around homes, farmlands, and various other locations, including slopes, stream banks, and even productive agricultural land (Berhanu, 2017).

The region supports diverse plant species, including *Cordia africana, Albizia gummifera, Croton macrostachyus, Ficus vasta, Ficus sur, Acacia abyssinica, Prunus africana, Rothmannia urcelliformis, Vepris dainellii, Erythrococca trichogyne, Vernonia amygdalina, Bersama abyssinica,* and *Ficus thoningi*. The predominant vegetation type is Dry Evergreen Afromontane Forest. The local economy is heavily based on mixed farming, primarily rain-fed agriculture, with limited conventional irrigation systems in place.

Participatory Forest Management (PFM) Project

The Guangua Elala Participatory Forest Management (PFM) project was initiated in 2012 by GIZ *Deutsche Gesellschaft für Internationale Zusammenarbeit* (German Society for International Cooperation) in partnership with the Amhara Regional Agriculture Office and continued until 2021. The project area covered approximately 6,949.53 hectares across four rural kebeles, of which 4,484 hectares constituted the actual forest area under management. Within this landscape, four forest user groups were established, composed of local community members who were formally mandated to manage forest resources sustainably. These responsibilities were granted through co-management agreements signed with the government, as part of the Participatory Forest Management (PFM) framework. Prior to the introduction of PFM, forest governance in the area was largely centralized, with limited local involvement and weak enforcement mechanisms. This top-down management approach contributed to widespread degradation due to unregulated exploitation, encroachment, and resource overuse.

Through the introduction of PFM, local communities were empowered both institutionally and legally to take ownership of forest stewardship. Forest boundaries were demarcated and internal zoning was established to distinguish between conservation areas, production zones, and regeneration blocks. Locally developed forest bylaws and management plans were prepared in consultation with stakeholders. Capacity building activities were carried out to train forest user groups in sustainable harvesting practices, fire prevention, enrichment planting, and forest monitoring techniques. GIZ also provided technical and financial support during the project's early years, covering essential transactional costs and facilitating institutional development.

The project contributed significantly to ecological and socio-economic improvements. Natural regeneration improved, seedling and sapling densities increased, and the structural integrity of the forest showed signs of recovery. In addition to ecological benefits, the PFM project introduced alternative livelihood options, including apiculture, agroforestry, and the promotion of energy-saving technologies such as improved cook stoves. These interventions reduced pressure on the forest and helped diversify community income sources. As a result, the forest condition improved visibly over the years, and community commitment to forest conservation strengthened.

Sampling Design and Data Collection for Forest Structure

Various field equipment was employed throughout the data collection process. Diameter and height measurements of trees were taken using calipers, measuring tapes, and Suunto

Clinometer. A reconnaissance survey was initially conducted to identify vegetation types and determine representative sampling sites. Following this survey, a systematic sampling design with a random start was used to collect vegetation data. A total of 44 sample plots, representing 10 % of the baseline survey plots, were selected.

The first plot was positioned randomly, with subsequent plots systematically established according to GPS coordinates recorded during the baseline survey. Within each 20 m × 20 m plot, all trees and shrubs with a diameter at breast height (DBH, measured at 1.3 meters above ground level) of ≥ 2 cm were measured using a caliper. For trees that branched at breast height, diameters were measured separately for each branch and then averaged. Trees and shrubs with multiple stems or forks below 1.3 meters were treated as single individuals according to the method by Ayanaw & Dalle (2018). Each main plot included all woody plant species, while subplots measuring 10 m × 10 m for saplings and 5 m × 5 m for seedlings were established in two opposite corners of the main plot. This sampling method was designed to align with the baseline data collection technique previously used at the study site.

Data Sources and Collection Methods for Land Use and Land Cover (LULC)

To analyze land use and land cover (LULC) changes in the Elala forest, two multispectral satellite images were obtained for 2012 and 2021. Cloud-free images from Landsat-7 ETM+ (2012) and Landsat-8 OLI (2021), covering the study area (Path/Row 170/53), were freely downloaded from the USGS website (http://earth explorer.usgs.gov/)Training samples for image classification and accuracy assessment were collected using a Garmin 74 GPS in the field. Google Earth was also utilized for land use classification and accuracy assessment for the 2012 dataset.

Table 1: Satellite data specifications

Data	Year of acquisition	No of bands	Resolution	Path/row
Landsat 7ETM+	01/27/2012	8	30m	170/53
Landsat 8	01/19/2021	11	30m	170/53

Data Analysis

The data analysis involved computing vegetation variables such as stem density (trees per hectare) and diameter distribution for both BPFM (before PFM) and APFM (after PFM) plots, to examine the impacts of Participatory Forest Management (PFM) on forest structure. The analysis was conducted using SPSS software.

The study of forest structure, defined as the frequency distribution of individuals in arbitrarily defined DBH (Diameter at Breast Height) or height classes, was carried out for woody species based on commonly used DBH and height classes in Ethiopia (Ayanaw & Dalle, 2018; Berhanu *et al*., 2017). Height, a straightforward parameter, was measured directly using a mechanical hypsometer called Suunto Clinometer. The DBH was categorized into nine classes with 10 cm intervals, and height into nine classes with 5 m intervals. The DBH classes were as follows: 2.0 - 10, 10.1 – 20, 20.1 – 30, 30.1 – 40, 40.1 – 50, 50.1 – 60, 60.1 – 70, 70.1 – 80, and > 80.1 cm. The height classes were ≤7.5, 7.6 – 12.5, 12.6 – 17.5, 17.6 – 22.5, 22.6 – 27.5, 27.6 – 32.5, 32.6 – 37.5, 37.6 – 42.5, and > 42.6 m, to represent the population structure in each management system.

Each tree's structure responds uniquely to management factors, so variations in floristic composition and structure are continuous when vegetation is considered with environmental variables. The collected data were organized using Excel software, and diameter and height were categorized into classes and intervals after field records were collected. To display the population structure, the density of individuals falling into the DBH or height classes was summed, and bar graphs were produced using SPSS software. The variation in diameter distribution for specific size classes in each forest was shown using bar graphs. Population structure is a crucial indicator of forest reproduction and recruitment health (Schulz *et al*., 2009).

Satellite Images Pre-processing

Before Land Use Land Cover (LULC) classification, it is essential to pre-process distorted and degraded images to ensure high-quality results and accurate representation of the actual ground scene. The Landsat images used for this study were pre-processed using ERDAS Imagine version 2012 software. The pre-processing activities included atmospheric and radiometric correction to minimize the effects of clouds and the sun's elevation angle in satellite images taken during different periods and from different sensors. Afterward, single-band images were combined (layer stacking) to create multi-band composite images. Image enhancement operations, such as contrast adjustment, edge enhancement, de-striping for scan line errors, and color composites, were employed to improve the interpretability of the image data. Finally, the area of interest (AOI), which covered the study area (Elala forest), was extracted using the vector polygon layer and the subset tool available in ERDAS IMAGINE software.

LULC Classification

Image classification is a critical remote sensing technique used to catalog all pixels in an image or raw remotely sensed data into a finite number of individual LULC classes to generate useful thematic maps and information. The image classification process is typically carried out by assigning different spectral signatures from the dataset to several classes based on reflectance attributes of the diverse types of LULC. For this study, a classification scheme was developed following Anderson *et al*. (1976) based on prior knowledge of the study area, reconnaissance field surveys, and information from previous studies. Accordingly, four LULC classes forest land, shrub land, grazing land, and cultivated land were defined to form the adopted general LULC classification scheme for this study, as shown in Table 2.

Table 2: The land uses land cover class and their descriptions, Source (Mesfin et al., 2020)

LULC class	Description
Forest land	Land covered by vegetative communities comprised principally trees of the same or different species which are capable of producing timber or other wood products
Shrub land	A land covered by vegetation that is dominated by shrubs or short-statured trees, generally < 5 m tall, often in a single canopy layer.
Grazing land	Predominantly covered by small grasses and herbaceous plant communities with a small proportion of shrubs and trees
Cultivated land	Includes annual rain-fed and irrigated cultivation. Lands are mostly used for cereal production in subsistence farming and mixed with bushes.

Image Classification Procedure

A computer-aided digital image classification procedure was employed to classify satellite images and generate thematic Land Use Land Cover (LULC) maps of the study area based on known features on the ground. For this purpose, training signatures were collected for each LULC class from the field and Google Earth (for the 2021 image). Ground-truthing points collected from the field were used to validate the results of the 2021 image classification. A supervised classification method based on the Maximum Likelihood Classifier (MLC) was applied to classify the Landsat image. A total of four LULC classes were identified in the study area.

The thematic layer of the classified LULC images for the two periods (2012 and 2021) was validated using data collected from the field and high-resolution images such as Google Earth. The classification accuracy was calculated in terms of overall accuracy and Kappa statistics. Change statistics were computed by comparing values of the area in one data set with the corresponding values of the second data set for each period. The percentage change to determine the trend of change was calculated by dividing observed change by the sum of changes and multiplying by 100(1), and the rate of change in percent between two time periods is computed using the approach of Puyravaud (2003), the formula (2),

$$\text{Percentage of change (trend)} = \frac{x-y}{y} X\ 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

where: x = recent (later) area of LULC

y = previous (initial) area of LULC

$$\text{Rate of change (\%)} = \frac{\text{Observed Changes between two Maps}}{\text{Time Intervals}} X\ 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2),}$$

RESULT AND DISCUSSION

Population Structure of Woody Species

Diameter and Height Class Distribution

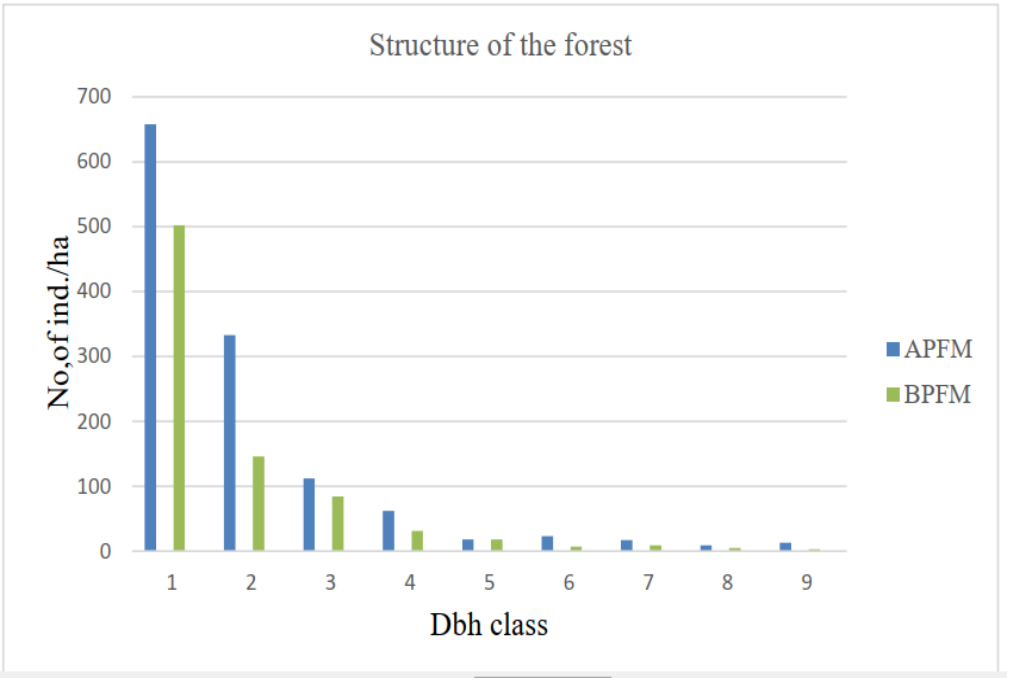
The population structure of the entire woody species showed higher stem densities in the lower diameter and height classes, with progressively declining stem densities as the diameter and height increased at both APFM and BPFM systems. The distribution of tree/shrub species in different DBH and height size classes was analyzed.

The number of individuals in the DBH class of 2.0 – 10 cm was found to be 373.86 ha^{-1} (52.85 %) for forest APFM and 285.23 ha^{-1} (62.44 %) for forest BPFM. The density of individual plant species with DBH 10.1–20 cm was 189.20 ha^{-1} (26.75 %) for forests after PFM and 82.37 ha^{-1} (18.03 %) for forests before PFM. In the DBH class of 20.1-30 cm, the densities of individual species were 63.63 ha^{-1} (8.99 %) for forests after PFM and 47.70 ha^{-1} (10.45 %) for forests before PFM. The densities of individuals with DBH between 30.1-40 cm were 35.23 ha^{-1} (4.98 %) after PFM and 17.61 ha^{-1} before PFM. For DBH greater than 40 cm, densities were 45.46 ha^{-1} (6.43 %) and 23.86 ha^{-1} (5.22 %) after and before PFM, respectively. These results were statistically significant ($p < .05$) (Table 5).

In forests after PFM, the highest DBH was recorded for *Apodytes dimidiata* (151 cm), followed by *Albizia gummifera* (115 cm) and *Prunus africana* (97 cm). In forests, BPFM, *Apodytes dimidiata* recorded the highest DBH (123 cm), followed by *Ficus vasta* (89.3 cm) and *Albizia gummifera* (87.5 cm). As shown in Fig. (2), the DBH distribution of tree/shrub species in both forests reveals the highest density of individuals at lower DBH classes, with

a sharp decline at higher diameter classes. This distribution curve demonstrates a regular inverted J-shaped distribution of individuals across the DBH classes.

Fig. 2: DBH classes versus the number of individuals per hectare in (BPFM) and (APFM) forests

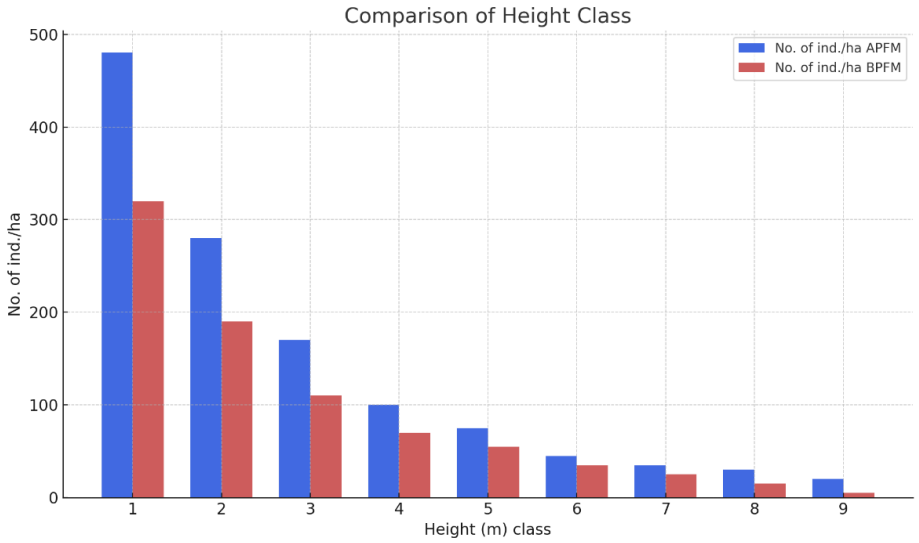


Note: *Diameter class were measured in centimeters (cm), and where: BFPM = Before Participatory Forest Management, APFM =After Participatory, Forest Management

*Class 1 = 2.0–10 cm, Class 2 = 10.1–20 cm, Class 3 = 20.1–30 cm, Class 4 = 30.1–40 cm, Class 5 = 40.1–50 cm, Class 6 = 50.1–60 cm, Class 7 = 60.1–70 cm, Class 8 = 70.1–80 cm, and Class 9 = > 80 cm

The height class distribution exhibited a pattern similar to that of the DBH classes. The majority of individuals were concentrated in the lower height classes (< 12.5 m) in both the APFM and BPFM systems (Fig. 3). Seven species *Prunus africana*, *Celtis africana*, *Albizia gummifera*, *Ekebergia capensis*, *Albizia schimperiana*, *Apodytes dimidiata*, and *Celtis africana* had individuals reaching heights above 44 meters, with *Prunus africana* being the tallest at 51 meters in the APFM forest site. Similarly, in the BPFM forest site, four species *Apodytes dimidiata*, *Prunus africana*, *Albizia gummifera*, and *Ficus thonningi* had individuals taller than 40 meters, with *Apodytes dimidiata* being the tallest at 45 meters. This distribution highlights the variability in tree heights, with both management systems supporting the growth of taller trees, particularly in the APFM site, where more mature individuals were observed.

Fig. 3: Height classes versus the number of individuals per hectare in both systems



Note: * Height classes were measured in meters (m), and where: BFPM = Before Participatory Forest Management, APFM =After Participatory, Forest Management.

* Class 1 = <= 7.5 m, Class 2 = 7.6 –12.5 m, Class 3 = 12.6 –17.5 m, Class 4 = 17.6 – 22.5 m, Class 5 = 22.6 – 27.5m, Class 6 = 27.6 – 32.5 m, Class 7 = 32.6 –37.5 m, Class 8 = 37.6 – 42.5m, and Class 9 = 42.6 m

The tree height classes in the Guangua Elala forest were categorized into five distinct structural patterns, reflecting variations in species density across different height class distributions in both forest management systems Fig. (4). These patterns provide insights into the growth dynamics and regeneration strategies of species within the forest.

The first structural pattern, which followed an inverted J shape, displayed the highest density of individuals in the lower height classes, with a gradual decline in density as height increased. Species such as *Albizia gummifera*, *Celtis africana*, *Croton macrostachyus*, *Albizia schimperiana*, *Millettia ferugenia*, and *Bersama abyssinica* exhibited this pattern, which is commonly associated with forest stands undergoing regeneration, where younger individuals dominate and mature individuals are fewer.

The second pattern was unimodal or bell-shaped, characterized by a higher proportion of individuals in the intermediate height classes. Both the lower and higher height classes exhibited a decrease in density. Species such as *Ficus sur*, *Ficus sycomorus*, and *Prunus africana* followed this pattern, often observed in forests with a well-established canopy and active regeneration, where tree growth reaches an optimal point in the middle height range before tapering off.

The third pattern, representing an irregular inverted-J shape, was observed in *Apodytes dimidiate*, where individuals showed a more erratic distribution across height classes, suggesting a less predictable or stable regeneration process for this species.

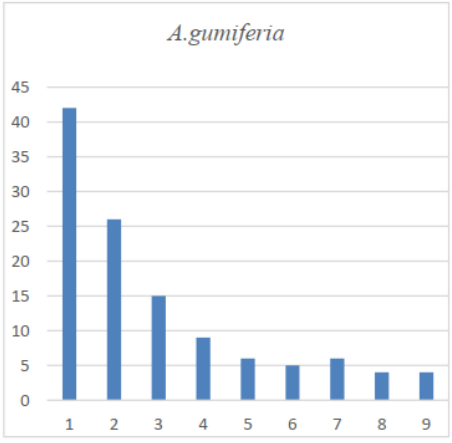
The fourth pattern, a broken inverted J shape, was marked by the presence of individuals exclusively in the lower height classes, with no individuals in intermediate or higher classes. Species like *Crateva adonsonia*, *Dombeya torrida*, *Ehretia cymossa*, *Olea capensis* subsp. *macrocarpa*, *Rytigynia neglecta*, *Rothmannia urcelliformis*, *Vepris dainellii*, and *Zehneria scabra* followed this pattern. This distribution suggests a high degree of juvenile presence

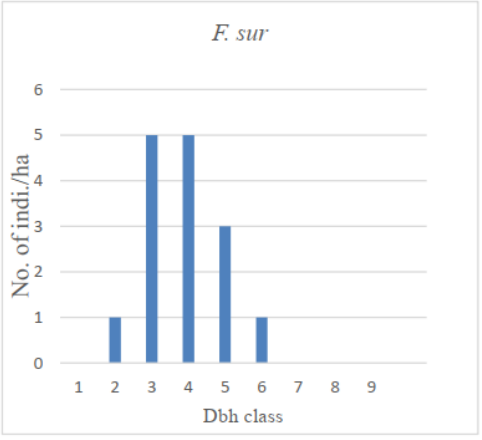
and limited growth or establishment in higher classes, possibly due to environmental constraints or competition.

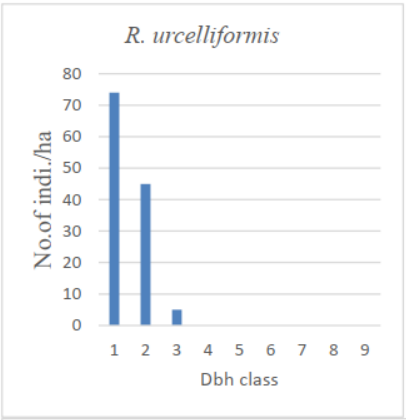
The fifth pattern lacked individuals in the lower and intermediate height classes but contained some mature individuals in the highest height classes. Species such as *Ekebergia capensis*, *Ficus vasta*, *Podocarpus falcatus*, and *Pouteria altissima* exhibited this pattern, which may indicate slow regeneration or the dominance of older, mature trees with limited recruitment in the understory.

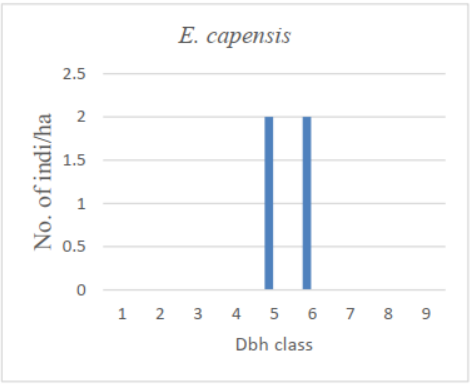
These structural patterns are consistent with findings from other studies. For instance, Berhanu *et al*. (2017) and Taju (2018) identified similar patterns, such as inverted-J, bell-shaped, and interrupted bell-shaped, across different natural forests. Additionally, a study of evergreen Afromontane forest patches in the Awi zone reported five distinct structural patterns, including inverted-J, bell-shaped, J-shaped, broken inverted-J, and an absence of individuals in lower and intermediate height classes (Berhanu, 2017). These patterns are indicative of the ecological dynamics and regeneration strategies of species within the Guangua Elala forest, providing valuable insights into forest structure and management.

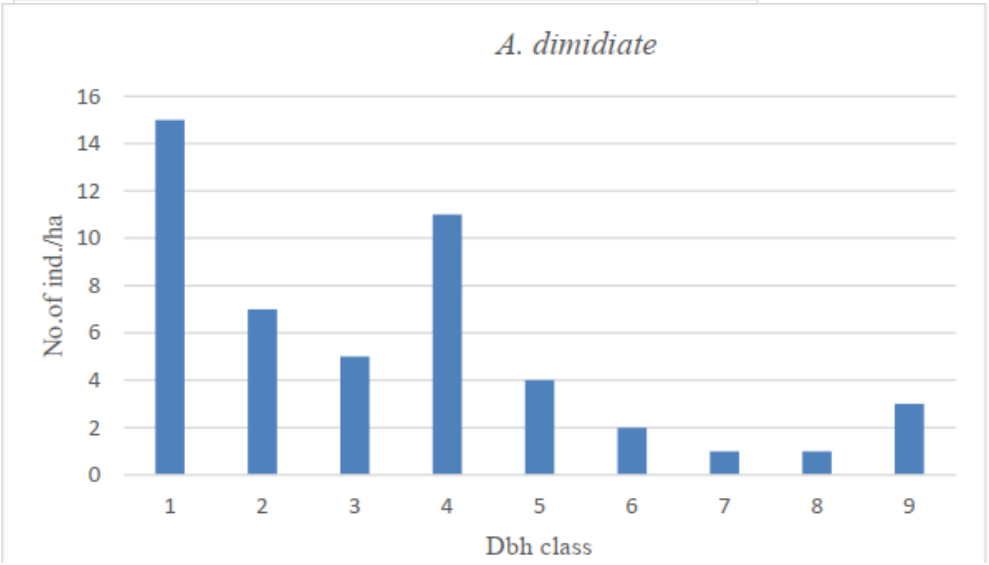
Fig. 4: Representative population structure patterns of each tree species in the study area











Note: *Diameter was measured in centimeters (cm), and where: and, *Class 1 = 2.0–10 cm, Class 2 = 10.1–20 cm, Class 3 = 20.1–30 cm, Class 4 = 30.1–40 cm, Class 5 = 40.1–50 cm, Class 6 = 50.1–60 cm, Class 7 = 60.1–70 cm, Class 8 = 70.1–80 cm, and Class 9 = > 80 cm

Vertical Structure of the Forest

The vertical structure of the Guangua Elala forest was classified into three distinct layers: lower, middle, and upper stories, following the International Union for Forest Research Organization (IUFRO) classification system, which is based on the mean height of canopy trees (Lampercht, 1989). This stratification allows for a better understanding of the distribution and growth patterns of woody species across different height levels within the forest.

The upper story consists of woody species that reach heights above 2/3 of the tallest trees in the forest, with the tallest tree in this study reaching 51 meters. Therefore, the upper story was defined as species greater than 34 meters in height. This layer contained 17 individuals per hectare (ha-1) from seven tree species, including *Albizia gummifera*, *Albizia schimperiana*, *Clematis longicauda*, *Ficus thonningi*, *Prunus africana*, *Pouteria altissima*, and *Apodytes dimidiate*. These species are typically dominant in the canopy and play key roles in maintaining forest structure and biodiversity at the highest levels.

The middle story includes individuals that are between 1/3 and 2/3 of the height of the tallest trees, i.e., those reaching between 17 meters and 33.9 meters. The middle story in this forest harbored 159 individuals per hectare (ha-1) from 28 woody species. Common species in this layer included *Rothmannia urcelliformis*, *Schefflera abyssinica*, *Celtis africana*, *Croton macrostachyus*, *Acacia abyssinica*, *Ficus sur*, *Millettia ferugenia*, *Cordia africana*, *Albizia gummifera*, and *Bersama abyssinica*. The middle story is typically composed of species that play an important role in forest regeneration and canopies, offering shelter and resources for undergrowth species.

The lower story consists of individuals with heights below 1/3 of the tallest trees or less than 17 meters. This layer had the highest density, with 549 individuals per hectare (ha-1) representing 73 different species. Dominant species in this layer included *Maytenus obscura*, *Salix mucronata*, *Rosa abyssinica*, *Allophylus abyssinicus*, *Acanthus eminens*, *Ehretia cymosa* Thonn., *Dombeya rotundifolia*, *Clausena anisate*, *Crateva adonsonia*, *Mimusops kummel* A. DC, and *Nuxia congesta* (BPFM system). The lower story supports the most abundant and diverse plant species, contributing to the forest's overall biodiversity and ecological resilience.

In the APFM system, the upper story included 85 individuals per hectare (ha-1) from 11 species, with *Albizia gummifera*, *Prunus africana*, *Apodytes dimidiate*, *Ekebergia capensis*, *Pouteria altissima*, *Celtis africana*, *Albizia schimperiana*, *Ficus sur*, and *Ficus thonningi* being the most common species. The middle story in this system had 230 individuals per hectare (ha-1) from 41 species, with prominent species such as *Vepris dainellii*, *Bersama abyssinica*, *Ficus sycomorus*, *Salix mucronata*, *Syzygium guineensis*, *Croton macrostachyus*, *Cordia africana*, *Rytigynia neglecta*, *Rothmannia urcelliformis, Olea europaea*, *Ehretia cymosa* Thonn., *Millettia ferugenia*, and *Ficus sur*. The lower story of the APFM system showed a higher density, with 917 individuals per hectare (ha-1) of 78 species, including *Vepris nobilis*, *Nuxia congesta*, *Rytigynia neglecta*, *Euclea racemosa*, *Steganotaenia araliacea*, *Dombeya torrida*, *Ehretia cymosa* Thonn., *Grewia ferruginea*, *Calpurnia aurea*, *Erythrococca trichogyne*, *Crateva adonsonia*, *Maytenus arbutifolia*, *Justicia schimperiana*, and *Vernonia myriantha*.

The diameter and height class distribution of woody species at the study site reflected an inverted J-shape, indicative of a normal population structure. Both the diameter at breast height (DBH) and height class distributions were well-represented across all categories, with the highest density concentrated in the smaller DBH and height classes (below 10 cm and 7.5 meters, respectively). This pattern is typical of forests experiencing intermediate disturbance, where regeneration is encouraged, particularly for light-demanding species. This structure is consistent with findings from Gobeze *et al*. (2009), which showed that forest management practices, such as those in PFM systems, promote healthier recruitment and regeneration compared to non-PFM forests.

Additionally, similar studies, including Atsbha *et al*. (2019), have found that the highest proportion of individuals in diameter classes lie between the first and second categories, which is often indicative of selective removal of larger trees for local use, such as for fuelwood or construction. In contrast, the vegetation structure of the PFM forest showed a healthier distribution across diameter classes, thanks to regulated access and community-managed development (Gobeze *et al*., 2009). Studies such as those by Getaneh (2007) and Tefera *et al*. (2005) also report selective removal of trees with DBH >30 cm for construction and charcoal production. These findings suggest that the PFM system, with its regulation of tree cutting and forest management practices, supports a more stable forest structure, better suited to long-term ecological health and regeneration.

Forest Cover Change

The land use/cover maps for the periods 2012 and 2021, presented in Figure 5 were generated to assess changes in forest cover over time. The overall map accuracy for both images was found to be 81 %, which was calculated using an error/confusion matrix, a widely used approach for evaluating per-pixel classification (Lu & Weng, 2007). This method compares the classified data to ground truth data to assess the accuracy of the classification process.

Additionally, Kappa statistics were computed for each classified map to measure the level of agreement between the classification results and the ground truth. The Kappa statistic for the 2012 land use/cover map was 0.81, while the 2021 map had a Kappa value of 0.83. Both values indicate a reasonably good level of accuracy and are considered acceptable for land use/cover classification. These results are summarized in Tables 3 and 4, where the Kappa values reflect the agreement between the classified map and the reference data, providing confidence in the reliability of the results.

Table 3: Confusion Matrix for the LULC Map of 2012

			Reference Data			
Data class	**Forest**	**Shrub land**	**Grazing land**	**Cultivated land**	**Raw total**	**User accuracy**
Forest	22	2	1	0	25	88.0
Shrub land	2	7	1	1	11	63.6
Grazing land	1	2	25	6	34	73.5
Cultivated land	0	0	2	23	25	92.0
Column total	25	11	29	30	95	
Producer accuracy	**88.0**	**63.6**	**86.2**	**76.7**		
			Overall accuracy			**0.81**

Table 4: Confusion Matrix for the LULC Map of 2021

			Reference Data			
Data class	**Forest**	**Shrub land**	**Grazing land**	**Cultivated land**	**Raw total**	**User accuracy**
Forest	28	3	0	0	31	88.0
Shrub land	1	21	3	2	27	63.6
Grazing land	3	1	23	5	32	73.5
Cultivated land	0	1	1	25	27	92.0
Column total	32	26	27	32	117	
Producer accuracy	**87.5**	**80.8**	**85.2**	**78.1**		
			Overall accuracy			**0.83**

The percentage area of the four land use/cover (LULC) classes in 2012 and 2021 revealed notable trends in forest and land use dynamics over the study period. The results of the image classification showed that the total land area of the Elala forest was around 6949.53 hectares (ha). Individual class area and change statistics for 2012 and 2021 are summarized in Table 5. In 2012, forest areas constituted the largest share of the total land use categories, representing 55.54 % (3,849 ha) of the total area. By 2021, forest cover slightly increased to 56.5 % (3,926 ha), showing a gain of 0.96 % (67.04 ha) over the nine-year period Table 5. This increase in forested areas suggests some degree of recovery or expansion within the forest system.

Table 5: LULC categories and their changes in the Guangua Elala forest

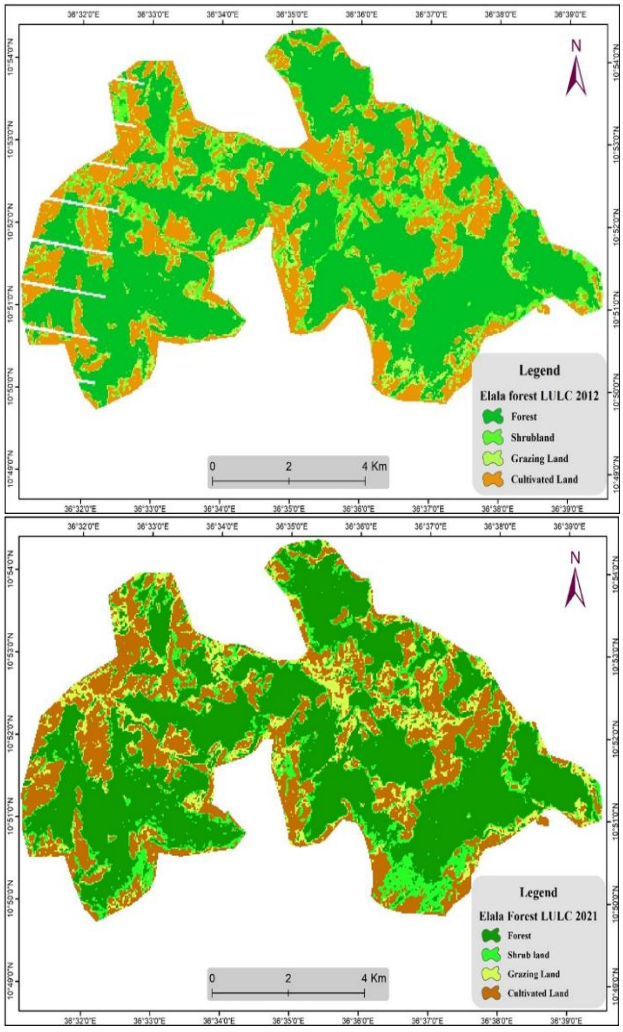
No	Land use and land cover categories	2012		2021		Rate of change 2012 to 2021
		Area (ha)	Area (%)	Area (ha)	Area (%)	
1	Forest	3859.56	55.54	3926.60	56.50	0.02
2	Shrub land	548.28	7.89	566.95	8.16	0.03
3	Grazing land	716.58	10.31	679.36	9.78	-0.05
4	Cultivated land	1825.11	26.26	1776.62	25.56	-0.03
	Total	6949.53	100.00	6949.53	100	

Shrub land, another important land use category, also showed a slight increase during this period. The area covered by shrubland rose from 7.89 % (548.28 ha) in 2012 to 8.16 % (566.95 ha) in 2021. This indicates a modest expansion of shrubland, which could be attributed to factors such as natural succession, abandonment of previously cultivated lands, or changes in land management practices.

In contrast, both cultivated and grazing areas experienced a decline during the study period. Cultivated land, which made up 26.26 % (1,825.11 ha) of the total area in 2012, decreased to 25.26 % (1,776.62 ha) by 2021. While this decline represents a reduction in the extent of cultivated areas, it was relatively small, suggesting that agricultural land use remained dominant but with a slight contraction. Grazing land also showed a small reduction, dropping from 10.31 % (716.58 ha) in 2012 to 9.78 % (679.36 ha) in 2021. This reduction in grazing land, though minor, may reflect changes in livestock management practices, shifting grazing patterns, or other environmental factors.

Overall, the trends indicate that forest reduction in the study area was primarily driven by the expansion of subsistence agriculture and grazing. These activities remain the leading causes of land conversion and forest loss, especially in the context of the BPFM system. The relatively stable or slightly expanding forest areas, coupled with the increases in shrubland, suggest some positive changes in land use management or shifts in land cover dynamics, but subsistence farming and grazing pressures continue to pose significant challenges to forest conservation.

Fig. 5: LULC map of Elala forest in 2012 and 2021 respectively



The total area of forest and shrubland in the APFM system was slightly higher compared to the period before the implementation of Participatory Forest Management (PFM). In contrast, both grazing land and cultivated areas showed a decline during the APFM period. This shift suggests that PFM can more effectively manage common forest areas compared to private management systems, likely due to the enhanced collaborative management and regulation that PFM encourages. It is important to highlight that PFM has been widely advocated for its ability to increase forest area by improving forest cover through community involvement and sustainable practices.

Similar findings have been reported in other regions. For example, in the Fagita Lekoma district, forest cover increased between 1987 and 2015, which was attributed to the introduction of Acacia decurrens and the expansion of Eucalyptus plantations (Alemayehu, 2015). Takahashi & Todo (2012) also reported an increase in forest cover of 1.5 % over two

years following the establishment of Forest User Groups (FUGs) in Ethiopian forest areas, demonstrating the positive impacts of community-based forest management.

In a similar context, evidence from an aid-funded project in southern Ethiopia (Kimutai & Watanabe, 2016) revealed a significant reduction in the rate of forest cover loss in the Lembus Forest of Kenya, from 0.4 % to 0.2 % annually. This decline in loss was attributed to reforestation programs led by FUGs, further supporting the idea that PFM can mitigate deforestation. However, in other regions, the trend has been less positive. For instance, between 2000 and 2018, cultivated lands in the Duguna Fango district increased at a mean annual rate of 366.96 ha/year, while dense forest areas declined at a rate of -228.27 ha/year. This loss of forest cover was primarily due to the conversion of natural forests for farm plots, settlement expansion, and the collection of construction materials (Badesso *et al*., 2020).

Similarly, Mesfin *et al*. (2020) reported a dramatic decline in woodland cover in the Central Rift Valley of Ethiopia, from 92.4 % to 42.4 % between 1986 and 2013. Solomon *et al*. (2018) also highlighted that dense and open forests in the Wujig Mahgo Waren Forest of Northern Ethiopia decreased by 10.4 % and 9.8 %, respectively, between 2000 and 2016. The main drivers of this decline included fuelwood collection, agricultural land expansion, population growth, free grazing, logging for income generation, and drought.

These studies underscore the complex dynamics of forest management and land use changes, highlighting the potential benefits of PFM in promoting forest conservation and the challenges posed by agricultural expansion and other anthropogenic pressures.

CONCLUSION AND RECOMMENDATIONS

Conclusion

This study shows that Participatory Forest Management (PFM) can have a positive impact on forest conservation. Under PFM, forest and shrubland areas have slightly increased, while grazing and cultivated lands have declined, suggesting that PFM helps manage forest resources more effectively than private systems. The increase in forest cover, along with the expansion of shrubland, points to the success of community-led efforts in promoting sustainable land use. However, challenges remain, as agricultural expansion and settlement growth continue to threaten forest areas, particularly in districts like Duguna Fango. Similar studies in other regions also highlight the benefits of PFM in slowing forest loss, such as in Ethiopia and Kenya, where PFM and reforestation efforts have led to positive changes in forest cover. Still, the ongoing pressures from agriculture and population growth, as seen in areas like the Central Rift Valley, remind us that forest conservation requires addressing multiple drivers of land use change.

Recommendations

To enhance forest conservation under Participatory Forest Management (PFM), it is essential to empower local communities through training and active participation. Promoting agroforestry and addressing external drivers of deforestation, such as population growth and urban expansion, through integrated land-use planning will help to balance farming needs with forest protection. These efforts can improve PFM effectiveness and support long-term environmental and socio-economic resilience.

CONFLICT OF INTEREST

The authors declare that they have no competing interests.

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