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Research Article

Estimating soil erosion and identifying erosion hotspots for conservation priority in Bidara watershed, upper catchment of Lake Ziway, central Rift Valley of Ethiopia

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Article Info

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Abstract

Soil erosion poses a global challenge on the environment and agriculture. Understanding soil loss in a specific watershed could assist in planning effective conservation measures. The objective of this study was to estimate annual soil loss, identify erosion hot-spots, and prioritize management strategies using Revised Universal Soil Loss Equation with Geographic Information System and Remote Sensing. Meteorology record (rainfall), lab analysis of soil properties, digital elevation model analysis of topography, normalized difference vegetation index-based land cover analysis, and field observation of conservation practices were inputs of the model. In the watershed, the annual soil loss ranged from 0–1129.47 t ha-1 yr-1, surpassing the tolerable limit. Approximately 74.6% of the study area exhibited low to moderate soil loss (¡20 t ha-1 yr-1), while 25.4% faced high to extremely severe erosion (¿20 t ha-1 yr-1). Upstream regions were identified as areas with high soil erosion risk mainly due to cultivation and grazing on steep slopes. The areas with ¿20 t ha-1 yr-1 soil loss require immediate, intensive and integrated soil and water conservation measures including bunds, terraces and tree planting. Implementation of soil and water conservation measures are required to reduce erosion particularly in the highly susceptible southern parts of the watershed. Implementing contour plowing, grass strips and bunds can reduce erosion in areas experiencing low erosion(¡10 ha-1 yr-1). Mapping erosion hotspots provides valuable insights for the development and execution of effective and sustainable conservation plans. Planners and decision makers should prioritize implementation of integrated soil and conservation measures in areas with intolerable erosion.

Keywords: Erosion risk; Hotspot area; Slope; Conservation priority; Land degradation

1 Introduction

Soil erosion by water is among major processes that significantly and negatively affecting soil quality and global food production in recent decades (Hu et al., 2021; Ighodaro et al., 2013; Kim et al., 2005; Pimentel, 2006; Pimentel & Burgess, 2013; Van Oost et al., 2005). Globally, soil loss from cultivated land can vary widely, ranging from zero to exceeding100 t ha-1 yr-1, leading to an annual reduction in crop productivity of 15–30% (Borrelli et al., 2020;

Morgan, 2005). Annual soil erosion increment of 0.22 Mg ha-1 was reported (Hu et al., 2021), showing its severity. Aggravated soil erosion removes nutrient-rich topsoil, declining its nutrient concentration and ecological functioning. Continuous soil erosion can reduce cultivable area due to abandoning low productivity lands and formation of gullies (Morgan, 2005; Mukanov et al., 2019). Approximately 80–85% of agricultural land is estimated to be affected by soil erosion of certain extent, resulting in the annual loss of six million hectares of fertile land due to water erosion and associated degradation processes (Rodrigo-Comino et al., 2018). Global economic activities and land management practices contribute to soil erosion and its impacts. The climate and land use changes are predicted to escalating soil erosion (Borrelli et al., 2020; Eekhout & de Vente, 2022).

Highland areas of Ethiopia are subjected for extensive soil and land cover manipulations due to concentration of the country's agriculture and population. As a result, soil erosion rates exceeding soil formation (about 11 t ha-1 yr-1) were reported in many areas (Ali & Hagos, 2016; Fenta et al., 2024; Hurni et al., 2010; Wolka et al., 2021; Zerihun et al., 2018). A study conducted in Ethiopia reported significant soil loss rates in the highlands land, reaching as high as 170 t ha1 yr1 (Hurni et al., 2010), and 300 t ha1 yr1 (Gadisa & Midega, 2021) . This poses a significant threat to agricultural productivity and land sustainability. Conventional cultivation on sloping lands, inadequate soil and water conservation measures, and excessive vegetation removals are among important human activities that aggravated erosion. soil erosion can increase food insecurity and socio-economic challenges, primarily in rural areas where majority of the nation lives. The severity of erosion expected to vary spatially due to natural topography, land management and rainfall differences. It is crucial to estimate soil loss spatially and assess the extent of soil erosion risk at watershed scale to implement effective erosion control measures.

At watershed scale, soil erosion can be estimated using different models. The Revised Universal Soil Loss Equation (RUSLE) has been widely used soil erosion estimation method in various landscapes, including steep slopes and rugged terrain, and can be applied in GIS interface. Since it developed many years back (Wischmeier & Smith, 1978), this model has been applied in different areas across the world (Borrelli et al., 2020; Eekhout & de Vente, 2022), and in Ethiopian highlands (Ali & Hagos, 2016; Wolka et al., 2015; Zerihun et al., 2018). The model combines rainfall, soil physical properties and organic matter content, topographic characteristics, vegetation cover and conservation practices to estimate annual soil loss ha1 yr1. Models help soil erosion estimation in large areas, which are otherwise expensive and time taking to estimate erosion and to plan conservation measures. Applying models is also important to estimate erosion for areas with limited data availability, which is a common problem in the country.

In Bidara watershed, where this study focuses, soil erosion has not been estimated to assist planning for soil and water conservation at local scale. However, in some other sub-watersheds of Lake Ziway, soil erosion was estimated (Aga et al., 2018; Negasa & Goshime, 2024; Woldesenbet et al., 2020). In the Bidara watershed different initiatives including public campaign invest on watershed-based soil and water conservation activities. There are some signs of soil erosion including gullies and rills in the area. However, soil erosion risk areas are not identified and mapped for conservation planning. Thus, this study aimed: (i) to estimate the mean annual soil loss rate; and (ii) to identify and prioritize hotspot areas that are particularly susceptible to erosion. This study could provide spatial information on areas prone to erosion, enabling better planning and management of the Bidara watershed.

2 Methods and Materials

2.1 Description of the study area

The study was conducted in the upper catchment of Lake Ziway, situated in the central Rift Valley Basin (Figure 1). The study watershed is within Mareqo district, which is located approximately 165 km from Addis Ababa city and 25 km from Ziway town. The Bidara watershed is geographically positioned between 38º 24' 00" E to 38º 36' 00" E longitude and 7º 55' 12" N to 8º 4' 48" N latitude (Figure 1). The annual rainfall in the watershed varies between 700 and 1400 mm, while the mean minimum and maximum temperatures are recorded at 12.8 °C and 28 °C, respectively. The area is situated within a dry, semi-arid lowland.

Bidara watershed covers approximately 3,966.32 ha on a topography characterized by mountains, deep incised valleys, and escarpments on altitudinal range of 1796 to 2059 meters above sea level. The land use consists of cultivated (85%), and grazing (10%) lands. The agricultural land holdings are typically small and degraded. Crop production, including wheat, maize, pepper, barley, and sorghum, is the primary economic activity. Livestock production is also an integral part of the farming activity.

2.2 Data Sources and Collection

The RUSLE model requires inputs for rainfall erosivity, soil erodibility, topography, land cover and conservation practices. Satellite images, observation and laboratory analysis were used to acquire relevant data.

2.2.1 Watershed delineation

To delineate watershed, Digital Elevation Model (DEM) with resolution of 30m*30m was acquired from United States Geological Survey (USGS) Earth Explorer website (https://earthexplorer.usgs.gov/). The watershed was delineated using QGIS 3.16. To ensure accurate watershed delineation, the DEM was processed to fill sinks in areas of internal drainage. This process involved identifying depressions within the DEM and adjusting the elevation values to create a depression-less elevation grid. From the filled DEM, flow direction and flow accumulation maps were generated. In principle, flow direction indicates the path water would take from each cell, while

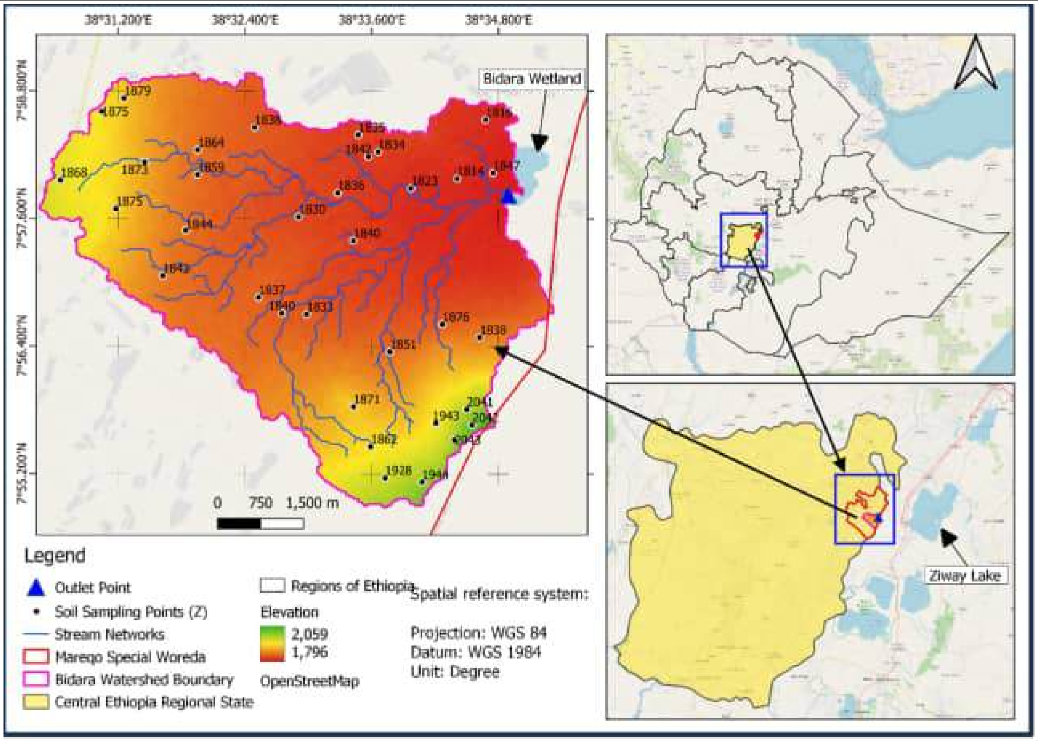

Figure 1: Location map of Bidara Watershed in Ethiopia

flow accumulation represents the accumulated flow from upstream cells. The watershed boundary was delineated based on the filled DEM and the flow accumulation map.

2.2.2 *Rainfall erosivity (R-factor) data*

The rainfall erosivity was estimated using 25 years (1996-2020) records of precipitation at meteorological stations of Ziway, Mareqo/Koshe, Butajra, and Hosana (Table 1). The R-factor, representing rainfall erosivity, was calculated using mean annual rainfall data from those four weather stations. The precipitation data from those stations, which are available meteorology stations near the watershed, were used due to the lack of rainfall stations within the study watershed, and the calculated R-factor values could provide reasonable information on rainfall erosivity in the watershed.

The normal ratio method was followed to estimate the missing rainfall records as described in equation (1). The normal ratio method is applied when the normal annual rainfall from surrounding station exceeds 10% of the considered gauge (Miller & Singh, 1994; Samuel et al., 2014). Since the normal annual rainfall of the meteorological station in the study area exceeded the specified threshold, the missing data were estimated and reconstructed using the normal ratio method. The specific method is given as follows:

$$P_X = \frac{A_x}{M}\left(\frac{P_1}{A_1} + \frac{P_2}{A_2} + \frac{P_3}{A_3} + \cdots + \frac{P_i}{A_i}\right) \quad (1)$$

Where: PX = is normal annual precipitation at station X to be estimated; Ax = is annual precipitation at station X; M = total number of stations (N) other than station X (N-1); and Pi /Ai = ratio of normal annual precipitation to annual precipitation of each station. After filling the missing data that collected from the National Meteorological Agency for stations mentioned above, in this study, Hurni's model for Ethiopia's highland, equation 2 (Hurni, 1985), was applied for estimating R-factor. The mean annual rainfall was interpolated using the IDW interpolation tool in ArcGIS 10.8 to generate continuous rainfall data for each grid cell. The R-value was then derived based on the spatially interpolated mean annual rainfall of the watershed.

$$R = 0.55MAR - 4.7 \quad (2)$$

Where R is the rainfall erosivity factor and MAR is the mean annual rainfall (mm).

2.2.3 *Soil erodibility*

The K factor in soil erosion modeling represents the susceptibility of different soil particle types to erosion caused by rainfall and runoff (Williams et al., 2000). To estimate the K factor, fractions of the topsoil layer, including sand, clay, silt, and organic carbon, were considered. Researchers often focus on the topsoil layer when calculating the K factor because it is directly affected by the energy of raindrops and surface runoff. Soils with high infiltration capacities and moderate structural stability typically have K factors ranging

Table 1: Mean annual rainfall of the meteorological stations considered in the study.

5Name of stations	Longitude	Latitude	Elevation (m)	Rainfall (mm)
5Ziway	7.93639	38.7147	1876	767.802
5Koshe	8.01083	38.5314	1646	753.958
5Butajra	8.1225	38.3758	2074	1024.65
5Hosana	7.56778	37.8561	2306	1203.85

from 0.2 to 0.3, while easily erodible soils with low infiltration capacities may have K factors of 0.3 or higher (Brady & Weil, 2008). Soil erodibility (K) values generally range between 0 and 1 (Farhan et al., 2013), where the lesser value indicates low sensitivity to erosion, while a higher value implies greater susceptibility to water erosion.

The soil organic carbon indicates its erodibility as it contributes to particle aggregation through the presence of chelating agents and water infiltration (Rao et al., 2014; Zakerinejad & Maerker, 2015). Walkley and Black method was used to determine soil organic carbon concentration of the soil samples collected for this study (Benavidez et al., 2018). The fractional proportion (sand, silt and clay) is another essential characteristic of soil that determines erodibility of soil through its impact, among others, on water infiltration rate.

For this study, soil erodibility parameter was estimated following the lab analysis of soil that collected from systematically distributed locations within the watershed. To collect representative soil samples, the watershed was divided into three slope classes viz lower (¡8%), medium (8-15%), and steep slopes (¿15%). Within each slope class of the watershed, agriculture, forest/woodland, and grassland were considered for soil sampling. From each land use/cover type within the respective slope class, three soil sampling points were selected. From entire watershed, a total of 36 soil samples were collected using auger at 0–20 cm depth. Using lab procedures, the soil samples were analyzed in the lab to determine silt, sand, and clay fractions and soil organic carbon. The K factor was determined using equations below.

$$K = f_c^{\text{sand}} \cdot f_c^{\text{l-si}} \cdot f^{\text{orgC}} \cdot f_h^{\text{isand}} \quad (3)$$

$$f_c^{\text{sand}} = \left(0.2 + 0.3 \cdot \exp\left[-0.256 \cdot m_s \cdot (1 + m_{100}^{\text{silt}})\right]\right) \quad (4)$$

$$f_c^{\text{l-si}} = \left(\frac{m^{\text{silt}}}{m^c + m^{\text{silt}}}\right)^{0.3} \quad (5)$$

$$f^{\text{orgC}} = 1.0 - \frac{0.256 \cdot \text{orgC}}{\text{orgC} + \exp\left[3.72 \cdot \text{orgC} - 2.95 \cdot \text{orgC}\right]} \quad (6)$$

$$f_h^{\text{isand}} = 1 - \frac{0.7 \cdot (1 - m_s/100)}{(1 - m_s/100) + \exp\left[5.51 + 22.9(1 - m_s/100)\right]} \quad (7)$$

Where the factor fcsand represents the effect of coarse sand content on lowering the K factor in soils The factor fcl-si accounts for the clay-to-silt ratio and assigns low soil erodibility factors to soils with a high clay-to-silt ratio. The factor forgC reduces the K values in soils with a high organic carbon content. The calculations for fcsand, fcl-si, forgC, and fhisand were performed using Equations 3–7.

2.2.4 *Topographic data*

Topographic characteristics of the land such as slope gradient and length are important in estimating erosion as well as in planning soil and water conservation measures. The slope length factor (L) represents the length of a slope at upslope of water way or barrier for surface runoff, while the slope steepness factor (S) reflects the influence of the slope gradient. Both factors affect the rate of soil erosion by water due to their effect on volume and speed of surface runoff. Initially, the LS factor supposed to provide the expected ratio of soil loss per unit area of a field slope compared to the loss from a standardized 22.13 m length of a uniform 9% slope under equivalent conditions (Wischmeier & Smith, 1978).

For this study, the LS factor was estimated to be using DEM in ArcGIS 10.8 and spatial analysis tools. Initially, the restored and repaired DEM of the watershed was used to analyze the slope (in degrees) across the study area. Next, the flow direction was generated from the filled DEM of the watershed. Flow accumulation was then derived from the flow direction. Finally, the LS factor was calculated in the raster calculator (Equation 8).

$$LS = \left(\text{Flow accumulation} \times \frac{\text{cell size}}{2.13}\right)^{0.4} \times \left(\frac{\sin(\text{slope} \times 0.01745)}{0.0896}\right)^{1.3} \quad (8)$$

2.2.5 *Land cover data*

Land cover data was derived from a Landsat image captured in May 2022, which was obtained from the USGS website (https://earth.explorer.usgs.gov), then transformed to the WGS-84 datum and Universal Transverse Mercator Zone 37 North coordinate system. The pre-processing of Landsat 8 imagery involved atmospheric corrections using the respective algorithms within QGIS 3.16. Prior to land cover classification, pre-processing and post-processing tasks such as sub-setting, layer stacking, and image enhancement were completed. Those steps were aimed to enhance image quality and remove any atmospheric interference for accurate land cover classification. Major land covers considered in the study are defined in Table 2 below.

Table 2: Description of land cover types classified.

Land cover type	Description	Source
Cultivated	Cultivated land includes area used to grow annual crops. Cultivated lands are plowed continuously or periodically depending on quality of soil and interest of farmers.	Desta and Hurni (2011)
Grazing	Grass and herb cover with scattered trees and shrubs, and are areas supposedly with permanent grass cover used for livestock grazing. Grazing land tends also to be open areas with good visibility on flat areas and hill slopes and are relatively homogeneous, with little pattern compared to cultivated land.	Desta and Hurni (2011)
Forest	The land area dominantly covered with trees and shrubs, mainly with dense canopy (¿30%).	Girmay et al. (2020)

The integration of field data with the original Landsat 8OLI allowed for the identification and delineation of these land cover types. Field observations, including direct assessments and surveys within the study watershed, provided valuable ground-truth data for understanding the composition and characteristics of the land cover. To perform the image classification, the Normalized Difference Vegetation Index (NDVI) approach was adopted. This approach allowed the classification algorithm to learn the spectral characteristics and patterns associated with each land cover class based on the NDVI values.

A Landsat 8 satellite image that acquired for the study area provided the necessary spectral bands for calculating NDVI. To minimize computational requirements and to focus on the study area, a subset of the Landsat 8 image covering the specific region of interest was selected, which contains the necessary spectral bands for NDVI calculation. The near-infrared (NIR) and red bands of Landsat 8 were extracted from the selected subset. These bands are essential for calculating NDVI because they capture the reflectance in the red and near-infrared portions of the electromagnetic spectrum. Finally, the NDVI value was determined by using eq. 9. The NDVI was computed using the extracted NIR and red bands.

$$\text{NDVI} = \frac{\text{NIR} - \text{Red}}{\text{NIR} + \text{Red}} \tag{9}$$

Where NIR represents the reflectance in the near-infrared band and Red represents the reflectance in the red band. The calculation of NDVI provides a quantitative measure of vegetation health and density, allowing for the analysis of vegetation dynamics and monitoring changes over time (Jensen, 2009).

The value of the C factor depends on various factors, including vegetation type, growth stage, and percentage of cover (Gitas et al., 2009). The C factor of 0 represents a condition where soil erosion is negligible due to high plant cover, while a C factor of 1 indicates a greater potential for soil loss due to extensive tillage, leaving a smooth surface that generates significant runoff and renders the soil susceptible to erosion (Rabia, 2012; Renard et al., 1997). The Normalized Difference Vegetation Index (NDVI) was used to derive the C factor as it positively correlates with the amount of green biomass and indicates variations in green vegetation coverage (Van der Knijff et al., 2000). Higher C factor values imply greater vulnerability to soil erosion, as they indicate unprotected barren land. The calculation of the NDVI spectral index follows the equations proposed by Ahmed et al. (2013).

$$C = \exp\left[-\alpha\left(\frac{\text{NDVI}}{\beta} - \text{NDVI}\right)\right] \tag{10}$$

The parameters α and β are unitless parameters that determine the shape of the curve representing the relationship between NDVI and the C factor. For the parameters and , values of 2 and 1 were chosen, respectively. This equation has been effectively employed by numerous researchers to determine the spatial distribution of the C factor (Kouli et al., 2009; Prasannakumar et al., 2011) .

To calculate the C-factor values for the study area, obtained a Landsat 8 OLI/TIRS C1 image covering PATH 168 and ROW 55 downloaded from the United States Geological Survey (USGS) Earth Explorer (https://earthexplorer.usgs.gov). Only images with cloud cover below 6% were selected, and data from May 2022 was utilized. The accuracy of the image was validated through ground truth data obtained from field observations.

2.2.6 *Conservation practices (P-factor)*

The P-factor quantifies the ratio of soil loss with a specific conservation support practice to the corresponding soil loss (Dabral et al., 2008; Renard et al., 1997; Wischmeier & Smith, 1978). Various factors, such as contour plowing, strip-cropping, and terracing, were taken into account when assigning P-factor values, which reflect the effectiveness of erosion control measures. table 3 below displays the support practice factor values corresponding to different cultivation methods and slope conditions (Morgan, 2005; Pesaran et al., 1999). The values range from 0 to 1, where a value of 0 indicates excellent conservation practices implemented to control erosion, while a value of 1 indicates the absence of any erosion control mechanism.

In the study area, there are few terraces. Thus, to calculate the P-factor, slope and contouring values were used (Wischmeier & Smith, 1978). The P-factor values were then calculated considering the effectiveness of contouring in reducing soil erosion based on slope and

Table 3: Values for conservation practices under different slope classes considered for the study (Morgan, 2005).

Slope (%)	Contouring	Strip-cropping	Terracing
0–7	0.55	0.27	0.10
7–11.3	0.60	0.30	0.12
11.3–17.6	0.80	0.40	0.16
17.6–26.8	0.90	0.45	0.18
>26.8	1.00	0.50	0.20

contouring practices. This analysis helps assess the potential risk of soil erosion in different areas, considering the challenges of the limited terracing and the less common strip-cropping practices in the study area.

2.2.7 Combining the RUSLE inputs

Soil loss estimation and erosion risk assessment were conducted by the RUSLE model in a raster GIS environment (grid-based approach). Individual GIS files were built for the rainfall erosivity, soil erodibility, topography (slope length and steepness), land use/land cover, and conservation practice (denoted by RKSLCP) combined by cell grid modeling procedures in GIS software to predict soil loss in spatially. After completing the data input procedure and preparing the necessary maps of RUSLE factors with a pixel size of 30 m *30 m, they were combined and analyzed using the raster calculator in ArcGIS 10.8. The average annual erosion expected on the field slopes was estimated (fig. 2) (Wischmeier & Smith, 1978).

$$A = R \times K \times LS \times C \times P \tag{11}$$

3 Results

3.1 Rainfall erosivity

The IDW interpolation technique in ArcGIS revealed a range of R-factor values from 407.044 to 393.039 MJ mm-1 ha-1 yr-1, indicating spatial variations in rainfall within the study watershed. Higher R-factor values were observed in the southern areas of the watershed, while lower values were found in the northwestern parts of the watershed (Table 4; Figure 3). The R-factor value implies the possible rainfall force that could generate surface runoff and exert power to detach and transport soil particles.

3.2 Soil erodibility factor

According to this study, a high soil erodibility (K-factor) value was recorded in agricultural land (0. 179 t h MJ-1 mm-1), while a low value was found in vegetation-covered land (0.146 t h MJ-1 mm-1) in the upper and central parts of the watershed (Figure 4). A higher K-value indicates a greater susceptibility to soil erosion (Figure 4b). The low K-value was observed in the western parts of the watershed, while the high soil erodibility was identified in the northeastern and in the southeastern parts of the study watershed.

3.3 Topographic factor

In this study, the LS values ranged from 0 (indicating low erosion potential) to a high value of 49.24. The areas with higher LS values were observed in the mountainous regions characterized by steep slopes, particularly in the southern and western parts of the watershed **??** Conversely, lower LS values were observed in the northeastern and southwestern parts of the study watershed. The variability in LS values can be attributed to the complex and rugged natural landforms found within the study watershed. Higher LS values were predominantly observed in areas prone to erosion within the Bidara watershed. However, it is worth mentioning that most of the catchment area, approximately 79.46% (3,151.59 ha), is in the western to eastern parts of the watershed (Table 5; Figure 5a).

3.4 Land cover factor

The land cover indicates the protective effect of vegetation in reducing soil erosion vulnerability. The estimated NDVI values within the watershed ranged from 0.06481 to 0.3486, with higher values indicating areas with abundant vegetation (table 5). The analysis showed a range of C-factor values within the watershed, with lower values (0.3428) in vegetated areas and higher values (0.864) in agricultural land. This suggests that areas with less vegetation and absence of dense shrubs have higher erosion vulnerability in the watershed.

3.5 Supportive conservation practice

The P values within the watershed exhibit variation, ranging from 0.55 in the northern, eastern, and central parts of the watershed to 0.9 in steep slope areas located in the southern and the northwest parts of the study watershed (fig. 7,table 6). Notably, the P factor map highlights elevated P values in areas characterized by vegetation and dense shrub land.

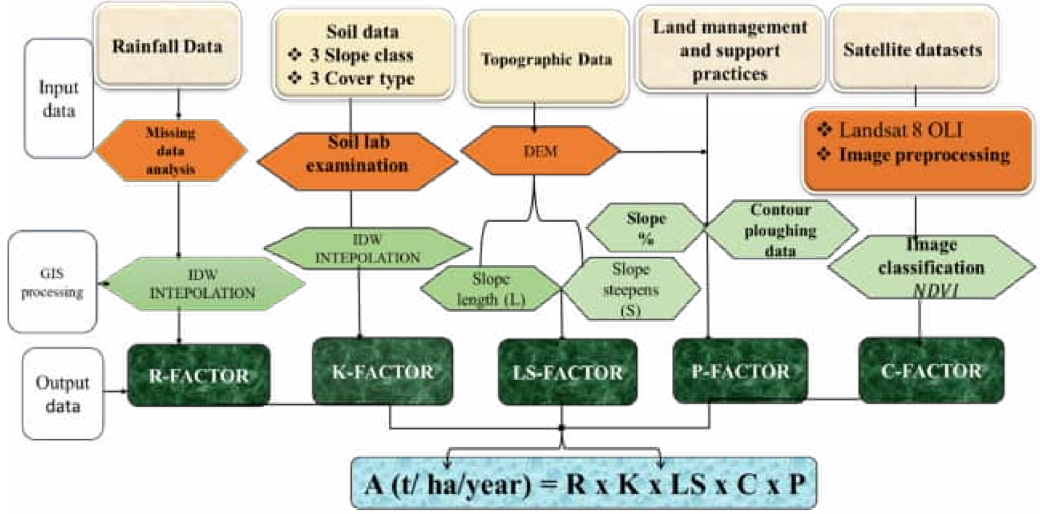

Figure 2: Input data combination in RUSLE

Table 4: R-Factor within station.

Mean Annual Rainfall (mm)	R-Factors (MJ mm/ha/yr)
760.09	393.039
772.45	400.179
777.85	403.145
784.57	407.044

3.6 Soil loss estimation in Bidara watershed

The findings of this investigation revealed that the watershed is currently experiencing a high soil erosion rate with significant spatial variation. Soil loss ranges from zero in flat terrain to $1129.47\ \mathrm{t\,ha^{-1}\,yr^{-1}}$ in sloping areas of the watershed, with a mean annual soil loss of $16.41\ \mathrm{t\,ha^{-1}\,yr^{-1}}$. In total, an estimated 65 087.47 t of top fertile soil is lost annually from the entire watershed of the Bidara (Figure **??**; Table **??**).

From the total area of the study watershed, the distributions of soil loss are 55.92% (2217.77 ha) of the land experiences soil loss ranging from 0-10 t ha-1 yr-1 of fertile topsoil, 17.27% (685.08 ha) experiences loss ranging from 10–20 t ha-1 yr-1 ; 10.55% (452.61 ha) experiences loss ranging from 20–30 t ha-1 yr-1; 7.58% (301.3 ha) experiences loss ranging from 30–45 t ha-1 yr-1ha); 3.5% (138.22 ha) experiences loss ranging from 45–60 t ha-1 yr-1 ; 2.66% (107.06 ha) experiences loss ranging from 60–80 t ha-1 yr-1 and the remaining 1.62% (64.295 ha) experiences loss exceeding 80 t ha-1 yr-1 of fertile topsoil. These findings are consistent with a previous study (Fenta et al., 2021), which reported a mean annual soil loss of 16.5 t ha-1 yr-1 based on the agro ecological zones of Ethiopia.

The results of this study indicated significant soil loss in the upstream mountainous and hilly areas of the study watershed as well as in the middle-slope areas of the catchment (Table 8). In contrast, relatively lower mean annual soil loss rates ranging from 0–10 t ha-1 yr-1 were observed in the bottom areas of the watershed, specifically in the eastern part, enclosing the centers of the watershed. Based on these findings, it is recommended to prioritize the development of a management plan to reduce soil and nutrient losses in the steep and middle slope areas of the watershed. Furthermore, the results reveal that the low soil loss category covers a substantial portion of the study area, accounting for 55.92% (2217.77 ha) of the total land area (Table 8 Figure 10).

3.7 Identifications and prioritization of hotspot areas

3.7.1 Identifications of hotspot areas in Bidara watershed

Based on the soil loss and erosion rates observed in the study area, the hotspot areas were classified into seven categories: low (0–10 $\mathrm{t\,ha^{-1}\,yr^{-1}}$), moderate (10–20 $\mathrm{t\,ha^{-1}\,yr^{-1}}$), high (20–30 $\mathrm{t\,ha^{-1}\,yr^{-1}}$), very high (30–45 $\mathrm{t\,ha^{-1}\,yr^{-1}}$), severe (45–60 $\mathrm{t\,ha^{-1}\,yr^{-1}}$), very severe (60–80 $\mathrm{t\,ha^{-1}\,yr^{-1}}$), and extremely severe (>80 $\mathrm{t\,ha^{-1}\,yr^{-1}}$). The low to moderate soil loss category covered 73.262% (2,902.8518 ha), while the high to extremely severe classes accounted for a total of 26.812% (1,063.487 ha) of the study area (Table **??**). This area is extensively grazing and has experienced a relatively high level of degradation and relatively high steep slope areas (Figure **??**). The mean annual soil loss rate in this study was 16.41 $\mathrm{t\,ha^{-1}\,yr^{-1}}$, which exceeds the soil loss tolerance level of 1–16 $\mathrm{t\,ha^{-1}\,yr^{-1}}$ specified by **Hurni1985**.

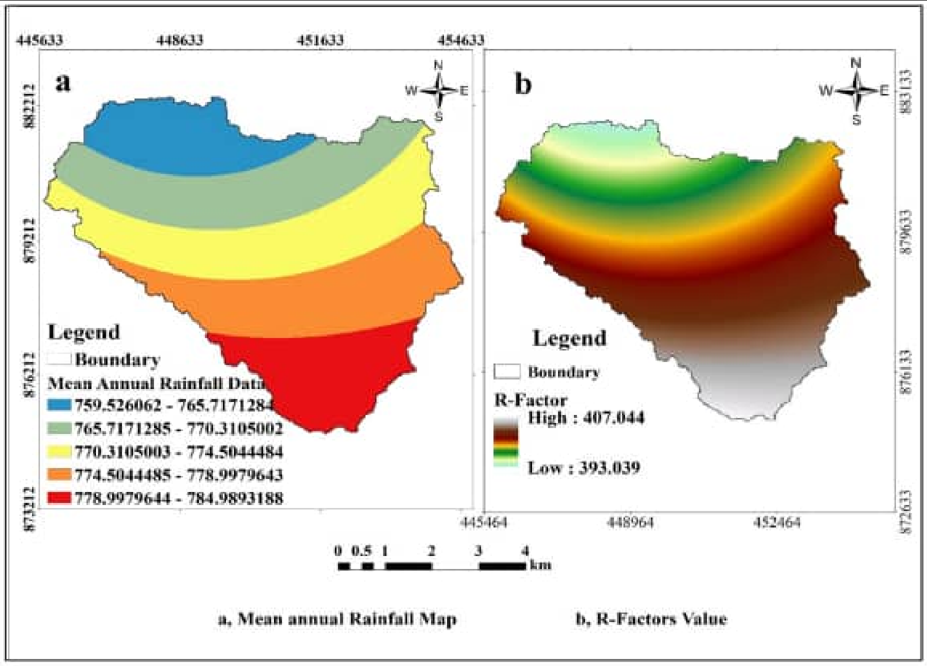

Figure 3: Rainfall erosivity factor in Bidara watershed.

Table 5: Area under slope classes in the Bidara watershed.

No	Slope Class (%)	Description	Area (ha)	Area (%)
1	0–0.5	Flat-Level	592.44	14.94
2	0.5–1	Nearly Level	267.001	6.73
3	1–2	Very gently sloping	342.142	8.63
4	2–5	Gently sloping	1950.01	49.17
5	5–10	Sloping	758.001	19.11
6	10–15	Strongly sloping	51.52	1.30
7	15–30	Moderate Steep	5.16	0.13
	Total		3966.3	100

3.7.2 Prioritization for specific conservation plans of Bidara watershed

Proper identification of vulnerable areas to soil loss is crucial for effective soil and water conservation (SWC) planning (Wischmeier & Smith, 1978). The study area, Bidara watershed, was ranked into seven conservation priority levels based on soil erosion severity and risk. Approximately 1.62% (64.29 ha) is extremely severe (priority level I), 2.699% (107.06 ha) is very severe (priority level II), and 3.49% (138.22 ha) is severe (priority level III) (Table **??**). Topography has significantly contributed to high soil loss rates. Other areas with high and very high soil levels covered 19.01% (753.91 ha) of the total area.

The results of the soil loss analysis indicated that approximately 55.92% (2,217.77 ha) of the watershed was categorized as a low erosion risk area, which falls within tolerable values adapted for the highlands of Ethiopia (Rizeei et al., 2016). The expansion of bare land and cropland on sloping land was identified as the primary drivers of land cover change, contributing to high soil loss rates in areas experiencing non-tolerable erosion. Across the Bidara Watershed, 65,087 tons of soil is lost annually. The watershed necessitates site-specific planning for conservation and restoration of fertile topsoil.

3.8 Soil erosion susceptibility class for decision-makers

Bidara watershed has been classified into three major erosion susceptibility classes. The first class, situated in the southern parts of the watershed, exhibits extremely severe soil loss exceeding 80 t ha-1 yr-1. Immediate mitigation measures are deemed necessary for this area due to its high susceptibility to soil erosion. The second class comprises areas located on the northwestern part of the watershed, which have been identified as requiring second-level mitigation. The planners and decision-makers must prioritize and implement appropriate and effective measures to address soil erosion (Figure 12).

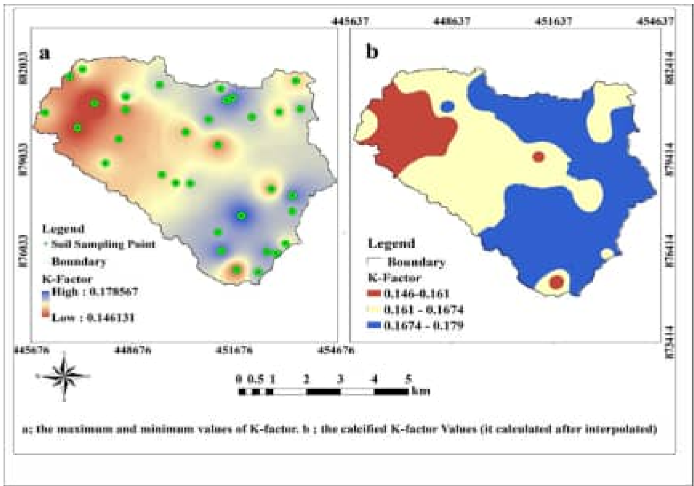

Figure 4: Soil sampling point and erodibility (K factor) for Bidara watershed.

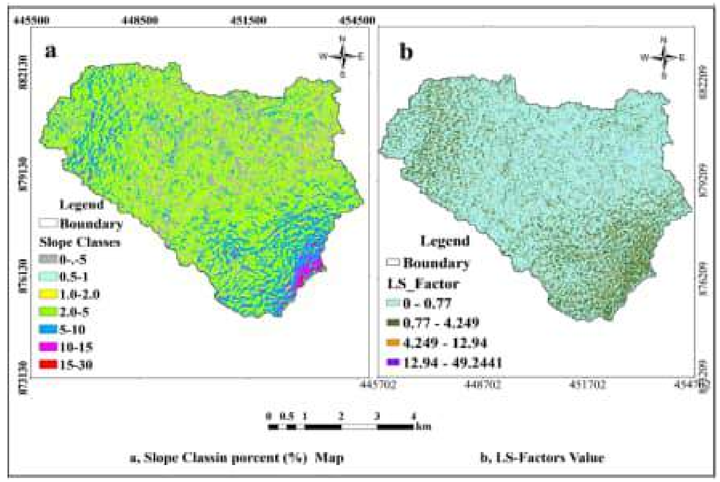

Figure 5: Map showing the topography (LS-factor) of the Bidara watershed.

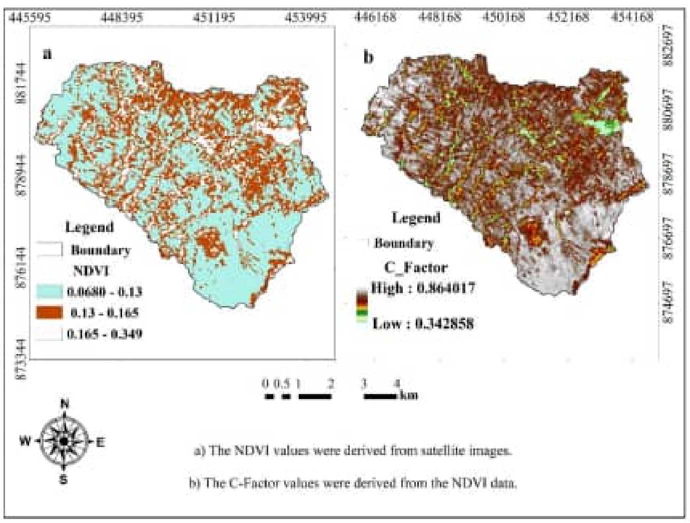

Figure 6: NDVI and C-Factor for the Bidara watershed.

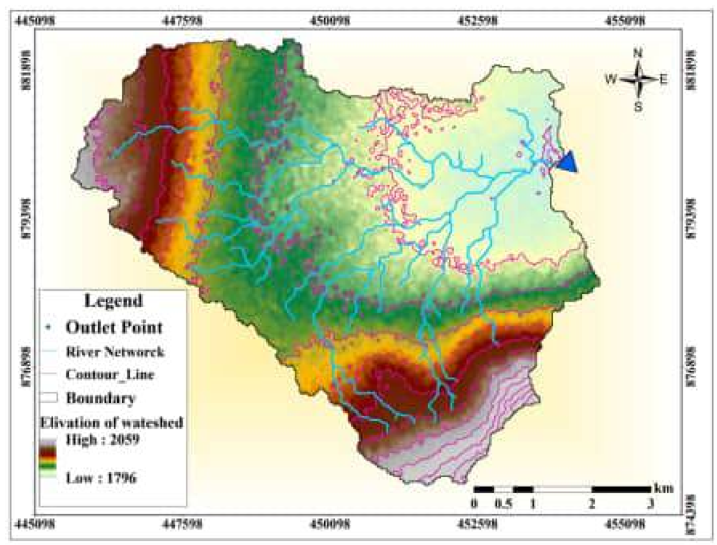

Figure 7: Slope class and P factor map of the Bidara watershed.

Table 6: The conservation practice (P Factor value) for Bidara watershed

Slope (%)	P Factor Value	Area (ha)	Area (%)
0–7	0.55	224.484	5.66
7–11.3	0.6	3711.39	93.57
11.3–17.6	0.8	29.7364	0.75
17.6–26.8	0.9	0.710 44	0.018
Total		3966.320 84	100

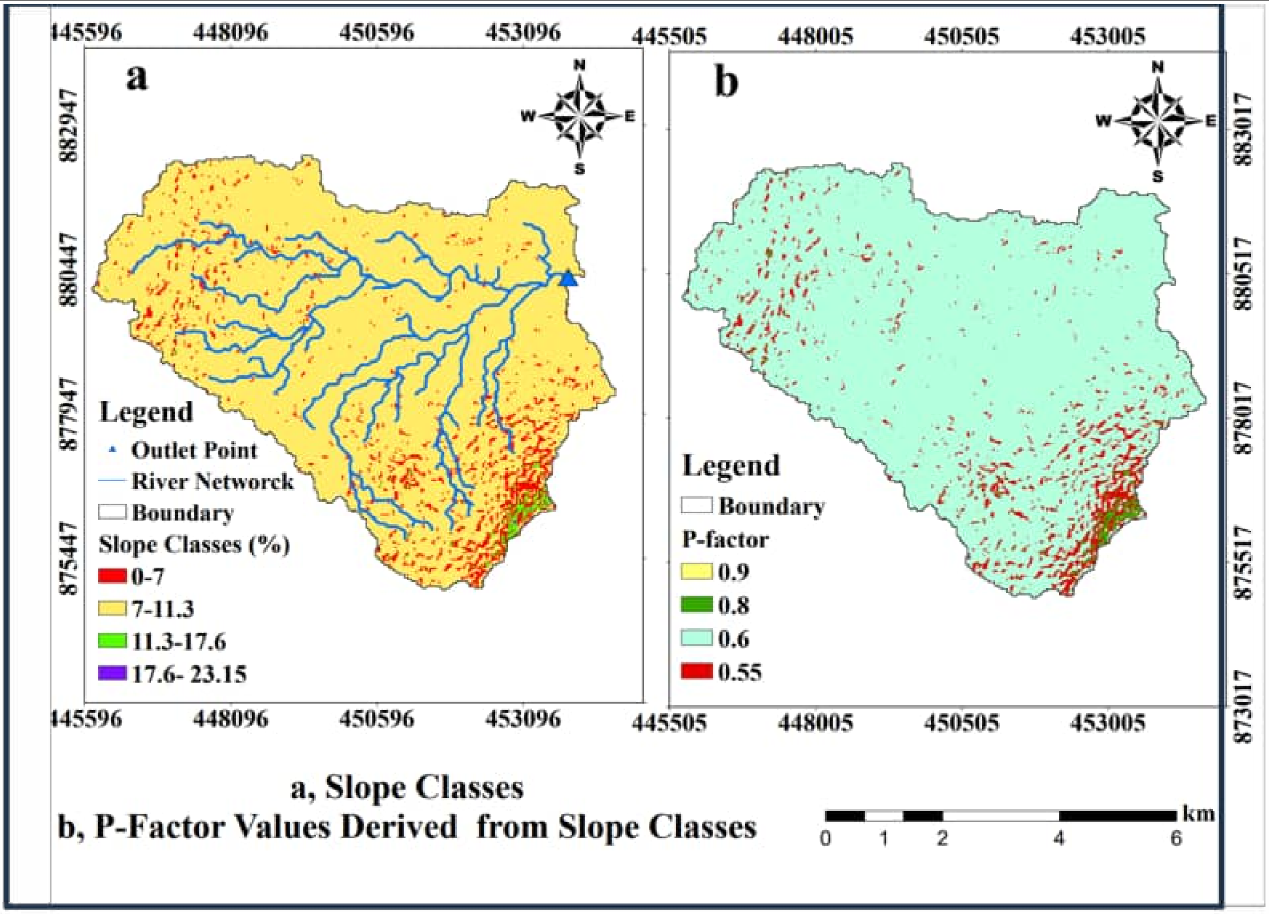

Figure 8: Slope class and P factor map of the Bidara watershed

4 Discussion

The mean annual soil loss rate of 16.41 t ha-1 yr-1 in the Bidara watershed is greater than the tolerable rate, 5 to 11 t ha-1 yr-1 (Renard et al., 1997) . A study by Nigatu (2014) in the Denki River catchment of Ankober woreda reported soil erosion rate of 0.006 to 505.7 t ha-1 yr-1 with a mean annual soil loss rate of 17.69 t ha-1 yr-1.. Mean annual soil loss of 18.7, 19.7, and 20 tons ha -1 yr-1 were reported by Belay and Mengistu (2021) for watersheds of Somodo, Muga, and Afa, respectively. The findings of those studies were in line with our results, demonstrating similar rates of soil loss in various watersheds in other parts of Ethiopia. It is important to note that the Bidara watershed experiences relatively lower soil loss rates compared to some other regions in the country. For instance, in the Chemoga watershed (Bewket & Teferi, 2009) an average soil erosion rate of 93 t ha -1 yr-1, while Moisa et al. (2022) found a mean annual soil loss of 83.7 t ha-1 yr-1. Also, less mean annual soil loss (9.63 t ha -1 yr-1) was reported for Medego watershed (Tripathi et al., 2003), which is less than the soil loss rates found in our study. Depending on erosion factors, which expected to vary with a specific locality, even within watershed, the magnitude of erosion observed could vary between watersheds. In the study area, the intolerable soil erosion could be due to land cover, topography, and lack of adequate and appropriate conservation measures. For instance, conventional agriculture is dominating and supposed to aggravate erosion, especially on steep sloping topography. As observed in the field, the soil and water conservation structures such as terraces are few and not sustainable to reduce soil erosion in the long run.

In this study, areas with high soil loss rates are identified and prioritized for SWC measures. This prioritization can greatly assist decision-makers and conservation planners in designing suitable SWC interventions based on the severity of soil loss. The first, second, and third priority levels encompass approximately 309.57 ha (7.8%) of the watershed area and require immediate, intensive and integrated SWC measures including bunds, terrace and tree planting. These priority areas are predominantly located in Washe Faka kebele in the northwest and Bidara Faka and Faka Repe kebeles in the southern parts of the watershed. These areas are characterized by steep slopes, with slope gradient ranging from 11.3% to 23.15%. A recent report by Karamage et al. (2016), for the Nyabarongo River Catchment in Rwanda and Chaleleka wetland watershed of Ethiopia Wolka et al. (2015) support our findings by demonstrating higher soil erosion in areas with steep slopes. Steep slopes contribute for the velocity of surface runoff and increase eroding force of the water.

Fortunately, about 56% of the Bidara watershed is estimated to experience tolerable erosion and thus, erosion controlling measures such as grass strips and contour plowing could control soil loss. Hence,

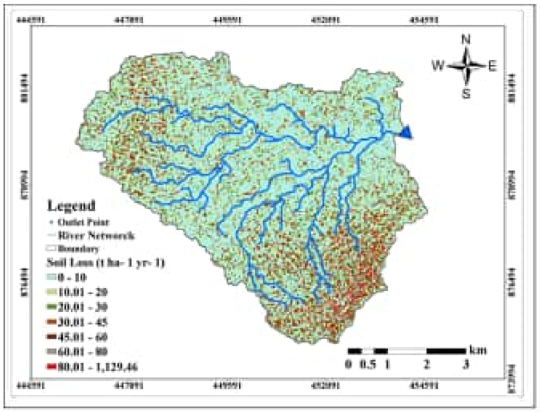

Figure 9: Estimated soil loss using the RUSLE in Bidara watershed.

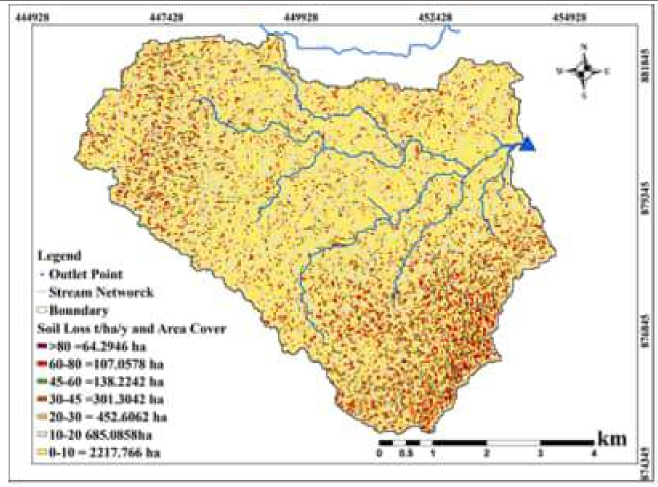

Figure 10: Soil loss classification map.

Table 7: Annual soil loss in Bidara watershed

No	Area (ha)	Area (%)	Soil loss (t ha^{-1} yr^{-1})
1	2217.77	55.92	0–10
2	685.08	17.27	10–20
3	452.61	11.41	20–30
4	301.30	7.60	30–45
5	138.22	3.50	45–60
6	107.06	2.69	60–80
7	64.29	1.62	¿80
Total	**3966.33**	**100.00**	

the identification of priority areas considering the spatial variability in soil erosion risk within the Bidara watershed is crucial for effective planning and implementation of appropriate SWC measures (Adugna et al., 2015; Bhattacharyya et al., 2016; Keesstra et al., 2018). Soil and water conservation measures can address the varying levels of soil loss and erosion risk.

The proper prioritization of soil and water conservation areas in the Bidara watershed, taking into account the severity levels of soil loss, is essential for effective conservation planning. It is crucial to identify and address the high-priority areas characterized by steep slopes with urgent erosion protection measures. In the context of Ethiopia, specifically the Central Rift Valley area, some other studies have highlighted the significance of erosion protection measures and conservation planning. For example, Wolka et al. (2015) emphasized the importance of prioritizing soil and water interventions through improved vegetation cover and terrace based on the severity of soil erosion in the Central Rift Valley. They stressed the need for targeted measures in areas with higher erosion risk to prevent further soil degradation. Furthermore, studies by Gebregergs (2018) focused on SWC practices in the Central Rift Valley, emphasizing the effectiveness of terracing and other erosion control measures in reducing soil loss and enhancing soil conservation. In the region, soil and water conservation measures such as bunds and Fanya juu have positive effect on soils of cultivated and grazing lands due to their erosion protecting role (Dangiso & Wolka, 2024; Husen et al., 2017; Wolka et al., 2024). Planners and experts in the district could apply output of our study in designing watershed-based soil and water conservation measures.

In general, models are important and applied for estimating soil erosion as field experiments are expensive in terms of time and budget. In addition, monitoring erosion at watershed scale to choose soil and water conservation measures is difficult unless models are used. Still there are uncertainties in model and its output due to resolution and quality of spatial and temporal data. For instance, in the study area, we applied interpolation method for soil properties and rainfall parameters. This could have some uncertainties on output, but we believe this scientific method we applied can result in a reasonable range.

5 Conclusion and recommendations

The RUSLE model effectively evaluated soil erosion intensity and variability in the Bidara watershed. The findings revealed a mean annual soil loss rate of 16.41 t ha-1 yr-1, resulting in an estimated loss of 65,087.3 t of fertile topsoil annually across the watershed. Approximately 7.8% (309.57 ha) of the evaluated areas experienced severe to extremely severe soil erosion rates. Spatial distribution maps depicted varying soil loss patterns ranging from 0 to 1129.47

Table 8: Erosion hotspot area (severity class) in Bidara watershed

No	Area (ha)	Area (%)	Soil loss (t ha^{-1} yr^{-1})	Severity Class
1	2217.77	55.91	0–10	Low
2	685.09	17.23	10–20	Moderate
3	452.61	11.41	20–30	High
4	301.30	7.60	30–45	Very High
5	138.22	3.48	45–60	Severe
6	107.06	2.70	60–80	Very Severe
7	64.30	1.62	>80	Extremely Severe
Total	**3966.33**	**100.00**		

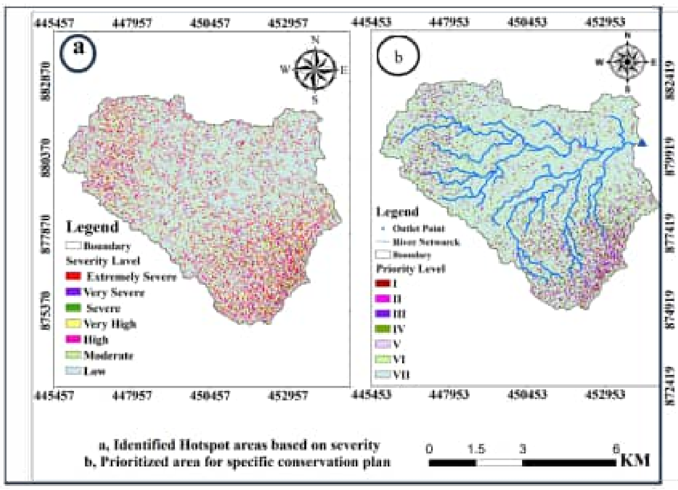

Figure 11: Severity class and priority level map in Bidara watershed.

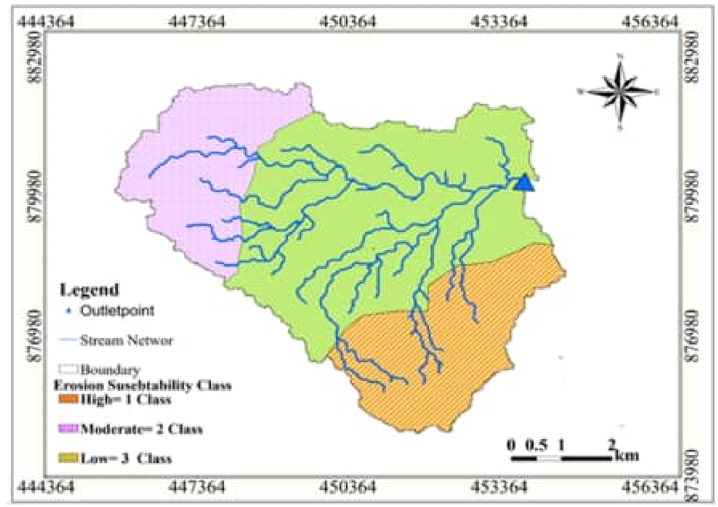

Figure 12: Soil erosion susceptibility map

t ha-1 yr-1 throughout the watershed. The mean annual soil loss exceeded the tolerable limit of 11 t ha-1 yr-1, primarily attributed to steep slopes. Urgent implementation of soil and water conservation practices is imperative, particularly in areas with high erosion rates. These research findings provide valuable insights for researchers seeking to address soil erosion challenges and promote effective conservation strategies in similar watersheds. The identified areas with high erosion risks should be prioritized for soil and water conservation measures. A comprehensive implementation plan for soil and water conservation should be prepared and executed in collaboration with local communities, government agencies, and non-governmental organizations. Multi-disciplinary integrated watershed management approach should be conducted to develop sustainable natural resource management in the study watershed for a healthy ecosystem by concerned stockholders. In the long, government should increase datasets that are important for natural resource research including establishing meteorology stations to monitor rainfall in the woreda.

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Table 9: Prioritized for conservation plan in Bidara watershed

No	Area (ha)	Area (%)	Soil loss (t ha^{-1} yr^{-1})	Severity class	Priority level
1	2217.76	55.91	0–10	Low	VII
2	685.08	17.27	10–20	Moderate	VI
3	452.60	11.41	20–30	High	V
4	301.30	7.59	30–45	Very high	IV
5	138.22	3.48	45–60	Severe	III
6	107.05	2.69	60–80	Very severe	II
7	64.29	1.62	>80	Extremely severe	I
Total	**3966.33**	**100.00**			

Competing interests

The authors declare that they have no conflicts of interest.

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Research Article

Socio-economic utilisation Of Upas Tree (*Antiaris toxicaria* Lesch): A case study Of Mabira Central Forest Reserve, Uganda

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Abstract

Antiaris toxicaria Lesch (upas tree) is a monoecious and medicinal tree species belonging to the Moraceae family and is known for its medicinal value, plywood, and veneer. The tree has been over-utilized, leading to degradation, over-exploitation, and a decrease in population size. The study aims to assess the socio-economic factors associated with the utilization of *Antiaris toxicaria* Lesch in Mabira Central Forest Reserve. A cross-sectional research design was conducted using a semi-structured questionnaire and participant observation guide from 410 randomly selected households across 10 villages. A total of 10 key informant interviews were also conducted among persons who were knowledgeable persons about the upas tree and Mabira Central Forest service. Descriptive statistics and inferential statistics (chi-square tests) were used for analysis. Results indicate eight primary uses of the tree, with timber (42.1%) and medicinal (23.6%) uses being the most common while firewood (0.9%) and fertilization (2.3%) ranked least. Significant factors influencing utilization of upas trees included residence duration (p=0.001), occupation (p=0.002), and household income (p=0.028). The National Forestry Authority and local government should work hand in hand with local communities to protect Mabira Central Forest Reserve and promote upas tree domestication. The study recommends conservation awareness among communities living in the vicinity and inclusive policies for sustainable use of upas trees.

Keywords: *Antiaris toxicaria*, forest conservation, Mabira Central Forest Reserve, socio-economic factors

1 Introduction

Despite its toxic nature, *Antiaris toxicaria* Lesch (Upas tree) has been a part of traditional livelihoods in various communities in Uganda and beyond. The tree is termed an “industrial forest plant” and is known for its commercial rather than subsistence use (Umdale et al., 2020). Upas tree is used in traditional medicine, as proven by numerous phytochemical analyses of its latex, confirming the presence of many active chemical compounds, including Antiarin (Subiono et al., 2017). Furthermore, qualitative phytochemical studies presented the existence of alkaloids, phenols, glycosides, anthraquinone, protein, amino acids, flavonoids, phytosterols, and saponins that were reported to cure different ailments. Upas tree has several medicinal applications in traditional systems across various cultures.

The different parts of the tree were found important in treating various ailments and used for other cultural values. For example, leaves, seeds, and bark are used as an astringent and febrifuge, while seeds are used as anti-dysenteric. The bark is used as an anodyne and vermifuge to treat hepatitis and mental illnesses (Ugwoke et al., 2017).

In some countries, the tree is known to treat cancer due to medicinal properties found in the components of its sap. For example, scientific studies conducted in the East African region revealed that *Antiaris toxicaria* Lesch can be used to treat tuberculosis (Obakiro et al., 2020). In Uganda, the tree is known to treat headaches and weakness in pregnancy (Tumuhe et al., 2018). However, the tree species was not only found useful in providing medicine but also in other uses. In Kerala-India, the bark of the tree was found essential in making a type of bark cloth called Maravuri among the Muthuvan people and other uses are plywood and veneer (Umdale et al., 2020). In essence, this makes the upas tree of great cultural significance and essential for the preservation of cultural practices.

Traditional medicine use is common among the old people in Sub-Saharan Africa as a result of cultural identity and traditions passed on. The use of medicinal plants in sub-Saharan Africa is linked to several socioeconomic characteristics, including age, wealth, marital status, and educational attainment. In a study done in Moroto district, Uganda, older adults, married people, and those who live far from contemporary medical facilities are more likely to use medicinal herbs (Logiel et al., 2021). A socio-economic baseline study conducted on six (6) Central Forest Reserves (CFR) in Uganda unveiled a significant increase in households (31.3%) living adjacent to CFR including Mabira Central Forest Reserve. This high population increases the chances for excessive extraction of forest resources like firewood, charcoal, poles, timber, and herbal medicine for personal use or commercial purposes (Ministry of Water and Environment, 2017). Mabira Central Forest Reserve (Mabira CFR) is facing increasing demand and the surrounding high population exerts pressure in the struggle for livelihood improvement. A forest reserve is home to many trees important to the surrounding communities, who mostly harvest these plants for their livelihood support.

Socioeconomic status of *Antiaris toxicaria* Lesch provides a clear understanding of interconnected reasons for its utilisation. On the other hand, *Antiaris toxicaria* Lesch is known to have a poor regeneration rate and hence a threatened species (Mirgal et al, 2016) and this could lead to its extinction if conservation efforts are not undertaken. A few studies on the upas tree exist and especially its socioeconomic utilization in nearby communities of Mabira CFR. The present study was undertaken to understand the socioeconomic utilisation of *Antiaris toxicaria* Lesch in the communities of Wakisi and Najjembe sub-counties around Mabira CFR, Uganda, and justify its conservation.

2 Methods and Materials

2.1 Description of the study area

Mabira CFR covers an area of 29,974 hectares. It is located in Mukono, Buikwe, and Kayunga districts, counties such as Buikwe, Nakifuma, Mukono and Ntenjeru, and sub-counties such as Wakisi, Nagojje, Najjembe, Kimenyedde, Nama and Kangulumira of Kayunga district. Geographically, Mabira CFR is located between latitudes 000 22' and 000 35' N and longitudes $30^0 56'$ and $33^0 02' E$. The management and control of Mabira Central Forest Reserve (Mabira CFR) is vested in the National Forestry Authority (NFA) under the National Forestry and Tree Planting Act, 2003 (Ministry of Water and Environment, 2020) (Figure 1).

2.2 Research design and sample size

Buikwe district holds a total of 97,833 households. Najjembe Division has a total of 8,007 households, while Wakisi has 9,256 households (Uganda Bureau of Statistics (UBOS), 2014). Najjembe and Wakisi were purposively selected from Buikwe District because they were close to the forest reserve and held the forest's largest part. From a total number of 17,263 households in the two divisions, the sample size was estimated using Yamane's formula

$$n = \frac{N}{1 + N(e)^2} \tag{1}$$

where n stands for sample size, N for population size, and e for level of significance (5%).

Additionally, to account for non-response, 5% of the households that were obtained were added. The study employed a cross-sectional research design and 410 households were randomly sampled from the two divisions. Ten villages were purposively chosen from the divisions based on their proximity to Mabira CFR (Wakisi division-four villages and Najjembe-six villages). Fewer villages were selected from Wakisi because some of the villages that bordered the forest were inhabited by temporary workers for sugar and tea industries, who were constantly coming and going from different districts of Uganda and were not knowledgeable about the utilization of forest resources in the study area. The respondents were mainly farmers, non-farmers, and traditional healers across all the villages.

2.3 Sampling procedure and data collection

Ten (10) villages were purposively selected from the study area, as they were the closest to the forest reserve. The villages are Ssese, Dangala, Lugala, Kinoni, Buwola, and Kitoola from the Najjembe Division and Nakalanga, Wabusanke, Bugule, and Nnkonko from the Wakisi Division. Two hundred and forty-six (246) households were randomly selected from Najjembe, while one hundred and sixty-four (164) were randomly selected from Wakisi. Respondents were selected randomly from the register shared by the chairperson of the village ensuring that every household had an equal chance of being selected and avoiding bias. A semi-structured questionnaire was used to obtain primary data, and the interviews were conducted face-to-face with the respondents who were willing to participate in the study. The questionnaire had four (4) sections, the first section had the introduction and consent part and socio-demographic factors, the second section comprised questions on the collection and utilisation of *Antiaris toxicaria* Lesch, the third section was on

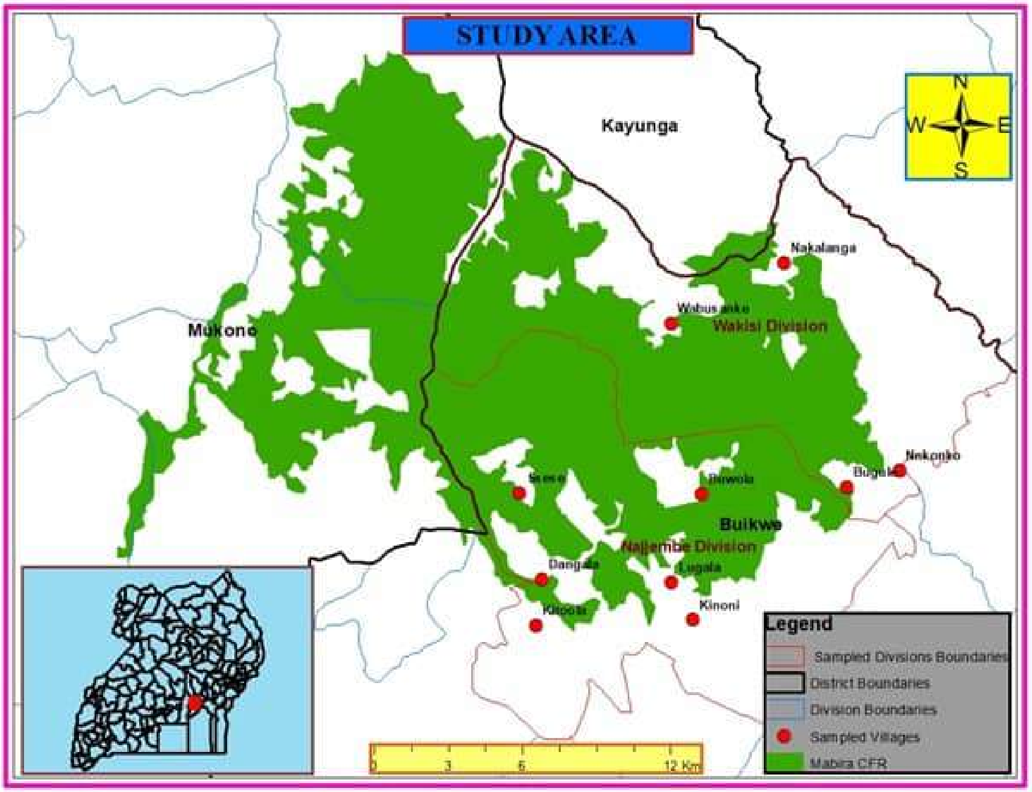

Figure 1: Location map of Bidara Watershed in Ethiopia

disturbance factors, and the last section was made up observation checklist. A key informant guide was designed, and interviews were conducted with ten (10) persons who were knowledgeable about the upas tree and Mabira Central Forest reserve.

2.4 Data analysis

The collected data were zanalyzed by Statistical Package for Social Sciences (IBM SPSS, version 29.0). Chi-Square (x^2) was used to test the significance of the association between the utilisation of *Antiaris toxicaria* Lesch and socio-economic factors, while type I and type II errors were controlled by using a 5% level of significance. Other results were transformed into frequencies and percentages, and presented in tables or chart form.

2.5 Ethical consideration

The Director of Research and Graduate Training at Kyambogo University provided us with a letter of recommendation before starting the data collection process. The letter requesting authorization to conduct the research project was delivered to the National Forestry Authority (NFA) and the local government authorities in the study area and permission was granted. Moreover, consent was sought from participants, and their involvement was entirely voluntary. Participants were free to withdraw from the study at any stage without giving any reason and without there being any negative consequences. Before participation in the study, the participants were informed of the objectives of the study and were made to understand their responses would be kept strictly confidential and only used for the research. Participant names were not linked with the research materials, and we would not be identified anywhere in the report. Each participant was required to sign a written informed consent form before taking part in the study.

3 Results

3.1 Socio-demographic characteristics of participants

The present research study assessed the association between the socio-demographic characteristics of the survey participants and the use of A. toxicaria Lesch (Upas tree). The majority of household heads (65.1%) who participated in the survey were males, while 34.9% were females. A significant number of participants (64.4%) were between 18 and 43 years old, while 35.6% were aged 44 years and above. The majority of households were farmers (82.4%) who mainly survived on subsistence farming.

Employed household heads (formally employed or self-employed in activities other than farming) constituted 15.4%, while those without formal jobs were 2.2%. There were relatively few employment opportunities in the study area while farming was the main occupation. In terms of education levels, about 64.1% of participants received formal education (primary, secondary education, tertiary education), while the remaining 35.9% did not receive formal education. The marital status of most participants (75.1%) was married, while 21.5% were single and 3.4% were widows. Many of the households (55.6%) had only one to four people, 30.7% had five to eight people, and 13.7% had nine or more people living together. Most households (85.3%) earned less than 200,000 Ugandan shillings (Ugx) per month which is equivalent to 55dollars, followed by those who earned 201,000 and 500,000 Ugx (13.2%), and those who made 501,000 or more (1.5%). Generally, most households in the research area were low-income earners and relied on subsistence farming.

3.2 Collection and local utilisation of A. toxicaria Lesch

The results indicated that 66.7% of the households in the research area utilized *Antiaris toxicaria* Lesch in various ways. The remaining proportion of participants included households that did not use the tree resource and those who denied providing information for private reasons. The households which were collecting and utilizing the upas tree for both economic and cultural reasons.

A key informant (chairperson of one of the villages) noted that upas tree is greatly harvested by locals in this area as he narrated:

> ....upas tree is a key resource in this village and it is collected and utilized to produce timber later various types of furniture are made depending on the client's needs and preferences. It should be noted that the collection of upas trees is not authorized and locals stealthily go to harvest from the forest reserve unnoticed.

The collection and utilization of the upas tree are detailed in Fig. 2.

The two plates illustrate the collection and use of *Antiaris toxicaria* Lesch in the study area. The plate (a) shows a young tree of *Antiaris toxicaria* Lesch in Mabira CFR after cutting, while plate (b) displays timber of upas tree found in some households in Buwola village, close to the forest.

3.3 Ethnobotanical uses of A. toxicaria Lesch

Eight local uses of *Antiaris toxicaria* Lesch were identified, and the majority used the tree for medicinal purposes and timber (Fig. 2). Participants revealed more than fifteen diseases that were treated by A. toxicaria Lesch. Most reported diseases include headache (2.1%), mental illness (0.5%), weakness in pregnancy (0.7%), yellow fever (0.9%), skin diseases such as rash (2.8%), wounds (1.4%), cough (5.5%), ulcers (1.5%), Ekigalanga (1.3%), stomach complications such as parasitic worms (4%), diabetes (0.5%), blood pressure (0.9%), Enoga (0.5%), and poultry diseases (1%). The main tree parts used in disease treatment were stem (34.9%), bark (28.3%), and leaves (36.8%).

A key informant who identified himself as a traditional healer noted that upas tree is a great traditional medicine and as he narrated:

> ....upas tree is greatly used by locals and it is known to treat skin diseases, wounds, and many parasitic diseases and so the plant but he hinted that it must be used with the guidance of a knowledgeable person because it is toxic when used in high dosages.

The tree species were reported to contribute to households' livelihood improvement through income generation from commercialization (18.5%), medicinal use (25%), and bark cloth (Embugo , 4.2%). Other use of upas trees in the study area included; fencing materials, firewood, food from edible fruits, and making bark cloth and bee hives. The results showed that the use of A. toxicaria Lesch for medicinal purposes was reported among traditional healers (69.2%), farmers (25.3%), and non-farmers (5.5%).

A key informant (traditional chief) noted that the upas tree is used for cultural practices and as he narrated:

> ... We make bark cloth from upas tree and this bark cloth is used as a burial shroud and ceremonial garment that chiefs put on during Buganda cultural ceremonies. Also, traditional dances make different outfits from bark cloth for entertainment purposes.

Association between age and local utilisation of A. toxicaria Lesch This section examines the association between the age of participants and the use of A. toxicaria Lesch. The association between age and utilization of the tree species was not significant (chi-square (x^2)) p=0.065). The percentage frequency of usage of upas tree was high among middle age groups, 31-43 years (85.7%) followed by 44-56 years (50%) in this study area (Fig. 3).

Association between the level of education and utilisation of A. toxicaria Lesch The utilisation of upas tree increased with a decrease in education level. Results indicated a higher utilization among participants with a low level of education (Fig. 4). There was no significant association between the level of education and the use of the tree ($x^2, p = 0.615.$)

3.4 Association between Residence duration and utilisation of A. toxicaria Lesch

The longer the residence in the study the more the person was knowledgeable about the utilisation of upas tree. Results on the association between the duration of residence of participants and the use of A. toxicaria Lesch were found significant $(x^2), p = 0.000$. The lowest utilization was among people who resided in the study area for a

(a) (a)

(b) (b)

Figure 2: A. toxicaria Lesch after cutting (a) and timber of a mature A. toxicaria Lesch (b)

short period of time (0-5 years) and highest in those who resided in the area for the longest time (18 years and above).

3.5 Association between household size and the utilisation of A. toxicaria Lesch

The utilisation of upas tree was evaluated with household size in the area and the average household size was 5 persons per household in this study area. The results indicate that the use of the tree resource increased with a decrease in household size. The majority (55.6%) of the households had one to four persons living together as a family. Chi-square (x^2) test results showed a p=0.371 meaning the association was not significant.

3.6 Association between occupation and the utilisation of A. toxicaria Lesch

The results indicated that the majority of the participants were farmers (mainly subsistence farmers) and a few were in formal employment. Association between the participants' occupations and the use of A. toxicaria Lesch was established with Chi-square (x^2) p=0.002, hence a significant association.

3.7 Association between household monthly income and the utilisation of A. toxicaria Lesch

The association between the family's monthly income and the utilization of the Upas tree was determined. A high utilization was observed in the low-income household category that earned an average of 150,000Ugx (the equivalent of 40dollars) every month (Fig. 5). The Chi-square test (x^2) results p=0.028 indicated a significant association between households' monthly income and utilization of upas tree.

4 Discussion

4.1 Collection and local utilisation of A. toxicaria Lesch

The utilisation of A. toxicaria Lesch was high and this could be because the plant has multiple uses to the community living around the forested reserve. The results of this study were related to the findings of Ministry of Water and Environment (2017), who found high utilization (66%) of the Prunus africana (Hook. F) Kalkman among communities living close to Nandi forests. Similarly, Andriamparany et al. (2014) discovered that Ficus lutea, Euphorbia tirucalli L., and Acacia bellula Drake had a high utilization rate of 82% in Madagascar by the communities. The high utilization of tree species climaxes into over-exploitation. Upas tree appears on the International Union for the Conservation of Nature (IUCN) Red List as Least Concern, its population size is declining in some areas due to over-exploitation and loss or degradation of habitats (Ugwoke et al., 2017). This denotes that the tree species could experience unsustainable harvesting pressure due to its multifunctional value. The collection/gathering of the forest resources is mainly enhanced by how vital they are for livelihoods of the communities living around them.

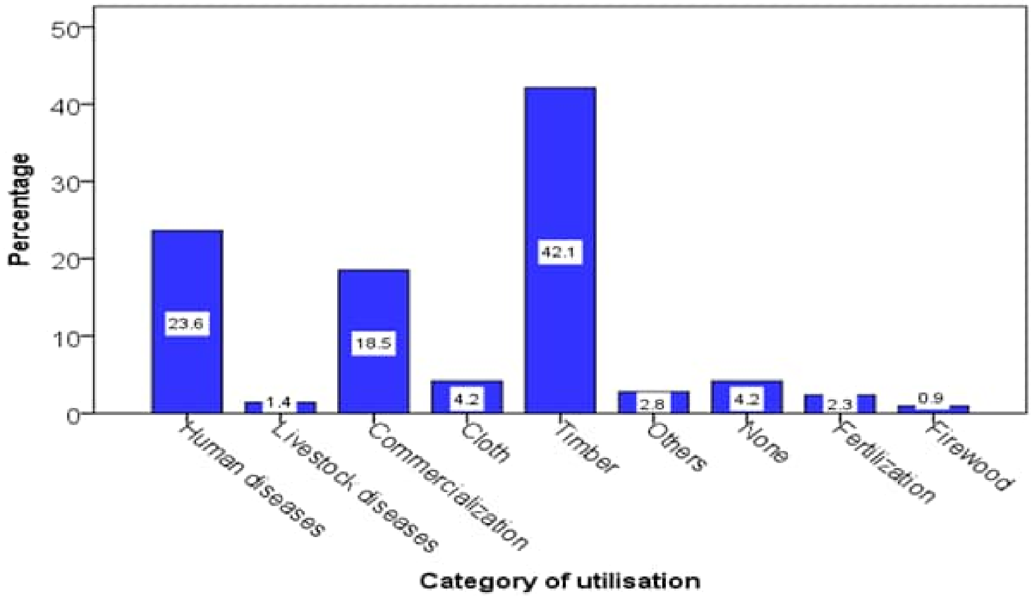

Figure 3: Ethnobotanical uses of A. toxicaria Lesch

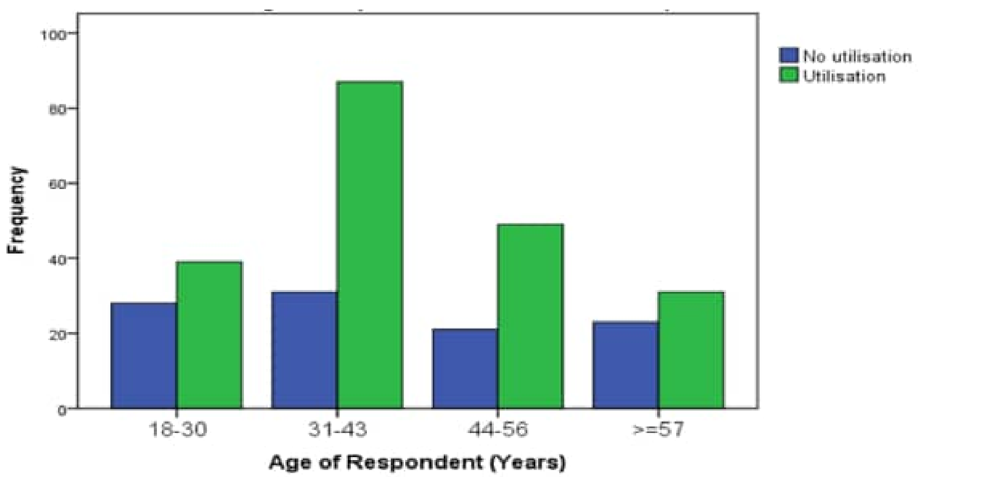

Figure 4: Association between the age of participants and utilisation of A. toxicaria Lesch

4.2 Ethnobotanical uses of A. toxicaria Lesch

People of different cultures/regions use upas trees for various purposes. It is found to be widely distributed around the world but is predominant in South and Southeast Asia countries like Indonesia, India, and the Philippines and widespread in tropical and subtropical regions like Central, West, and East Africa. In Uganda, it is found in forested regions, including the Mabira Central Forest Reserve. The various ethnobotanical uses of A. toxicaria Lesch include; traditional medicine for both human and livestock diseases, cultural significance, and timber. Several scholars point out the use of the upas tree for medicine values Andriamparany et al. (2014), Tumuhe et al. (2018), and Ugwoke et al. (2017) and this relates to the results of this study. Other uses of *Antiaris toxicaria* Lesch namely; food, making bee hives, and firewood by the local communities spell out its multiple uses by the communities. In southwestern Ethiopia, A. toxicaria is of great economic importance through the provision of quality timber and sustains the livelihoods of local communities in the vicinity (Seid et al., 2020).

The various ethnobotanical uses of upas trees could lead to accelerated population decline Mabira CFR. In a related study in Niger, it was found that woody tree species with high ethnobotanical use values were the most preferred by local communities (Abdourhamane et al., 2015). The high use-value of tree species could lead to its over-exploitation and hence extinction of species that have a poor regeneration rate like A. toxicaria (Mirgal et al., 2016). The bark of A. toxicaria Lesch was important in making bark cloth and in the central region of Uganda called Buganda, this is of great cultural significance. The bark cloth is used as a burial shroud and its fabric is worn by men and women at cultural gatherings. In a related study, it was found that bark products of A. toxicaria Lesch and Ficus natalensis were used for shoe making (foot-wear industry) as a substitute for leather Emmanuelle et al. (2024). Other products from the bark cloth include; royal and spiritual attire and several art crafts for domestic use. Similarly, in India, the bark cloth from A. toxicaria

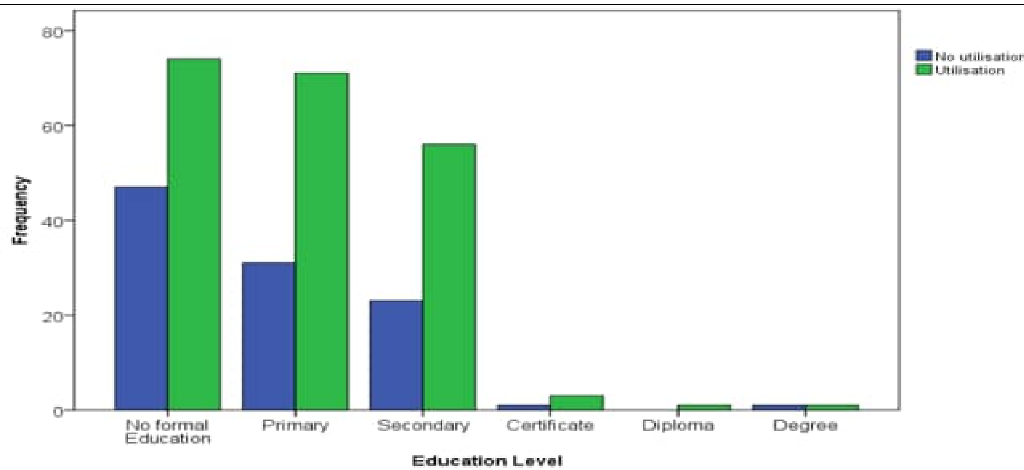

Figure 5: Association between level of education and utilisation of A. toxicaria Lesch

Lesch was found to make Maravuri amongst the Muthuvan tribe in Kerala (Umdale et al., 2020). The Maravuri was commonly used for clothing, bedspread, and ceremonial garments.

The multiple uses and wild collection of *Antiaris toxicaria* Lesch are closely associated with that of P. Africana and in both tree species, the bark is extracted except for different uses (Koros et al., 2016). Unskilled tree bark extraction can damage the plant leading to high mortality rates of the tree species. This calls for educating local harvesters in sustainable techniques and conservation of species.

4.3 Association between age and local utilisation of A. toxicaria Lesch

There was no statistically significant association between age and the use of upas trees. These findings are related to those of a study in Uganda by Bari et al. (2017) where the use of Afzelia africana Sm. had no significant difference in age. In another study in Benin, it was also found that the relationship between the use of African rosewood (a medicinal plant) and the participants' age was insignificant (Ouinsavi et al., 2021). This provides a new insight that age distribution does not influence the utilization of the forest tree resource. This could suggest that the use of *Antiaris toxicaria* Lesch does not differ meaningfully across age groups.

4.4 Association between the level of education and utilisation of A. toxicaria Lesch

Moreover, the results showed no significant association between the level of education and the utilisation of A. toxicaria Lesch. The results of this study relate to the findings of Bari et al. (2017), who found no significant association between education level and the utilisation of Afzelia africana Sm. However, there was high utilization of upas trees in respondents with low education and this relates to another study where utilisation of medicinal plants was higher in persons with low education levels (Corroto et al., 2022). The higher utilization of upas in respondents of low education could be linked to cultural transmission or accessibility or affordability that could relate to its use.

4.5 Association between Residence duration and utilisation of A. toxicaria Lesch

There was a statistically significant association between residence duration and the utilisation of *Antiaris toxicaria* Lesch. This means that residents who have lived in an area longer are more likely to utilize local resources. This may imply that long-term residency fosters deeper Indigenous ecological knowledge, highlighting the critical role of local experience and familiarity in sustaining ethnobotanical practices. The findings of this study are consistent with the findings of Wayland and Walker (2014), who stated that a longer stay in forested environments is positively associated with both greater knowledge and increased use of medicinal plants. This can be explained by the fact that people living in the same locality over time tend to rely on low-cost or free resources for basic needs, especially in rural or low-income settings, and adapt their lifestyles and knowledge systems to maximize the use of the ecological services available in their environment. Moreover, they are more familiar with plant availability, locations, and seasonal cycles.

4.6 Association between household size and utilisation of A. toxicaria Lesch

Household structure influences patterns of ethnobotanical resource use, and it should be taken into account when planning for sustainable forest management. The highest utilization of A. toxicaria Lesch is among the smallest household size class, indicating that smaller households may experience greater per capita dependence on natural resources, possibly due to limited shared labor capacity. In addition, results indicate that there is no statistically significant association between household size and the utilisation of the tree. The average household size of 5 persons from this study relates to

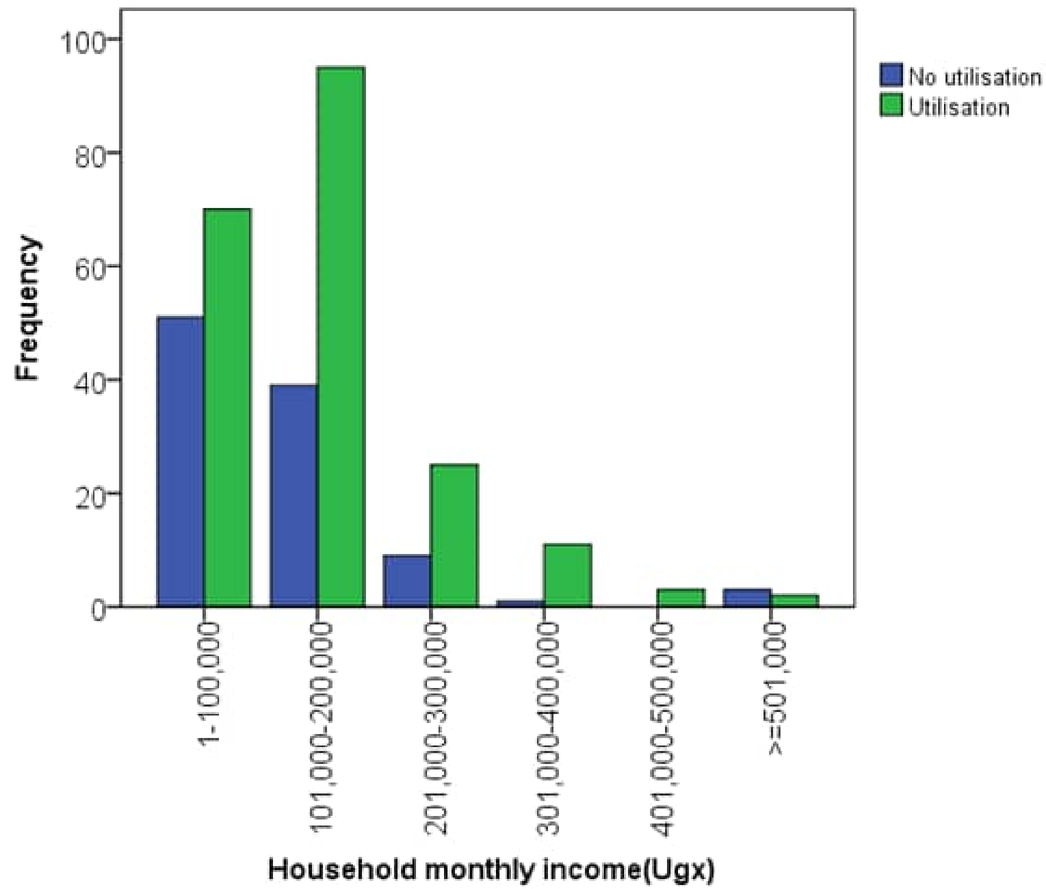

Figure 6: Association between monthly income and utilisation of A. toxicaria Lesch

the national average household size of 4.7 persons (Ministry of Water and Environment, 2017). There was no statistically significant association between household size and the utilisation of *Antiaris toxicaria* Lesch could mean that household size does not meaningfully influence how local communities utilise this tree. However, the findings of this study are not consistent with the results of Andriamparany et al. (2014) and Bari et al. (2017) in a related study where family size was significantly associated with the utilisation of medicinal plants. Similarly, a significant association was found between the utilisation of Pterocarpus erinaceus Poir and household size (Ouinsavi et al., 2021). This high dependency of households could be that the forest resources are easily accessible and available for livelihood improvement.

4.7 Association between the occupation and utilisation of A. toxicaria Lesch

Most of the participants who used upas trees were in the category of farmers and showed a significant association between the occupation of participants and the utilisation of the tree resource. This demonstrates that occupational roles influence how people interact with and rely on local plant resources. This suggests that occupation like subsistence farming strongly influences reliance on forest resources, indicating that farmers possess practical ecological knowledge and depend on multifunctional species like A. toxicaria Lesch for meeting both household and agricultural needs. The findings of Ouinsavi et al. (2021) on the socioeconomic use of Pterocarpus erinaceus Poir also indicate that farmers were the majority of the users. The same study indicates that the way people use a plant species depends not only on who they are but also on which plant species it is and the cultural or ecological context.

4.8 Association between household monthly income and utilisation of A. toxicaria Lesch

The high utilisation of A. toxicaria Lesch amongst low-income households in this study could imply more reliance on freely accessible plant species to meet essential needs, which highlights the tree's role as a socio-ecological safety net in the study area. A significant association was found between household monthly income and use of the tree species, suggesting that access, frequency, or a need to use forest resources within households are shaped by income levels, indicating that economic capability has a direct impact on dependency on natural resources. A report indicates that households living around Mabiria CFR earn income from forest resources and many resources in poor Uganda earn a livelihood from them (Ministry of Water and Environment, 2017). It implies that forest resources supply low-cost resources for household income generation hence increasing dependence. There is a need for targeted conservation strategies that take into consideration income disparities.

5 Conclusion

A. toxicaria Lesch is a multipurpose tree species mainly used for medicinal, timber, bark cloth, and ecological and cultural importance. The multiple uses of this tree render it a highly threatened species and hence needs targeted conservation strategies. High utilisation of Upas tree was mainly among farmers, low monthly income households, households who have stayed longer in the area, and low-educated groups. Alternative sources of livelihood need to be supported to offset the temptation for households to engage in the overwhelming extraction of upas tree species. National Forest Authority and local government should work hand in hand with local communities to protect Mabira CFR and promote the upas tree's domestication. Integrating local ecological knowledge into forest resource management and conservation policies is crucial for the tree's importance to low-income, long-settled, and farming communities. Promote conservation awareness among locals living in the vicinity and have inclusive policies for the sustainable use of upas trees.

Ethics approval and consent to participate

Permission to conduct this study was sought from relevant administrative authorities in the Buikwe district (study area). Consent to participate in the study was also sought from participants at the household level.

Consent for publication

The authors declare that this manuscript has not been published, or accepted for publication, or is under editorial review for publication elsewhere, and thus consent to publish this manuscript with the Food Security Journal.

Availability of supporting data

The datasets used in this study are available from the corresponding author on reasonable time requests.

Competing interests

The authors declare that there is no conflict of interest regarding the publication of this paper.

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Research Article

Assessing the patterns of crime on a nature reserve in Nigeria

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Abstract

The incidences of illegal activities around nature reserves have dire effects on biodiversity and significant environmental, social, and economic consequences. Therefore, this study examines the fundamentals of crime on nature reserves in and around Omo Forest Reserve (OFR) in Nigeria. Data were gathered using mixed methods, including focus groups, in-depth interviews, and questionnaire administration. Eight randomly selected enclaves within a 5-kilometer radius of Omo Forest Reserve were included in the study. A systematic random sampling was used to administer 164 questionnaires in the selected enclaves. Additionally, convenience sampling was used to interview administrators of Omo Forest Reserve. The collected data were analyzed using descriptive statistics. Findings show that the majority of residents in the study area were male (63% of the respondents), and they are actively involved in crime in the nature reserve, with few women playing subordinate roles in the crime. All respondents identified illegal logging and deforestation as the primary types of crime in the nature reserve. The respondents also indicated that dwellers of the communities surrounding the reservoir, hunters, and corrupt officials of the forest reserve are among the top perpetrators. Lack of law enforcement was mentioned as the major influencing factor, while alternative employment opportunities will serve as a major preventive measure. Moreover, the study found that crime on the nature reserve was on the rise in the study area. The study concluded that the increasing lack of law enforcement, growing demand for natural resources, lack of political stability, and mounting pressure for land access pose a great challenge that is likely to escalate crime in nature in the study area in the future. This study offers policy and research recommendations that engage with relevant stakeholders.

Keywords: Forest reserve; criminality; conservation; wildlife; Omo Forest Reserve

1 Introduction

Crime generally has been a persistent aspect of human existence since the earliest stages of civilization. Over time, as societies grew more advanced, the complexities of criminality also increased (White & Ronald, 2015). These complexities often stem from the combination of individual influences, such as upbringing, personality, and psychological conditions, and broader societal issues like poverty, inequality, and exclusion (Lynch & Stretesky, 2019). However, despite the establishment of legal frameworks, crime remains a significant challenge (Ward, 2014), with gaps between laws and enforcement enabling persistent violations, including crimes against humanity and nature. While high-profile crimes such as kidnapping, human trafficking, and terrorism capture substantial public attention due to their direct impact on human lives (Smith et al., 2020), environmental offenses, commonly referred to as 'crimes against nature reserves', receive less visibility despite their extensive consequences for biodiversity and ecological systems.

According to the United Nations Environment Programme (Nellemann & INTERPOL, 2016), illegal logging driven by agricultural expansion accounts for more than 30% of global timber, contributing to deforestation and climate change. Similarly, wildlife trafficking has decimated populations of endangered species, pushing them to the brink of extinction. The 2019 Global Assessment Report on Biodiversity and Ecosystem Services further indicates that up to 1 million of the estimated 8 million plant and animal species on Earth face the risk of extinction, with many likely to occur within the coming decades (Consalo, 2020). The impact of these crimes extends beyond ecological degradation; they also have far-reaching social and economic consequences (Lambrechts, 2016) . These crimes do not only threaten individual species but also disrupt entire ecosystems, leading to cascading effects on food chains, water systems, and climate regulation (UNODC (United Nations Office on Drugs and Crime), 2020) . Moreover, the transnational nature of many environmental crimes, facilitated by corruption and weak regulatory frameworks, makes them particularly challenging to address on a global scale (Barber et al., 2021) .

In Africa, the continent's rich biodiversity and natural resources have increasingly become targets for environmental crimes. Poaching, for instance, has ravaged populations of elephants and rhinoceroses, driven by international demand for ivory and rhino horn, which are used in traditional medicine or as luxury items (Lawson & Vine, 2014) . In South Africa, home to most of Africa's rhinoceroses, this crisis has escalated despite efforts to strengthen anti-poaching laws and increase surveillance (Congressional Research Service, 2021) . In Nigeria, the consequences of crime on nature reserves are particularly severe. Approximately 70-80% of the country's original forest cover, including coastal and mangrove forests, has been lost due to unsustainable logging and agricultural expansion (United Nations Country Team, 2022). Furthermore, wildlife in Nigeria is under significant threat, with recent estimates indicating that 6,000 fauna species are either threatened or extinct (Ayanniyi et al., 2024) . Besides, previous studies in Nigeria (see, for instance, Badiora and Oresanwo (2022, 2024)) have found crime against wildlife to be on the rise in different regions in the country and has become a topic of national concern, even with regional and global interest.

Given these pressing issues, this research focuses on the Omo Forest Reserve (OFR), a vital conservation area in Ogun State, Nigeria. It investigates the types, characteristics, and causes of crime on nature reserves in the region. For this study, crime on nature reserves are illicit activities that damage the environment and wildlife, including illegal logging, mining, fishing, forest conversion, environmental pollution, wildlife habitat encroachment, and animal trafficking done through a variety of means where animals and their parts are trafficked. Specifically, the study aims to answer the following questions: What is the socio-economic profile of the people living around Omo Forest Reserve, Ogun State, Nigeria? What are the types and characteristics of crime on nature reserves prevalent in the reservoir? Who are the perpetrators of crime on nature reserves in the study area? What are the factors influencing the occurrence of crime in nature reserves in the OFR? What are the efforts put in place to prevent crime on nature reserves in the study area? By addressing these questions, this study provides valuable insights that can inform policies on conservation and crime on nature reserve prevention, contributing to better protection for Omo Forest Reserve and similar areas in Nigeria and beyond. Furthermore, by integrating both qualitative and quantitative methods, this study contributes to the growing body of literature on crime in nature reserves in Nigeria, providing valuable insights into the administration of natural reserves and the preservation of biodiversity. The remaining sections include pertinent details regarding the study's location, research methodology, findings, and discussion. The article concludes with recommendations on addressing crime on nature reserves in the study area and future research directions.

2 Materials and methods

2.1 Description of study area

Nigeria occupies a special geographic position in sub-Saharan Africa and the variation in climate and geographic features endows her with one of the richest biodiversity in Africa. Its diversity of natural ecosystems ranges from semi-arid to mountain forests, rich seasonal floodplain environments, rainforests, vast freshwater swamp forests, and diverse coastal vegetation (Oluduro & Gasu, 2012). Nigeria's Niger Delta contains the largest tract of mangroves in sub-Saharan Africa. The individual components of biodiversity, such as genes, species, and ecosystems, provide the country with a wide array of goods and services. Nigeria's biodiversity is not only a matter of environmental significance but also of substantial socio-economic and cultural value (Yager et al., 2019) . One key attraction in Nigeria's natural endowment and biodiversity is its buoyant forest estate and ecology.

Nigeria is home to a diverse array of forest ecosystems, including mangroves, freshwater swamps, tropical rainforests, and savannah woodlands (Food and Agriculture Organization of the United Nations, 2019) . These forests are rich in diverse flora and fauna, providing a variety of forestal goods to the country. They also provide human settlements with eco-hospitality resorts, thereby supporting their social well-being. These forest reserves are distributed across the country, in various ecological zones, with the southern region, particularly the states of Cross River, Ogun, Edo, and Akwa Ibom, boasting the highest concentration. The Cross River National Park, renowned for its unique fauna and vegetation, is Nigeria's most prominent forest reserve. Additionally, other notable forest reserves in the country include the Afi Mountain Wildlife Sanctuary in Cross River State, the Omo Forest Reserve in Ogun State, and Okomu National Park in Edo State. These reserves hold significance not only for their biodiversity but also for their potential in supporting ecotourism, research, and conservation efforts.

This study is carried out in Omo Forest Reserve in Ogun State, Nigeria. Omo Forest Reserve is a tropical rainforest in Ogun State, Nigeria, and was named after the Omo River that runs through it. Geographically, it is located between latitude 6°15´N and 6°41´N and longitude 2°42´E and 4°14´E and is approximately 135 kilometers (84 miles) northeast of Lagos and 80 kilometers (50 miles) east of Ijebu Ode. It shares boundaries with other forest reserves in Osun State (i.e. Ago-owu and Shasha forest reserves) and Oluwa forest reserve in Ore, Ondo State (Figure 1). This natural reserve encompasses 130,500 hectares (322,000 acres/1305 km2) and is blessed with a diverse range of animal species like antelopes, bushbucks, duikers, African elephants, chimpanzees, white-throated monkeys, and forest buffalo, some of which are critically endangered (Akande et al., 2020). Similarly, Omo Forest Reserve is home to numerous majestic tree and plant species, including common trees like Melina (Gmelina arborea), African mahogany (Khaya ivorensis), African ebony (Diospyros crassiflora), and Iroko (Milicia excelsa). These dominate the forest canopy, while the undergrowth is teeming with ferns, orchids, and other plant species.

Omo Forest Reserve comprises varied ecosystems such as rainforests, savannah woods, wetlands, and riverine habitats, as well as wildlife, which all form an important part of Nigeria's natural history (Ajayi, 2022) . The Forest Reserve experiences a tropical climate with distinct wet and dry seasons. The rainy season generally lasts from March to October, with a long rainy season from March to July and a shorter one from September to November. The dry season typically occurs from November to March. Temperatures are generally high and humid throughout the year. The study area has an average daily high temperature of 32 degrees. High humidity and hot temperatures make the weather pleasant at times but also tropical humid (Amusa et al., 2017). It is warm to hot all year round, inviting bathing at average water temperatures of 27 degrees.

Omo Forest Reserve is bordered by 45 villages with about 50,000 people living in and around the reservoir (Amusa et al., 2017) . For centuries, the local communities surrounding Omo Forest Reserve have had a strong connection to the forest, relying on its resources for their livelihoods, cultural practices, and traditional knowledge. The forest provides them with food, medicinal plants, fuelwood, and materials for handicrafts. However, this symbiotic relationship between humans and nature is gradually becoming parasitic as more crimes on nature reserves are committed daily (Ajayi, 2022) . Over the years, the forest has been continuously threatened by large-scale illicit logging and incursions by a growing human population involved in farming and hunting in the surrounding areas.

2.2 Sampling procedure

The respondents were selected using a multi-stage selection process that considered the geographic proximity of various communities to the protected Omo Forest region. The Jungle 4 J4 areas, comprising 27 enclaves, were deliberately chosen due to their closeness to the nature reserve (around a 3-hour travel distance or 5-kilometer radius) and the diverse population of reserve employees and residents. From this area, eight communities based on the villages bordering the reservoir were randomly selected: Osoko, Aberu, Fowowa, Bashiru, Oloji, Erinla, Onimatisan, and Etemi, with population sizes of 430, 420, 390, 300, 380, 400, 500, and 345, respectively. Subsequently, a systematic random sampling technique (see Makwana et al. (2023)) was employed to select one out of every twenty residents, totaling 164 participants and representing approximately 5% of the households within these eight communities.

The research utilized a convenience sampling approach to conduct a focus group discussion with Omo Forest Reserve authorities, which included both reserve workers and community members. It should be noted that following the sampling methodology employed, a total of 164 questionnaires were distributed, and 160 were successfully retrieved from the study area.

2.3 Method of data collection

The study employed a mixed-methods approach, utilizing both quantitative and qualitative research techniques. Structured questionnaires were administered to residents living within a 5-kilometer radius of the Omo Forest Reserve in Ogun State, Nigeria. This specific distance was chosen because previous research by De Jong and Stewart (2019) has suggested that communities close to protected areas tend to be more directly involved in and affected by crime on nature reserves. Additionally, semi-structured interviews were conducted with the reserve workers and some community dwellers, while the focus group discussion involved some reserve workers (managers, PRO officers, ecologists, and maintenance crew) and some community members to gain a deeper understanding of their perspectives on crime on nature reserves and associated issues.

Each focus group discussion comprised a minimum of five participants. For qualitative research, there is no strict number that is agreed on to reach data saturation. Nevertheless, this study took advice from Ho (2006), who claimed that a focus group should be small enough to allow for rich and deep data analysis. If more data is needed after one focus group, the researcher may need to conduct at least one more. The average duration of these focus group discussions was thirty minutes. Previous studies have established focus groups should last between 30 and 90 minutes to capture robust data and should consist of 2 to 12 participants (Ho, 2006) . Throughout the administration of the questionnaires and focus group discussions, the study ensured the maintenance of confidentiality and the prevention of any assault. Each respondent was provided information about the purpose and objectives of the study and was given the option to participate or withdraw at any time. The data obtained from the focus group discussions was analyzed using narrative reporting techniques.

Data collection was conducted in September 2023. The questionnaires were administered to the heads of households or their designated representatives within the selected communities. English served as the primary language for the questionnaire administration and interviews. However, the instrument was occasionally interpreted into the participants' native languages to bridge any language barriers.

The questionnaire covered the socio-economic characteristics of respondents, the types of perpetrators, and factors influencing them, as well as the precautionary measures to prevent crime in nature reserves in OFR. Regarding the types of crime on nature reserves, the respondents were asked to express their point of view using one of the three-point Likert scales: Rarely (R), Occasionally (O), and Always (A), while the respondents expressed their view on the time of day each type of crime on nature reserves occurs by choosing either Morning, Afternoon, or Night. Concerning the perpetrators of crime

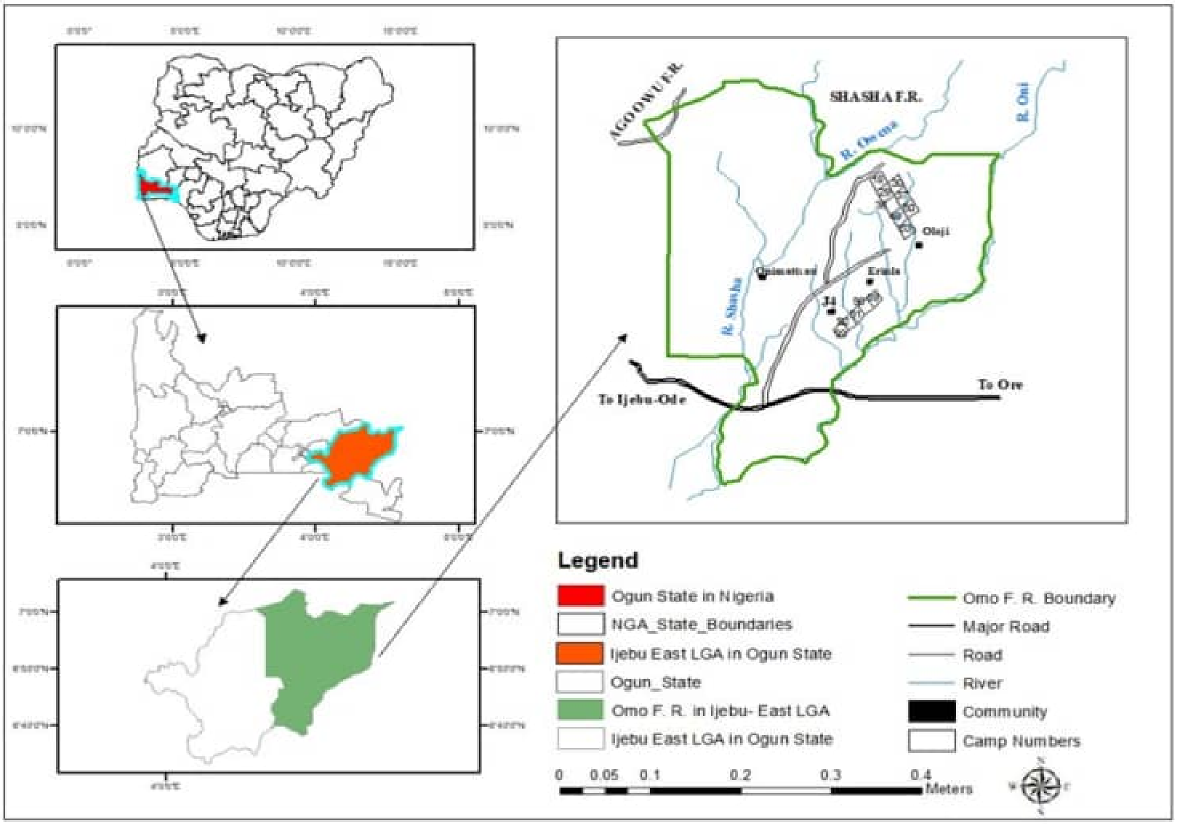

Figure 1: Location of Omo Forest Reserve in the context of Nigeria and Ogun State

on nature reserves, the respondents rated each perpetrator using one of the three-point Likert scales: Agree (A), Neutral (N), and Disagree (D). One of the three-point Likert scales: Agree (A), Neutral (N), and Disagree (D) was used by the respondents to rate the factors influencing crime on nature reserves.

2.4 Data analysis

Descriptive statistics were generally used in this study, and it was analyzed using the statistical software (SPSS 16.0). The socio-economic distribution of respondents and preventive measures of crime on nature reserves were analyzed using the frequency distribution. However, mean indices ranking and frequency distribution were used in analyzing the types, causes, and perpetrators of crime on nature reserves in OFR. The mean indices were used to summarize the Likert scale into three different indices: Perceived Frequency Index (PFI) and Relative Agreement Index (RAI). Each of the rating categories received a weight value of 1, 2, and 3 to calculate the PFI and RAI. Additionally, the Summation of weight values (SWV) was discovered. This SWV is the result of multiplying the number of respondents by the weight value assigned to a rating. This was adapted from the work of León-Mantero et al. (2020) and can be stated mathematically as:

$$SWV = \sum_{i=1}^{5} X_i Y_i \tag{1}$$

Where: SWV is the summation of the weight value, X_i is the number of respondents to rating and Y_i is the weight assigned to a value (1, 2, and 3)

The SWV is further divided by the total number of respondents ($n = 160$) to achieve the PFI and RAI. This is mathematically expressed as:

$$PFI = \frac{SWV}{\sum_{i=1}^{5} X_i} \tag{2}$$

$$RAI = \frac{SWV}{\sum_{i=1}^{5} X_i} \tag{3}$$

The summation of the PFI/RAI is then divided by the total types, perpetrators, or factors influencing crime on nature reserves identified to get the Mean Index (MI) for the study area. The mean deviation for each type is then derived by subtracting the PFI from the mean index.

3 Results and Discussion

3.1 Description of residents' socio-economic characteristics

Findings revealed that the study area is predominantly inhabited by males (62.5%), with most residents being youths (83.1%), aged 16–50 years, while adults above 50 years make up 16.9% of the population. The community is generally well-educated, as 96.3% of respondents have at least a primary school education, leaving only 3.7% without formal education. Regarding employment, 50.8% of the population engage in primary production activities such as farming, while civil and public servants account for 45.6%, and the unemployed represent a small fraction (3.8%). These primary economic activities, according to Smith et al. (2019), significantly influence crime in nature reserves.

Demographically, most inhabitants are non-indigenes (70.6%), and 63.8% of the population have lived in the area for one to ten years, suggesting a substantial level of familiarity with the environment. The study area also exhibits ethnic diversity, with respondents representing various Nigerian tribes, including Hausa, Fulani, Igbo, and Yoruba. Nevertheless, the dominant tribe is Yoruba (especially the Ijebu and Egba extractions of the Yoruba tribe), representing 72.5% of the respondents. Respondents' average length of stay in the study area is 11.4 years, while some 5% of the respondents have been residing in the study area for more than 30 years. The primary reason cited for residing in the area was proximity to places of work, particularly for those involved in primary production. Additionally, 72.5% of respondents reported being aware of crime on nature reserves, while 51.9% admitted to direct involvement in such activities within or outside the study area.

These findings indicate that the heads of households in the communities around the reserve are primarily young adult males. This demographic trend is likely linked to the physically demanding nature of their dominant occupations, which include animal and crop production.

3.2 Types and incidences of crime on nature reserves

From the summary presented in Table 1, findings revealed that illegal logging, with a Perceived Frequency Index (PFI) of 2.33, is the most prevalent type of crime on nature reserves in Omo Forest Reserve (Figure 2). This observation aligns with site visits where trucks were frequently seen transporting felled trees out of the reserve throughout the day. Despite measures to protect wildlife, most animals are confined to the core protected area of the reserve (known as Omo Reserve), located approximately three hours from the campground. This strategic placement has helped reduce wildlife trafficking but has not eliminated it. Wildlife trafficking and illegal hunting (Figure 3), ranked as the second most common crime on nature reserves (PFI = 2.27), remain significant issues and indicate that despite the existing body of laws guiding forest reserves in Nigeria, indiscriminate hunting and shooting of animals as well as trafficking them in whole and parts still run effectively in protected areas. Other notable crimes on nature reserves in descending order include environmental pollution (PFI = 2.10), habitat destruction, including loss, degradation, or fragmentation of natural habitats (PFI = 1.98), and illegal fishing (PFI = 1.90).

During a focus group discussion with the crop production department at OFR, a participant remarked: "[...] Although many of the trucks moving in and out of the reserve are from authorized bodies, some unauthorized vehicles exploit the reserve. These unauthorized vehicles enter through unregulated exit points, fell precious trees like teak, and transport them via illegal routes [...]" (Male, 40 years, reserve staff). The evidence strongly indicates that illegal logging is the dominant crime on nature reserves in the reserve, corroborated by prior research from Charles et al. (2021), who identified illegal logging as a major driver of crime on nature reserves. The timing of these crimes was also explored. While Open City Crime Data analysis (Grawert & Cullen, 2017) suggests that crimes are more likely to occur at night, a specific study was conducted at OFR to determine the timing of crime on nature reserves. The results showed that most crimes occur at night, with perpetrators leveraging the cover of darkness. This vulnerability is exacerbated by limited security measures, as security guards operate from 6 a.m. to 6 p.m., leaving the reserve unmonitored overnight.

A security guard commented: "[...] the gates of the reserve are only manned during our shifts from 6 a.m. to 6 p.m., there is no security presence at the checkpoints [...]" (Male, 35 years, reserve staff). An interview with a reserve official further revealed an incident where poachers were apprehended the night before our visit. These individuals were caught illegally felling trees and killing animals. Their lack of official markings or certification as authorized loggers led to their capture. The forest reserve officer said: "[...] ust last night, we apprehended four individuals a monkey, two antelopes, a bushbuck, and a duiker that were killed indiscriminately with gunshot. If you had arrived yesterday, you could have been lucky to see them with the illegal trees and lifeless animals. We have moved them to the police custody for prosecution [...]" (Male, 40 years, reserve staff). From these discussions, it is evident that crime on nature reserves is significantly more frequent at night, highlighting the critical need for enhanced nighttime security measures to mitigate these activities. Besides, findings show evidence of offenders' arrests. However, whether justice would be served remained unanswered.

3.3 Perpetrators of crime on nature reserves

Crime on nature reserves does not occur in isolation but is largely driven by human activities. To understand the key offenders, a survey was conducted to identify those responsible for crime on nature reserves within Omo Forest Reserve. The results, summarized in Table 2, revealed that community dwellers are the primary perpetrators, with a Relative Agreement Index (RAI) of 2.86, while abattoir owners are the least involved, with an RAI of 1.53. These findings support the assertion by Smith et al. (2019) that individuals living in or near protected areas are often the main contributors to crime on nature reserves in those regions. Other notable perpetrators, ranked in descending order of RAI, include hunters (RAI = 2.64), corrupt officials (RAI = 2.51), farmers (RAI = 2.43), reserve workers (RAI = 2.25), and miners (RAI = 2.18). This highlights the significant

(a) (a)

(b) (b)

Figure 2: Illegally felled Melina trees (Gmelina arborea) apprehended by the rangers (Photo Credited: Odofuwa)

Table 1: Types of crime on nature reserves in the study area

Types	R	(1) O	(2) A	(3) SWV	PFI	MD
Illegal logging and deforestation	37	34	89	372	2.33	0.26
Wildlife trafficking and illegal hunting	42	33	85	363	2.27	0.2
Environmental pollution	34	77	49	335	2.10	0.03
Habitat destruction (i.e. loss, degradation, or fragmentation of natural habitats)	54	56	50	316	1.98	-0.09
Illegal fishing	55	66	39	304	1.90	-0.17
Wildlife habitat encroachment	65	56	39	294	1.84	-0.23

involvement of local community members and corrupt officials in crime on nature reserves within the reserve.

Opinions varied, however, regarding the primary offenders. A community dweller claimed thus: "[...] Most of these perpetrators are reserve workers, especially the rangers, as they have access to the restricted parts of the reserve where the wildlife is kept [...]" (Female, 45 years, community dweller). Similarly, a senior public servant in the reserve stated: "[...] Many of these crimes are caused by reserve officials and workers. They engage in hunting wildlife, often for personal consumption or sales, and sometimes act under pressure from higher-ranking corrupt officials demanding bushmeat [...]" (Male, 50 years, reserve staff).

Other perspectives pointed to external actors. A respondent suggested that:"[...] Offenders often come from outside communities, such as Ore in Ondo State and Ijebu-Ode in Ogun State. The lack of security at reserve checkpoints and the multiple entry and exit points encourage this behavior [...]" (Male, 28 years, reserve staff). Furthermore, another respondent highlighted the role of external stakeholders regarding the issue thus: "[...] International organizations permitted to plant cash crops in the reserve indirectly contribute to crime on nature reserves. Their absence results in the employment of individuals who may engage in illegal activities within the reserve [...]" (Male, 30 years, Reserve staff). In conclusion, the findings indicate that community dwellers, corrupt officials, and reserve workers are the primary perpetrators of crime on nature reserves in the study area. This underscores the need for targeted interventions to address these groups and reduce the prevalence of such crimes.

(a) (a)

(b) (b)

Figure 3: Forest wildlife/animals (African civet - Civettictis civetta and Ogilby's duiker – Cephalophus killed by poachers for bushmeat trade (Photo Credited: Odofuwa)

3.4 Factors influencing crime in nature reserves

After identifying the types and perpetrators of crime on nature reserves in Omo Forest Reserve (OFR), it became evident that several factors contribute to these activities. Understanding these factors is crucial for addressing the underlying causes of crime on nature reserves, including societal dynamics, economic pressures, and gaps in legal frameworks. From Table 3, the lack of law enforcement emerged as the most influential factor (RAI = 2.68), followed by the demand for natural resources (RAI = 2.49). This indicates a significant deficiency in the enforcement of rules and regulations within the reserve. The absence of security at checkpoints after 6:00 p.m., as previously discussed, exemplifies this issue. Other factors influencing crime on nature reserves, ranked in descending order of RAI, include public awareness (RAI = 2.48), political instability (RAI = 2.38), consumer demand (RAI = 2.26), land conflicts (RAI = 2.23), rapid urbanization (RAI = 2.13), and technological advancement (RAI = 1.21).

An interview with a reserve official provided insight into the inadequacies of enforcement mechanisms. He explained: "[...] The guard room in the reserve is our only means of detaining offenders. When criminals are caught at night, they are held there until morning before being handed over to the Ogbere Police Division, the nearest police station. However, the guard room is poorly secured, allowing some offenders to escape before being transferred [...]" (Male, 33 years, reserve staff). Additionally, in a focus group discussion with cocoa specialists, it was revealed that all buildings within the reserve are government-owned and constructed, primarily temporary structures made of bricks. Private construction or land sales are prohibited, minimizing the impact of rapid urbanization. However, land conflicts do occur, particularly when one farmer encroaches on another's farmland.

Table 2: Perpetrators of crime on nature reserves in the study area

	Types	A	(1) N	(2) D	(3) SWV	RAI (2.36)	MD
1	Community dwellers are the perpetrators of crime.	143	12	5	458	2.86	0.5
2	Hunters are the offenders of crime on nature reserves.	116	30	14	422	2.64	0.28
3	Corrupt officials are the culprits of crime on nature reserves.	104	34	22	402	2.51	0.15
4	The guilty party of crime on nature reserves is farmers.	94	40	26	388	2.43	-0.07
5	The perpetrators are the reserve workers.	78	60	22	376	2.35	-0.01
6	Miners are the perpetrators of crime on nature reserves.	73	42	45	348	2.18	-0.18
7	Abattoir owners are the culprits of crime on nature reserves.	64	57	39	245	1.53	-0.83

Table 3: Factors influencing crime on nature reserves in the study area

Factors	**A (3)**	**N (2)**	**D (1)**	**SWV**	**RAI (2.36)**	**MD**
Lack of law enforcement	125	18	17	428	2.68	0.32
Demand for natural resources	90	58	12	398	2.49	0.13
Lack of public awareness	95	46	19	396	2.48	0.12
Political instability	83	55	22	381	2.38	0.02
Consumer demand	70	61	29	361	2.26	-0.10
Conflict of land	70	57	33	357	2.23	-0.13
Rapid urbanization	62	56	42	340	2.13	-0.23
Technological advancement	71	52	37	354	1.21	-1.15

A reserve official also highlighted the influence of political and workplace pressures, stating: "[...] Often, senior colleagues in other public sectors of Ogun State, or even politicians, request bushmeat or wood. We are compelled to fulfill these demands to avoid losing our jobs or facing false accusations of involvement in unrelated crimes [...]" (Male, 44 years, reserve staff). These discussions underscore the significant role of the lack of law enforcement as the primary factor influencing crime on nature reserves in OFR. Inadequate security measures and systemic corruption contribute to the persistence of these activities, demanding urgent attention to strengthen enforcement mechanisms and reduce vulnerabilities.

3.5 Preventive measures of crime on nature reserves

Studies have shown that the best and most effective solutions often come from the people who live in an area. Their long-term presence gives them a deep understanding of the local challenges and the practical ways to address them. In this study, respondents provided valuable insights into addressing crime on nature reserves in the Omo Forest Reserve (OFR), leveraging their lived experiences to propose practical measures. As summarized in Table 4, employment opportunities (15.8%) emerged as the most favored preventive measure. Respondents believe that providing jobs can redirect potential offenders toward more productive activities, encapsulating the idea that "an idle hand is the devil's workshop". They highlighted the poor state of the Nigerian economy as a contributing factor to high crime rates, including those impacting nature.

The second most advocated measure was awareness programs on crime on nature reserves (15.1%). In a statement one of the respondents, emphasized the importance of education and advocacy, stating that: "[...] More programs about the environment should be organized. These will help sensitize the public on the importance of nature, the adverse effects of certain actions, and how individuals can contribute to improving environmental health [...]" (Female, 40 years, reserve staff). Other suggested measures included implementing anti-corruption initiatives (14.1%), strengthening environmental laws (13.3%), leveraging technology and data (12.5%), supporting local communities (12.1%), reducing demand for illegal products (10.8%), and fostering international cooperation (6.3%).

The Chief Security Officer (CSO) of the reserve highlighted critical technological and infrastructure needs. He noted: "[...] As you may have noticed, there is no stable telecommunication signal in the reserve. This hinders our ability to contact external security agencies, leaving us to handle threats with limited resources. Additionally, the vastness of the reserve and its dense vegetation restrict our visibility. If equipped with stable network access and drones, we could significantly improve security and monitor activities across the reserve [...]" (Male, 43 years, CSO). This discussion underscores the importance of enhancing the reserve's security infrastructure and prioritizing public education about environmental preservation. By combining these efforts with robust law enforcement and economic interventions, crime on nature reserves in OFR can be effectively mitigated.

4 Conclusion and implications for policy and future research

This study examined the types, perpetrators, influencing factors, and preventive measures for crime on nature in Omo Forest Reserve (OFR), Ogun State, Nigeria. Findings reveal illegal logging/deforestation as well as wildlife/animal trafficking and poach-

Table 4: Preventive measures to curb crime on nature reserves

Measures	Freq.	Percent (%)
Employment opportunities	128	15.8
Awareness programs	122	15.1
Implement anti-corruption measures	114	14.1
Strengthening environmental laws	108	13.3
Use of technology and data	101	12.5
Support local communities	98	12.1
Reduce demand for illegal products	88	10.8
International corporation	51	6.3
Total	**810****	**100**

**Higher than the number of respondents due to multiple responses.

ing as the two most prevalent types of crime in nature reserves in the study area. Dwellers of the communities surrounding the reservoir were identified as the primary perpetrators, aiding and abetting the crime with contributing factors including inadequate law enforcement, urbanization high demand for natural resources, and limited public awareness. The study concludes that despite the existing legislation, crime in nature reserves still runs smoothly in protected forests, and this underscores the urgent need to develop effective strategies to mitigate crime and safeguard the critical resources essential to sustainable planning. Alarmingly, the trend of crime in nature in the reserve appears to be increasing, necessitating a comprehensive approach to address these issues holistically and ensure a safe, sustainable environment.

This study offers practical recommendations aimed at addressing the challenges of crime on the resources in the study area. As lack of law enforcement is a major issue being experienced in the reserve, the government should create and put into effect strict rules and regulations that target environmental crimes in particular. They should also ensure that environmental offenses have harsh enough punishments to discourage future offenders. More public awareness initiatives should be organized to inform people about the value of environmental protection and the penalties for crimes against it. This can also be tackled early by including environmental education in school curricula to encourage conservationist behavior from an early age. More funds should be provided for the smooth running of the reserve, especially in terms of technological tools like GPS monitoring, drones, and satellite images to help keep an eye on susceptible locations. Given the level of the reserve officials' involvement in crime on nature reserves, there should be a system that ensures that no official stays in the reserve for more than two years at a time. This will guarantee the reduction of corrupt officials in the reserve per time. The community dwellers should also be involved in decision-making and conservation initiatives by creating neighborhood-based monitoring initiatives where residents assist in reporting and stopping environmental offenses. Initiatives to repair and revitalize regions that are damaged by crime on nature reserves should be put in place. This will help to rejuvenate the health and status of nature. Finally, the government should offer substitute means of subsistence to populations dependent on practices that contribute to nature offenses, especially illicit logging or poaching.

Despite its contributions, the study has certain limitations. The one-month duration of fieldwork constrained the depth of investigation into reserve activities. Future research should extend fieldwork duration to gain a more comprehensive understanding of operations within the reserve. Additionally, the study employed primarily descriptive analysis and a relatively small sample size. Future research should consider larger samples, time-series data on crime in nature reserve incidents, and more sophisticated data analysis techniques. Lastly, while this study captured perspectives from community dwellers, most respondents were nature reserve workers. Future studies should ensure a balanced representation of responses from nature reserve administrators, community members, and other stakeholders, including international organizations involved in conservation efforts. Also, future studies could test the correlation between a resident's socioeconomic characteristics and the prevalence of wildlife crime. For instance, new studies could determine if crime on nature reserves varies by tribe or level of education, among others, using factor analysis and regression models. Caution should also be exercised when extrapolating findings, as the non-randomized selection of park staff may influence the outcomes. By addressing these limitations, future research can build on the findings of this study to advance understanding and offer even more robust strategies for combating crime on nature reserves and preserving the ecological integrity of natural reserves.

Competing interests

The authors have no conflicts of interest.

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Research Article

Diversity and distribution pattern of butterflies at emerald forest reserve, Ikoyi, Osun state, Nigeria

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Abstract

Butterflies are key pollinators and crucial indicators of ecosystem health. Studying these beneficial cluster organisms is important to develop conservation strategies at Emerald Forest Reserve. This study aimed to assess the species' occurrence; the species' richness and abundance; and the habitat preferences at site. Field sampling was conducted (October to December 2023) using transect walks and hand netting method across three sites: upper slope, lower slope, and valley bottom (each divided into three 200m transects and surveyed twice), ensuring data consistency. Data were analyzed using SPSS version 21. Species occurrence and abundance were represented in tables and percentages. One-way ANOVA was conducted to test for significant differences in species composition across the slopes. Data were evaluated using Shannon diversity index, Simpson's diversity index, Pielou's Evenness, and Margalef's species richness index. A total of 406 butterflies belonging to 31 species, 23 genera, and 5 families were identified. Nymphalidae were highest in abundance and species richness (70.97%) of the total abundance representing 22 species, while the least family Lycaenidae was represented by one species (3.23%). There was no significant difference in species composition (P¿0.05). The highest Shannon diversity index was at the Upper slope (H=2.55). The upper slope had the highest species richness index (R=3.50). Simpson's diversity index indicated higher species diversity in the Upper slope and Valley bottom (D=0.91 each). In Upper slope, Hypolimnas anthedon, Leptosia alcesta, and Ypthima asterope were abundant. Hypolimnas anthedon, and Ypthima asterope, were species found at the Lower slope. At the Valley bottom, Euphaedra medon, Junonia sophia, and Euriphene amicia amicia were mostly in abundance. This study provided information on butterfly species occurrence, richness, and abundance across habitats while highlighting the ecological value of specific microhabitats. Integrated conservation strategies involving floral diversity protection, continuous monitoring of butterfly-plant association and reducing human pressure is indispensable.

Keywords: Butterfly diversity, Conservation strategies, Habitat preferences, Line transect, Nymphalidae

1 Introduction

Insects belong to Kingdom Animalia, Phylum Arthropoda and class Insecta. Presently, there are records of at least 1 million described insect species with indications that numerous undiscovered species remain globally due to new discoveries by entomologists and ecologists (Stork, 2018). Insects inhabit diverse regions, ranging from temperate zones to tropical areas, and thrive in various habitats on land and aquatic ecosystems. Butterflies belong to the order Lepidoptera, the second largest group that are mostly widespread and globally recognized among the class Insecta. They are good indicators for verifying ecological and vegetative conditions in various ecosystems. They are identified to be among excellent groups for investigating the loss of traditional pasture and the effects of vegetation encroachment (Koch et al., 2015; Ubach et al., 2020). In addition, butterflies serve as foods to many insectivorous birds and other predators. In West Africa, over 1400 butterfly species are documented, with Nigeria hosting over 1000 of these species (Safian & Warren, 2015). While butterflies adapt to diverse habitats, a significant majority prefer forested environments, which are becoming increasingly fragmented (Hedblom, 2007).

most tropical countries of the world. Nigeria's tropical rainforest lies inside the Guinea Forests of West African Biodiversity Hotspots (Myers et al., 2000). This region is noted as the most threatened forests in the world and left out with 15.0% of its original forest cover(Conservation International, 2010). Evidence have depicted a 55.7% lost of Nigeria primary forest through anthropogenic activities such as massive logging, agricultural activities and fuel wood collection (Food and Agricultural Organization (FAO), 2005). This results to a high degree of threat to the endemic species, which affect the status of a global hotspot of biodiversity (Myers et al., 2000). Therefore, many species of butterflies have gone into extinction as a result of rapid disappearance of their natural habitats such as swamps and forests zone. This was corroborated in the study carried out by Kurylo et al. (2020), that modified habitats and anthropogenic activities influences abundance of butterfly species and their population dynamics. The increasing number of landscape fragmentation and destruction of natural habitats for the establishment of structures without deliberate attempts to maintain or re-establish pristine ecohabitat are detrimental to native butterfly species, which has resulted to imbalance in the ecosystem (Kurylo et al., 2020; Pignataro et al., 2020). Hence, the need to study species richness and abundance which are two critical variables required in conservation planning and Natural resources management (Jenber and Getu, 2020).

Emerald Forest Reserve was established to conserve biodiversity through various methods such as reforestation, conservation education, and the creation of garden with nectar sources and larval host plants. Previously, the forest reserve was a farmland that was highly exploited. However, recently, the implementation of strict conservation activities has brought protection to flora and fauna from poaching and illegal logging that has drastic effect on organism. Understanding the diversity and distribution pattern of the animals, especially butterflies, which are indicators of environmental health, would help to develop effective conservation strategies that would promote the sustainability of the resources in the reserve. Therefore, this humble effort was intended to contribute to the body of knowledge that would result in the documentation of empirical data on butterflies' diversity and distribution patterns at the reserve. Specifically, the objectives were to assess the butterfly species occurrence at the reserve, investigate their habitat preferences and evaluate their richness and abundance across various sites within the study area.

2 Materials and methods

2.1 Description of study area

Emerald Forest Reserve (EFR) is currently a 121-ha privately owned secondary rainforest located at the Abayomi Farm Estate, 25 km South of Ibadan in Ikoyi, Isokan Local Government Area of Osun State, South-West Nigeria (07°18'N 04°08'E). The Forest Reserve is bisected by two seasonal streams, the Aworin and Akinrin that join at the Emerald confluence to form the Aduni River, all of which are reduced to puddles in the dry season. The Aduni River flows over the Iyaniwura waterfall into the Osun River, which borders EFR in the West (Fig 1). The Osun River is an important perennial river, which is dammed by the government to provide water to2communities in the surrounding areas (Olajire & Imeokparia, 2000).

Topographically, the reserve has an elevation which changes across undulating landforms, and the forest ground is occasionally filled with rocky areas. Moreso, the region contains highly ferruginous tropical red soils which are associated with the basement rocks found in the region (Olusola & Adeboyejo, 2024). Emerald Forest Reserve is characterized by distinct wet season (spanning from April to November) and dry season (October to March), and within the reserve are a mix of trees, shrubs, and various types of undergrowth, creating a multi-layered canopy (Alade et al., 2023). The reserve is residence to many variety of wildlife, which includes numerous species of avifauna such as the endangered Ibadan Malimbe (Malimbus ibadanensis), Emerald cuckoo (Chrysococcyx cupreus), varieties of insects, and mammals such as Pangolins, Bushbuck (Tragelaphus scriptus), Tree squirrel (Sciurus spp.), African Civet cats (Civettictis civetta), and Mona monkeys (Cercopithecus mona). The proximity of the Osun River also contributes to the biodiversity of the area. In addition, the reserve experiences an annual precipitation of about 1400m, an average temparature of 24oC, and a relative humidity of about 88% (Olusola & Adeboyejo, 2024).

The abundance of butterflies in Nigeria often increases during the rainy season while some species may be more abundant during the dry season in specific locations like riverbanks, where resources may actually be more readily available. More so, some butterfly species are more widely distributed throughout the year, while others display effective seasonal patterns. For example, certain forms of Precis octavia, a common butterfly species, may not appear until December in the Calabar region (Ringim et al., 2022). In general, the availability of resources, such as host plants and nectar, which are often plentiful during the rainy season, heavily influences butterfly seasonality (Ojianwuna & Umoru, 2023).

2.2 Description of sampling site

The concept of catena sequence was adopted in this study for the selection of sampling sites. This concept is derived from the study of soil and vegetation science in which gradual changes in slope and drainage across a landscape influence the vegetation composition, and biodiversity present (Jenny, 1980). The Emerald Forest Reserve has a unique landscape to apply this model, creating rooms for the selection of three distinct sampling sites which are the upper slope, the lower slope, and the valley bottom (Fig 1). Each of these sites has different environmental composition thereby making it suitable to understand butterflies diversity, distribution pattern, and habitat preferences across the study area.

Upper slope: It is made up of butterfly garden, shrubs, grasses, trees with fewer canopies, agricultural farm, and accommodation center. Various plants are located in the butterfly garden. Examples are Hibiscus spp., Resinia spp., Hydrogea spp., Jasmine spp., Bachelor's button (Centaurea cyanus), Rose periwinkle (Catharanthus roseus), Cordyline (Cordyline fruticosa), Asparagon spp, Sunflower spp., Morning glory spp., Lantana (Lantana camara), etc. Other plants that are found at the upper slope include Elaeis guineensis, Citrus sinensis, and Ananas comosus.

Lower Slope: It is composed of trees with denser canopies, climbers, fewer grasses and shrubs. Examples of plants in this region are Croton caudatus, Albizia zygia, Antiaris toxicaria, Ceiba pentandra, Cola gigantea, Triplochiton scleroxylon, etc. The lower slope is mainly calm and cool due to tree canopies obstructing the penetration of sunlight.

Valley bottom: The valley bottom is the riverine area of the forest. Climbers, shrubs, rocks, few grasses, and less dense trees are present along the coastal region. The presence of the water bodies facilitates the biodiversity richness in this area.

2.3 Field sampling of Butterflies and Identification

Field sampling of butterflies was carried out across the three distinct study sites. Each of the sites was further divided into three sampling locations using a 200m transect per location following the study of (Alarape et al., 2018). Sample species were identified for prerecorded close to 5 meters length to the observer, naturally covering both broadside. A combination of Transect walk-and-count, and hand-netting methods was conducted. These two methods were chosen as they are non-invasive and among the most widely accepted techniques for butterfly sampling, especially in tropical forest habitats according to (Bonebrake et al., 2010). Using the two methods above, butterflies were sampled during nine consecutive rounds from October 2023 to December 2023. Each location was surveyed twice both in the early morning (9:00 AM and 12:00 PM) and evening period of the day (3:00 PM to 6:00 PM.), as these periods were the most active periods of butterflies observed during preliminary survey and supported by existing studies (Franzen et al., 2022). During transect walk, a steady walking pace of 10m/min Handersen and Correzzola (2014) making a total of 20 mins per transect, was maintained along the transect lines with frequent pauses to observe and record butterfly species within the transect range. Following this was the hand-netting method which was conducted for 10m/3 mins to make a total of 60 mins per transect, using sweep net with an orifice of 15cm in diameter. Therefore, a time range of 1hr 20 minutes was utilized for sampling in each location, creating space for repeatability (twice), and increased the homogeneity of the result. Though the sampling duration is shorter than it was recommended in intensive biodiversity inventories (Iserhard et al., 2013), it allowed a rapid assessment strategy without causing prolonged disturbance in the reserve.

Sampling was done by the lead researcher and the butterflies that were caught were counted and subsequently released after being identified in the field. For those butterflies that couldn't be identified on the spot, a capture-and-release approach was adopted, with careful consideration to minimize any harm to their physical well being. Photographs were taken of these unidentified butterflies from various angles to ensure an adequate visual record for later species identification. The photography process was carried out using a Digital camera (Canon Camera IXUS 175). Identification of butterflies relied on key characteristics such as their color patterns, wing spans, and body size. Field guides (Common Butterflies of West Africa by Larsen, 2003; Common Butterflies of IITA by Safian and Warren, 2015, and online field guide) were utilized for the identification process.

2.4 Data Analysis

Data collected from the field survey were analyzed using SPSS version 21. Descriptive statistics, specifically percentages and tables, were used to represent species occurrence and distribution. One-way ANOVA was conducted to test for significant differences in species composition across the three sites. Data were further evaluated using Shannon diversity index, Simpson's diversity index, Pielou's Evenness, and Margalef's species richness index.

A. Measurement of species richness

Species richness in the study area was determined by the use of Margalef's index. This was used as a simple measure of species richness (Magurran, 1988).

Margalef's index is given by:

$$R = \frac{(S-1)}{\ln N}, \tag{1}$$

where: S = total number of species, N = total number of individuals in the sample and $\ln$ = natural logarithm

B. Measurement of evenness

The Pielou's Evenness Index (e) was also used to determine the evenness of the species (Pielou, 1971).

$$e = \frac{H}{\ln S}, \tag{2}$$

where: H = Shannon-Wiener diversity index, S = total number of species in the sample

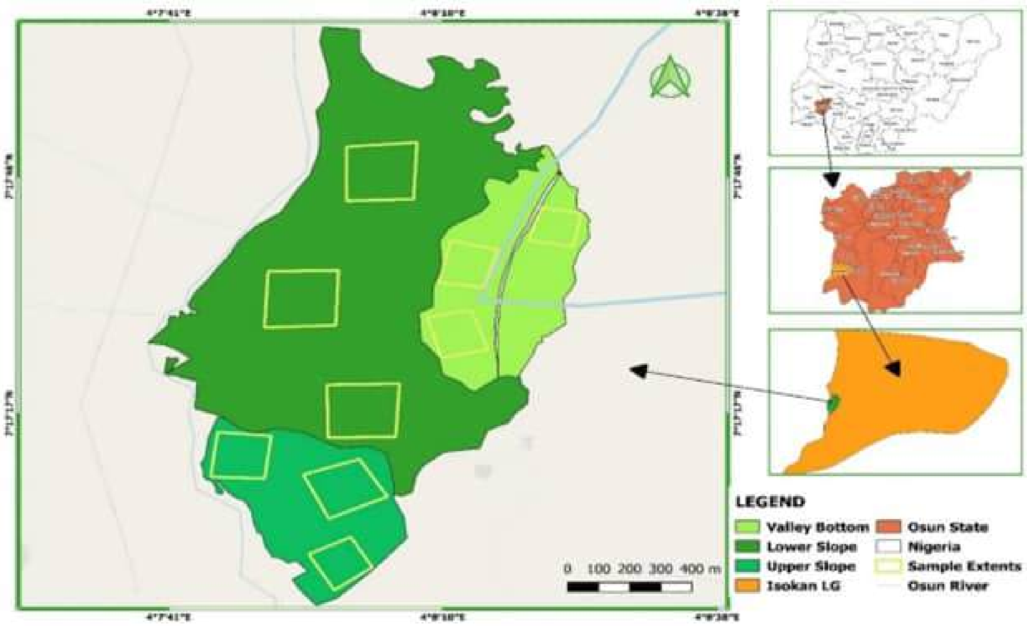

Figure 1: Map of Emerald Forest Reserve, Ikoyi, Osun state, Nigeria, showing the study sites. Source: Field work (2023)

C. Shannon diversity

The diversity of the species were compared during the study through Shannon-Wiener diversity index. This was measured by the given formula:

$$H' = -\left[\sum P_i \ln P_i\right], \tag{3}$$

where: H' = Diversity Index, P_i = proportion of each species in the sample and $\ln P_i$ = natural logarithm of this proportion

D. Simpson Index (D)

This was used to evaluate the butterfly species diversity. The probability to determine two individuals randomly selected in a sample that belong to the same species was known. This is calculated by the formula:

$$D = 1 - \left\{\frac{\sum n(n-1)}{N(N-1)}\right\}, \tag{4}$$

where: n = total number of butterflies of a particular species and N = total number of butterflies of all species

3 Results

3.1 Butterfly Diversity at Different Sites in Emerald Forest Reserve

The total number of 406 individual butterflies that belonged to 31 species, 23 genera, and 5 families were transcribed during the study. The abundance species with their proportion at different sites are reflected in Table 1. Observation revealed highest number (19) of species at the upper slope, followed by moderate number (17) of species at the valley button while the least number (15) of species were at the lower slope. Also, it was showed that highest number (170) of individual species was at the upper slope, followed by the moderate number (151) of individual species at the valley bottom while the least number (85) of individual species were at the lower slope. The most abundant species at the upper slope were Hypolimnas anthedon (Variable eggfly), Leptosia alcesta (African Spirit), and Ypthima asterope (Common three-ring) The most abundant species in the valley bottom were Euphaedra medon (Widespread Forester), Junonia sophia (Little commodore) and Euriphene amicia amicia (Friendly nymph). The most abundant species in the Lower slope were Hypolimnas anthedon (Variable Eggfly), and Ypthima asterope (Common three-ring).

3.2 Frequency of the distribution of butterflies' species and abundance among families at different sites

The species distribution and abundance among families at various sites were depicted in Table 2. Nymphalidae species were of the highest percentage (73.68%) at the Upper slope, followed by the moderate percentage (21.05%) of the Pieridae while the least percentage (5.26%) is the Papilionidae. Observation at the lower slope revealed that Nymphalidae have the major percentage 60.00% while the least percentage (20.00%) was shown. In Valley Bottom, the

Table 1: Families of butterflies in the three study sites at Emerald Forest Reserve indicating the total number of species, abundance, and their proportions

Family	TS	PTS (%)	TA	PTA (%)	Study sites					
					US		LS		VB	
					NS	NO	NS	NO	NS	NO
Nymphalidae	22	70.97	295	72.66	14	112	9	70	12	113
Pieridae	4	12.90	83	20.44	4	57	3	10	2	16
Lycaenidae	1	3.23	7	1.72	0	0	1	2	1	5
Hesperiidae	2	6.45	7	1.72	0	0	1	2	1	5
Papilionidae	2	6.45	14	3.45	1	1	1	1	1	12
Total	31	100	406	100	19	170	15	85	17	151

TS = Total of the species; PTS = Proportion of the total species; TA = Total of the abundance; PTA = Proportion of the total abundance; US = Upper slope; LS = Lower slope; VB = Valley bottom; NS = number of species; NO = total number of individuals.

highest percentage (70.59%) of Nymphalidae and least percentage (11.76%) Pieridae were recorded respectively. It was identified that Lycaenidae, Hesperiidae, and Papilionidae had the least percentage (6.67% each) number of species at the Lower slope and (5.87% percent at the Valley bottom while Lycaenidae and Hespriidae are absent in the Upper slope. High percentage (65.88%) of individual species of Nymphalidae species were recorded in the Upper slope habitat followed by moderate percentage (33.53%) Pieridae while the least percentage of individuals with an absence of Lycaenidae and Hesperidae. In the Lower slope, Nymphalidae has highest percentage (82.35%), followed by Pieridae (11.76%), and the least percentage (1.18%) is the Papilionidae . In the Valley bottom, Nymphalidae revealed the highest percentage,(74.83%) followed by moderate percentage (10.60%) in Pieridae and Papilionidae (7.95%) while the least percentages (3.31%) are in the Lycaenidae and Hesperidae.

3.3 Butterfly diversity indices

The significant test on the butterfly species diversity were determined at the three study sites. These were depicted in table 3 which shows that there is no significant difference in the composition of butterflies across the three sites ($P < 0.05$). From table 3, it can be depicted that the evenness indices of butterfly communities were similar. The highest Shannon diversity index of butterfly communities was at the Upper slope. The species richness index of butterfly communities was highest at the Upper slope while Simpson's diversity index also indicated higher butterfly species diversity in the Upper slope.

4 Discussion and conclusion

In this study, it was observed that the butterflies sighted represent about 3.10% of the 1000 known butterfly species in Nigeria. The outcome may be attributed relatively to the size of the study area and activities such as building construction and agricultural practices, especially at the upper slope which may negatively impact the butterfly community. Valley bottom habitat exhibited high butterfly richness and evenness which can be a result of the presence of water bodies. The diverse environment along riverbanks, characterized by abundant vegetation, rocks, and mud, provides essential resources for butterflies, including hydration and nutrient intake. Additionally, the open vegetation at the valley bottom provides ample breeding grounds and supports a variety of butterfly species, as exposure to sunlight facilitates optimal body temperature regulation to carry out their daily activities (Purnamasari & Santosa, 2017).

Conversely, the Lower slope habitat recorded the lowest diversity index. This could be a result of the presence of dense canopy covers inhibiting sunlight penetration. Plant photosynthesis required solar radiation to function. Hence, shaded areas that need different understory vegetation such as herbs and shrubs, which are potential nectar sources for butterflies for pollination activities (Weerakoon et al., 2015). Also, butterflies are ectothermic organisms with their activities depending on environmental temperature. As a result of this, they are mostly found in areas with abundant sunlight except for a few species which prefer shaded areas. This shaded area preference accounts for the reason why some forested species were specifically found on the Lower slope. This corroborates the finding of Rija (2022) who stated that some forested butterfly species prefer shaded areas, as shade availability favors egg oviposition and larval development during their breeding season. The rich diversity of the species at the upper slope habitat is due to openness of the areas as supported in the study which revealed that species diversity of butterflies is higher in open habitats than in habitats with dense canopy cover (Weerakoon et al., 2015).

Furthermore, the presence of Butterfly Garden and the absence of pesticide use on the plants could also have contributed to the high species richness in this habitat. Plants such as Centaurea cyanus, Gardenia Jasminoides, Catharanthus roseus, Cordyline fruticosa, present in the garden could serve as food sources for many butterfly species. This therefore aligns with the study of Fontaine et al. (2016) who stated that gardens represent food sources for butterflies and can contribute to their abundance in a particular region. In general, the habitat specificity of butterflies is closely linked to suitable environments that support plant food source which provide habitat of unique micro environment conducive to specific

Table 2: Frequency distribution of butterfly species encountered according to family at different sites in Emerald Forest Reserve

	Upper Slope		Lower Slope		Valley Bottom	
Family	Species (%)	Abundance (%)	Species (%)	Abundance (%)	Species (%)	Abundance (%)
Nymphalidae	73.68	65.88	60.00	82.35	70.59	74.83
Pieridae	21.05	33.53	20.00	11.76	11.76	10.60
Lycaenidae	0.00	0.00	6.67	2.35	5.87	3.31
Hesperiidae	0.00	0.00	6.67	2.35	5.87	3.31
Papilionidae	5.26	0.59	6.67	1.18	5.87	7.98
Total	100	100	100	100	100	100

Table 3: Species Diversity Indices at Various Sites in Emerald Forest Reserve

Habitat	Species Number	Shannon Diversity Index (H)	Evenness Pielou's Index (e)	Margalef Index (R)	Simpson's Diversity Index (D)
Upper Slope	19	2.55	0.87	3.50	0.91
Lower Slope	15	2.32	0.86	3.15	0.87
Valley Bottom	17	2.50	0.88	3.19	0.91

species. For example, species like Precis archesia, Charaxes protoclea, Junonia oenone, Euxanthe trajanus, Danaus chrysippus, Euriphene barombina, and Pseudoneptis bugandensis, were recorded from the Upper slope habitat; Sarangesa bouvieri and Amauris niavius were recorded specifically from the Lower slope habitat, and species-specific to the Valley bottom habitat were Catuna angustatum, Papilio nireus, Alcraea alciope, Euriphene amicia amicia, and Pyrrhochalcia iphis. However, approximately 13.0% of the species at the Emerald Forest Reserve exhibited a generalist distribution, indicating their ability to thrive across multiple habitats.

The study showed that Nymphalidae was the most occurrence species sighted in all sites. This corroborated similar findings in a forested region in Nigeria study conducted by Alarape et al. (2018). Also, the presence of fruit-bearing trees in the study area may have contributed to the abundance of Nymphalidae. This is in accordance with the work of (Amusan et al., 2014) who stated that Nymphalidae are exceptional fruit-feeding butterflies and are mostly found in areas with fruit trees. Pieridae ranked second in both abundance and species richness, likely due to their preference for sun-exposed environments, particularly in the upper slope habitat. Lycaenidae have a lower abundance which may be a result of the absence of their preferred host plants. This is contrary to the findings of Chidi and Emeka (2020) in the College of Education, Warri, Delta State but similar in findings conducted by Nwosu and Iwu (2011) in Okwu Ogbaku forest reserve, Imo State. Family Hesperiidae was represented by only two species. This resulted to their dawn general flight period as reported by Jenber and Getu (2020) while this study was day time.

Papilionidae was also represented by only two species. According to Matthew and Anto (2007), species in this family mostly prefer tall trees with moderate sunlight. This could typically be found in the Upper slope and Valley bottom since the Lower slope had lower sunlight because of the presence of trees with denser canopy cover. However, their presence is still lower at the Upper slope. This could be a result of human activities in the form of palm oil production, animal husbandry, building construction, ecotourism activities, and crop farming in the study site which may disrupt the availability or survival of certain species of butterflies. This study ultimately provides the first documentation of butterfly biodiversity in EMF, thereby providing a baseline for long-term ecological monitoring. The study on habitat preferences suggests that butterflies are definitely a reliable indicators of forest microhabitat conditions. More so, the high richness recorded at the valley bottom indicates that this site may serve as a biodiversity hotspot within the reserve and hence, should be prioritized for conservation. Conversely, the reduction in butterfly diversity noticed in more disturbed sites raises concerns about habitat degradation which may have broader implications for forest management and biodiversity conservation. Notably, maintaining habitat heterogeneity by preserving open, riparian, and lightly shaded areas is very essential for supporting both generalist and specialist species of butterfly, and conservation efforts should also aim to minimize land-use pressure, especially in upper slope which has evidence of agricultural encroachment and building construction. Furthermore, it cannot be concluded whether the butterfly fauna is increasing or decreasing since there's no existing data on it, hence, further study may be undertaken at five-year intervals as part of management plan, for proper identification and conservation. Additionally, this study identifies a limitation in the sampling strategy. This is embedded in the fact that the research is carried out during the dry season (October to December 2023), meaning that further study needs to be carried out in the study area to understand butterfly compositions during the rainy season. This would provide insight as to when certain species of butterflies are available and help in the proper documentation of the butterfly species. This study did not only meet its objective of assessing butterfly species occurrence, richness, and abundance across habitats but also highlighted the ecological value of specific microhabitats. The results emphasized the importance of integrated conservation strategies which involve pro-

Table 4: Checklist of Butterfly species at Emerald Forest Reserve, Ikoyi, Osun State, Nigeria

Family	Scientific Name	Common Name
Nymphalidae	*Precis archesia*	Garden Commodore
	Ypthima Asterope	Common three-ring
	Melanitis leda	Common evening brown
	Charaxes protoclea	Flame bordered emperor
	Junonia Sophia	Little commodore
	Hypolimnas anthedon	Variable egg fly
	Charaxes zingha	The Shining Red Charaxes
	Charaxes fulvescens	Forest Pearl Charaxes
	Junonia oenone	Dark Blue Pansy
	Euxanthe trajanus	Traja Forest Queen Butterfly
	Euphaedra medon	Widespread Forester
	Danaus chryssipus	Plain Tiger
	Junonia chorimene	Golden Pansy
	Euriphene barombina	The Common Nymph
	Catuna angustatum	Large Pathfinder
	Protagoniomorpha parhassus	Forest Mother of Pearl
	Hypolimnas misippus	Daneid Eggfly
	Acraea serena	Dancing Acraea
	Amauris niavius	Friar
	Acraea alciope	Alciope Acraea
	Euriphene amicia amicia	Friendly nymph
	Pseudoneptis bugandensis	Blue Sailor
Pieridae	*Eurema hecabe*	Common grass yellow
	Belenois calypso	Calypso white
	Leptosia alcesta	African Spirit
	Eurema floricola	Malagasy grass yellow
Lycaenidae	*Hypophytala nigrescens*	Black Flash
Hesperiidae	*Sarangesa bouvieri*	Bouvier's Elfin
	Pyrrhochalcia iphis	African giant skipper
Papilionidae	*Papilio dardanus*	Flying Handkerchief
	Papilio nireus	African blue-banded swallowtail

tecting floral diversity, reducing human pressure, and ensuring sustainable ecosystem functioning within the Emerald Forest Reserve.

Competing interests

The authors have no conflicts of interest.

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Research Article

The Role of Bamboo in Promoting Sustainable Livelihoods in Mizoram, Eastern Extension of the Himalaya

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Abstract

Bamboo is one of the most important natural resources in tropical and subtropical regions that include among others Eastern Himalayas and Northeast India. Similarly, the state of Mizoram has abundant bamboo resources. The objective of this study was to examine the role of bamboo in promoting sustainable livelihoods in Mizoram, an eastern extension of the Himalaya. Data were collected from both secondary and primary sources. Secondary data were obtained from the Department of Environment, Forests, and Climate Change in Aizawl. For primary data collection, a case study of Tanhril village was conducted with the involvement of 35 households engaged in bamboo production and product marketing activities. Additionally, 20 shopkeepers of Chanmari market in Aizawl were interviewed to investigate the benefits of selling bamboo products. An observation method was also employed after field visits. The analysis revealed that bamboo has significant potential in enhancing the livelihoods of rural communities as it can be a subsidiary economic activity. The study findings indicated that the per capita income from bamboo product manufacturing is 11,000 INR (Indian Rupee.) per month, while the income from selling these products is 9,000 INR per capita and month. The key factors that affect bamboo production and utilization are underutilization of bamboo resources, deliberate burning of large bamboo culms and shifting cultivation in the study area. The study suggests that small-scale village-based bamboo industries can be established at the local level, with financial assistance from the state government to support artisans and enable them to sustain their livelihoods independently.

Keywords: Bamboo resource; Eco-system services; Small-scale bamboo industry; Climate change; Economic development

1 Introduction

Bamboo belongs to a subfamily of grasses and is widely distributed across tropical and subtropical regions. Bamboo forests cover a total area of 35 million hectares, representing approximately 1% of the global forest area (FAO, 2020). Bamboo is cultivated in Africa, Asia, and Central and South America (Buckingham et al., 2014). According to Liese and Kohl (2015), about 80% of the world's bamboo species and forests are located in tropical and subtropical Asia, particularly Southeast Asia. There are more than 1,663 species across 123 genera worldwide (Vorontsova et al., 2016; Wang et al., 2013). As an essential component of forest ecosystems, bamboo plays a significant role in environmental conservation and enhancing rural livelihoods.

Bamboo is a vital species for its native ecosystems, known for its high resilience, versatility, and unique properties. Bamboo forests provide habitats for biodiversity, reduce land degradation, stabilize slopes, produce oxygen, absorb heavy metals, and sequester carbon by removing it from the atmosphere. Additionally, bamboo releases 35% more oxygen than equivalent tree species (INBAR, 2019). Its root systems can purify water and have the capacity to recharge groundwater. With over 10,000 documented uses, bamboo serves as a sustainable alternative to plastics and is widely used for making paper and wood. It also provides housing, shade, and food for millions of insect species, animals, and plants. Bamboo shoots are a popular vegetable, especially in Southeast Asia and Northeast India. As one of the fastest-growing plant species, bamboo can reach heights of up to 30 meters with a diameter of 30 cm and regenerates quickly after harvesting (Scurlock et al., 2000). Moreover, it is 100% biodegradable, making it an eco-friendly resource.

Bamboo is commonly known as the "poor man's timber" and serves as a major source of livelihood for rural communities, particularly those with limited alternative income options. Due to its growing economic and ecological significance, bamboo is now referred to as "green gold." Bamboo provides numerous ecological and economic benefits. On one hand, it contributes to ecological restoration and environmental conservation (Benzhi et al., 2015; Cai et al., 2021; Jiang et al., 2020; Zhu et al., 2021), controlling soil erosion and preventing landscape degradation. On the other hand, it provides food and shelter for both humans and animals. Additionally, bamboo serves as a significant carbon sink (P. Li et al., 2015; Venkatappa et al., 2020; Wang et al., 2013; Zhou et al., 2011) and plays a crucial role in climate change mitigation (Song et al., 2013) . Furthermore, bamboo-based industries, both large and small, generate income, create employment opportunities (Zhang et al., 2021) , and enhance rural livelihoods. Accurate mapping of bamboo forests can be valuable for resource planning, ecological protection, and economic development.

Bamboo, a primary source of livelihood, holds tremendous potential for sustaining rural economies as a natural raw material. It offers significant economic benefits by providing various tangible (Fig. 1) resources, including construction materials, handicrafts, fuelwood, and food (Nath et al., 2015; Partey et al., 2017) . Beyond its direct uses, bamboo is an integral component of rural farming systems, playing a crucial role in boosting local economies and enhancing rural livelihoods (Bajracharya et al., 2013; Dev et al., 2012) . It is considered one of the most valuable non-timber forest products (Hogarth & Belcher, 2013) . The bamboo industry has grown rapidly, contributing USD 60 billion in 2017 (INBAR, 2019) . In addition to its economic value, bamboo provides essential ecosystem services, including environmental conservation, soil erosion prevention, carbon sequestration, and the enhancement of scenic landscapes that support tourism (Liese, 2009) .

Bamboo has diverse applications, ranging from the production of high-value goods to climate solutions, carbon sequestration, and soil erosion control. Various bamboo-based products include toothbrushes, paper towels, sponges, single-use plates and cutlery, reusable water bottles, and coffee cups. In Northeast India, tribal communities use bamboo utensils for cooking rice and serve traditional wine in bamboo glasses. Bamboo is highly adaptable to different climates and soil conditions. It's hard stems enable it to withstand and recover from severe calamities or damage. The shoots and culms of bamboo emerge from its dense rhizome root system, allowing for rapid regeneration and sustainable harvesting.

India is the world's largest producer of bamboo, covering 11.4 million hectares, followed by China (5.4 million ha), Indonesia (2 million ha), and the Lao People's Democratic Republic (1.6 million ha) (Y. Li & Feng, 2019; Yang et al., 2010) . India is home to 136 species of bamboo, whereas China has 39 species (Sun et al., 2015) . Despite being the largest producer, India's share in the global bamboo trade is only 1% (UN, 2020). In India, the state of Mizoram ranks second in bamboo density and occurrence and 11th in overall bamboo production. It is often referred to as the "Bamboo Queen" of the country. Bamboo forests in Mizoram are primarily concentrated in the five northern districts, whereas in the eastern (Champhai) and southern districts, bamboo distribution is relatively sparse due to higher altitudes. Bamboo is commonly found along riverbanks and abandoned jhum lands. Homestead bamboo cultivation is primarily practiced on non-arable land, though in some areas, it is also grown on arable land. Among Mizoram's districts, Kolasib, Mamit, and Lunglei have the highest bamboo forest coverage.

Mizoram is home to abundant bamboo forests, hosting a rich diversity of species, including Melocanna baccifera (Roxb.) Kurz., Phyllostachys bambusoides Sieb., Schizostachyum dullooa Gamble, Teinostachyum wightii Beddome, and two unidentified species, locally known as Chingwa and Khupri. A significant portion of the population relies on bamboo-based products for their livelihoods. Bamboo is widely used for house construction, household items, kitchen utensils, agricultural implements, fishing devices, and as a food source in the form of bamboo shoots. Mizoram has a thriving small-scale bamboo industry, producing bamboo chips, ply boards, tiles, charcoal, and vinegar. Bamboo forests cover approximately 9,245 km², accounting for 44% of the state's total geographical area (FSI, 2019). The region hosts a total of 35 bamboo species, of which 20 are indigenous and 15 have been introduced from outside (Sati, 2017) .

Bamboo in Mizoram has rich social and cultural significance. It is used in several fairs and festivals. Chapchar Kut, a festival, is celebrated in February every year. In this festival, the bamboo dance is performed in a large playground by hundreds of people in groups. The bamboo dance is also performed on various occasions. Bamboo shoots are another important food item and a staple in the diet of the people of Mizoram. Mizoram plays a significant role in India's bamboo stock, contributing 125.8 lakh tonnes, which accounts for 3.1% of the country's total bamboo area. Furthermore, it has an estimated 2,205 million bamboo culms out of India's total of 23,297 million (FSI, 2019) . In Mizoram, bamboo grows mainly below 500. According to the Economic Survey of Mizoram (2023–24), bamboo-related activities generated a revenue of 1,304,160. Bamboo is deeply integrated into the daily lives and cultural traditions of the people of Mizoram. The famous Cheraw Dance, also known as the bamboo dance, showcases its cultural significance. Beyond tradition, bamboo plays a vital role in driving the socio-economic advancement of modern Mizoram.

Extensive literature on bamboo resources is available in publications by the (FAO, 2001, 2002, 2006; Londono, 2001; Pabuayon & Espanto, 1997). In India, the Department of Environment, Forests, and Climate Change has made significant contributions to bamboo research. However, studies specifically focusing on bamboo resources and their impact on sustainable livelihoods in Mizoram remain limited. This paper examines the role of bamboo in promoting sustainable livelihoods in Mizoram, the eastern extension of the Himalayas. The central research question is: How can bamboo resources be ef-

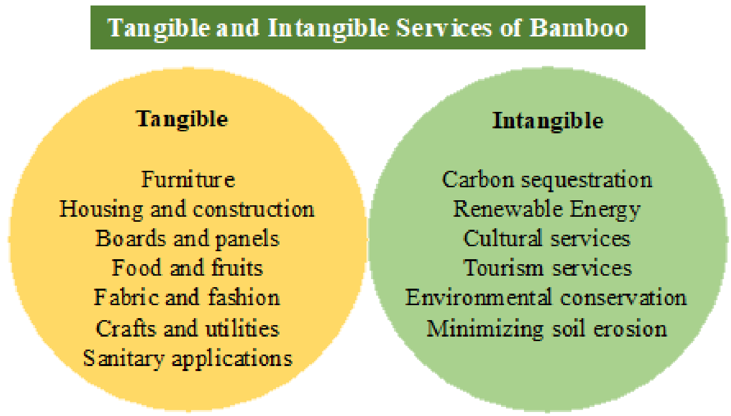

Figure 1: Tangible and intangible services of bamboo in Mizoram (Sati, 2023)

fectively utilized for sustainable livelihood development? The study analyses the potential of bamboo in terms of its distribution, area coverage, and species diversity. Additionally, it explores the dependency of local communities on bamboo-based products and their role in sustaining livelihoods through case studies. People's perceptions of the bamboo industry's contribution to livelihood sustainability were collected and analyzed. Finally, the paper offers recommendations on optimizing bamboo resources to enhance livelihoods. The study is guided by the hypothesis: "Optimal utilization of bamboo resources can significantly enhance livelihood opportunities."

2 Materials and method

2.1 Description of study area

Mizoram, a small state in the Republic of India, is located in the extreme south of Northeast India and is often referred to as the eastern extension of the Himalaya. It shares international borders with Myanmar to the east and south and Bangladesh to the west, making it the Indian state with the longest international boundary. Domestically, it is bordered by Tripura to the northwest, Assam to the north, and Manipur to the northeast, making it a landlocked state (Figure 2). Mizoram is part of the Indo-Myanmar biodiversity hotspot and is known for its rich ecological diversity. Of its total geographical area (21,087 km²), approximately 86% is forested, with bamboo forests covering around 40% of the total forest area.

The state's diverse landforms, including river valleys, floodplains, and rolling hills, contribute to its scenic beauty, earning it the titles "The Nightingale of India" and "The Land of Rolling Hills." Additionally, due to the prevalence of hilltop settlements, Mizoram is often referred to as "The Land of Highlanders." With a population density of just 52 persons per square kilometer (Census of India, 2011), Mizoram's population is sparsely distributed, with the majority concentrated in urban centers such as Aizawl and Lunglei. The state's economy is primarily agrarian, with more than 70% of the population engaged in agriculture. However, shifting cultivation (locally known as Jhuming) dominates agricultural practices, covering more than 50% of the arable land. Farmers engaged in this practice, known as Jhumias, often struggle with low crop production and productivity, which is insufficient to meet the needs of the growing population. Despite these challenges, Mizoram is endowed with abundant natural capital, including vast forests, rich bamboo resources, a pleasant climate, and ample water availability. Given the state's substantial bamboo reserves, marginal farmers have the potential to significantly improve their livelihoods by optimizing bamboo resource utilization.

2.2 Data Collection and Analysis

This study employed mainly qualitative approach, whereas some data were quantified. Data were gathered both from secondary and primary sources. The secondary data were gathered from the Department of Environment, Forest, and Climate Change, Aizawl. These data included district-wise total area, area under bamboo forests, bamboo types and their distribution, percentage of bamboo forests in each district, percentage of bamboo forests relative to the total forested area, and the distribution of bamboo forests across different forest divisions in Mizoram. Additionally, district-wise data on the number of culms, growing bamboo stock, estimated culms based on soundness in recorded forests, and key bamboo clusters in the Aizawl district were collected. For primary data collection, a case study of Tanhril village was conducted, surveying 35 households engaged in bamboo product-making. Additionally, 20 shopkeepers from Chanmari market in Aizawl were interviewed to assess the benefits of selling bamboo products. Data were also gathered through the participatory observation method during the field visits.

Sellers of bamboo products in Chanmari, Aizawl city, were interviewed regarding their monthly income and the benefits of selling bamboo. The study also analyzed people's perceptions of the role of bamboo in enhancing rural livelihoods and the challenges faced in developing small-scale bamboo industries. The collected data were further analyzed using the percentile method, descriptive statistical, correlation, and graphical representations. A map illustrating the distribution of bamboo in Mizoram was developed. Additionally, diagrams were created to depict the tangible and intangible benefits of bamboo.

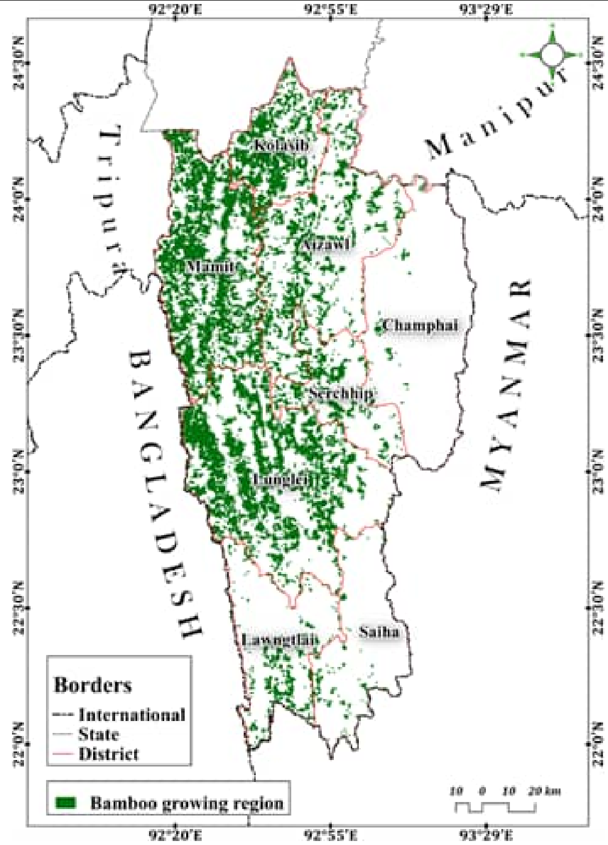

Figure 2: Distribution of bamboo in Mizoram, covering a large area of the state.

3 Results

3.1 Status of Bamboo Forests in Mizoram

Types of Bamboo and Area under Each Type

Mizoram has five types of bamboo: regenerated bamboo, bamboo without clumps, pure bamboo, scattered bamboo, and dense bamboo (Fig. 3). Dense bamboo covers the largest area, accounting for 66.15%, followed by scattered bamboo at 29.82%. Pure bamboo constitutes 2.44%, while bamboo without clumps covers 1.12%. Regenerated bamboo occupies less than 1% of the total bamboo area.

District-wise Area of Bamboo Forests

District-wise bamboo coverage as a proportion of the total area was analyzed and presented (Fig. 4). The highest bamboo-covered area was observed in Lunglei district, covering 1,956.59 km², followed by Mamit district (1,598 km²) and Aizawl district (927.69 km²). The remaining districts had less than 800 km² of bamboo coverage. The lowest bamboo-covered area was recorded in Champhai district, followed by Saiha and Serchhip. In terms of total forest area, Lunglei district had the largest coverage (4,538 km²), followed by Aizawl (3,576.31 km²), Champhai (3,185.83 km²), and Mamit (3,025.75 km²). The other districts had less than 3,000 km² of forest area.

District-wise Area Percentage of Bamboo Forests

This section presents the percentage of bamboo-covered area relative to the total area of each district, as well as the percentage of bamboo area out of the total bamboo coverage in Mizoram (Fig. 5).

Percentage of Bamboo Area to the District Area

Mamit district had the highest percentage of bamboo-covered area relative to its total district area (52.81%), followed by Kolasib (47.87%) and Lunglei (43.12%). The lowest bamboo coverage was recorded in Champhai district at 10.85%. Aizawl district had 25.94% bamboo coverage, while Lawngtlai had 28.58%. Saiha and Serchhip districts had nearly equal bamboo coverage, approximately 30

Percentage of Bamboo Area Out of Total Bamboo Area

The district-wise bamboo area as a percentage of the total bamboo-covered area was analyzed. Lunglei district had the highest proportion of bamboo forests (27.59%), followed by Mamit district

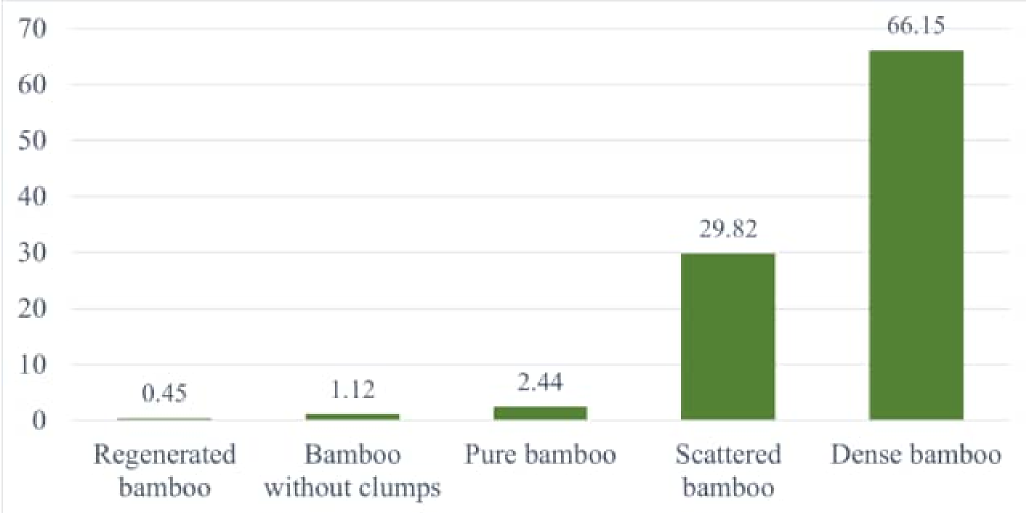

Figure 3: Type of bamboo forests and the area (%) under each type

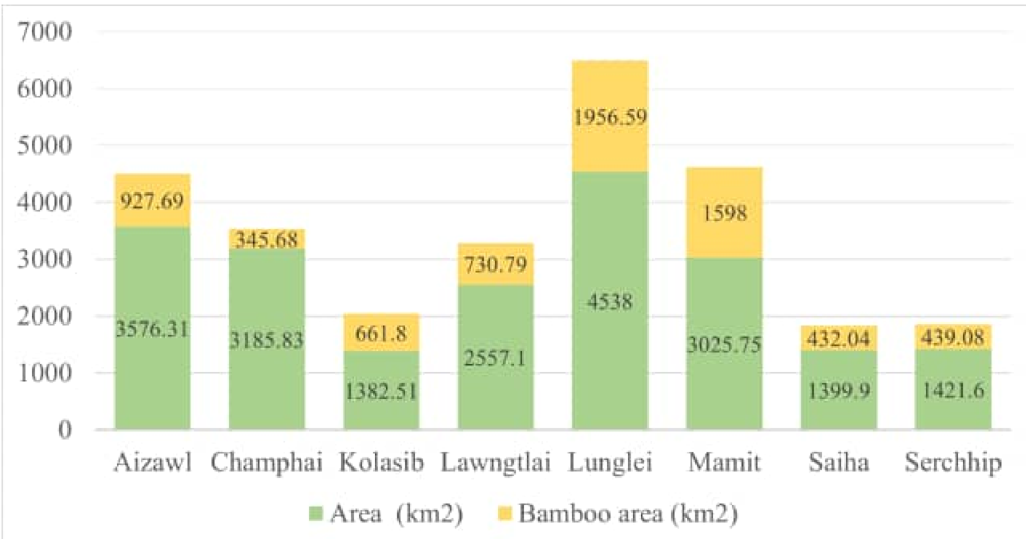

Figure 4: District wise bamboo area out of the total area of each district.

(22.53%). Aizawl district accounted for 13.08% of the bamboo forests, while Lawngtlai district had 10.3%. The remaining districts had less than 10

3.2 Forest Division-wise Distribution of Bamboo Area in Mizoram

Mizoram has 14 forest divisions, which include national parks and wildlife sanctuaries. The total area and bamboo-covered area of each division vary, as do the total number of culms and the growing stock area. Among these, the Thenzawl, Mamit, and Lunglei forest divisions have the highest bamboo coverage. In terms of the percentage of bamboo forests relative to the total forest division area, Dampa Wildlife Sanctuary has the highest proportion, followed by the Kawrthah and Mamit forest divisions. Thenzawl, Lunglei, and Mamit forest divisions have the highest number of bamboo culms. Regarding total growing stock, the highest figures are recorded in the Thenzawl, Kolasib, Lunglei, Darlawn, and Mamit forest divisions.

Number of Culms and Growing Stocks

The number of culms and total growing stock were examined and presented (Fig. 6). The total number of culms (in millions) was highest in the Lunglei district (1,558 million), followed by the Mamit district (1,062 million) and the Aizawl district (1,021 million). The lowest number of culms was recorded in the Champhai district (297 million), Saiha district (355 million), and Serchhip district (438 million). The Kolasib and Lawngtlai districts had a moderate number of culms. In terms of district-wise growing stock, the highest volume was recorded in the Lunglei district (6,109 m3), followed by the Mamit district (4,164 m3) and the Aizawl district (4,004 m3). Three districts—Kolasib, Lawngtlai, and Serchhip—had growing stock ranging between 2,800 and 1,720 cubic

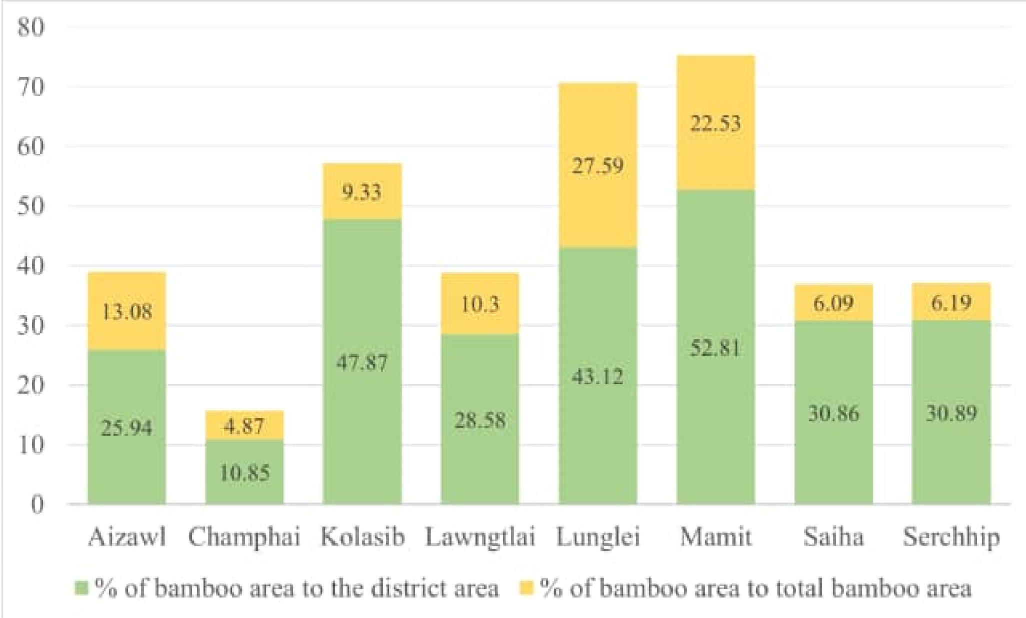

Figure 5: Percentage of Bamboo Area Relative to District Area and Total Bamboo Area. Source: EFCC (2023), Government of Mizoram.

meters. The Saiha and Champhai districts had the lowest growing stock.

Number of Estimated Culms by Soundness

There are three estimated types of culms based on soundness in the recorded forests of Mizoram—green culms, dry culms, and decayed culms (Table 1). Mizoram has 1,953 million green culms, 185 million dry culms, and 67 million decayed culms (FSI, 2019). Green culms have the highest quantity, accounting for 88.57%, followed by dry culms (8.39%). Decayed culms have the smallest quantity (3.04%).

3.3 Correlation Analyses

The bamboo area, total number of culms, and total growing stock were analyzed (Table 2). It was observed that the bamboo area is highly correlated (0.951) with both the total number of culms and the total growing stock. Furthermore, the total number of culms and the total growing stock exhibit a perfect correlation (1.000), indicating a direct proportional relationship.

3.4 Area, Number of Culms, and Growing Stock of Bamboo

Mizoram has a total area of 21,087 km², of which 7,091.67 km² is covered by bamboo forests, representing 33.63% of the total area (Table 3). Across the eight districts of Mizoram, the mean bamboo forest area is 886.46 km², with a maximum of 1,956.59 km² and a minimum of 345.68 km². The highest percentage of bamboo forest area relative to the district's total area is 52.81%, while the lowest is 10.85%, with a mean of 33.86%. Similarly, the mean percentage of bamboo forest area relative to the total bamboo forest area is 12.50%, with a maximum of 27.59% and a minimum of 4.87%. These figures indicate the availability of sufficient bamboo forests as a raw material source, which can be utilized for making bamboo crafts and other articles, thereby enhancing livelihoods.

Mizoram is rich in bamboo culms and growing stock. It has a total of 6,123.74 million culms and a growing stock of 24,014 cubic meters (Table 4). Across the eight districts, the mean total number of culms is 765.47 million, while the mean growing stock is 3,001.77 cubic meters. The maximum values recorded are 1,557.85 million culms and 6,108.97 cubic meters of growing stock, whereas the minimum values are 296.64 million culms and 1,163.26 cubic meters, respectively.

3.5 Bamboo Clusters in Aizawl District

Mizoram has five bamboo clusters, each specializing in the production of bamboo products (Table 5). The highest number of artisans is in the Hnam cluster, followed by the Lengpui cluster, while the other three clusters have an equal number of artisans. These bamboo clusters produce a variety of bamboo crafts and sell them in major cities across Mizoram. The primary bamboo products include computer brooms, floor brooms, bamboo containers, flower vases, tea coasters, bamboo hangers, vases and plates, and basket-coiled bowls. Each cluster specializes in different bamboo products.

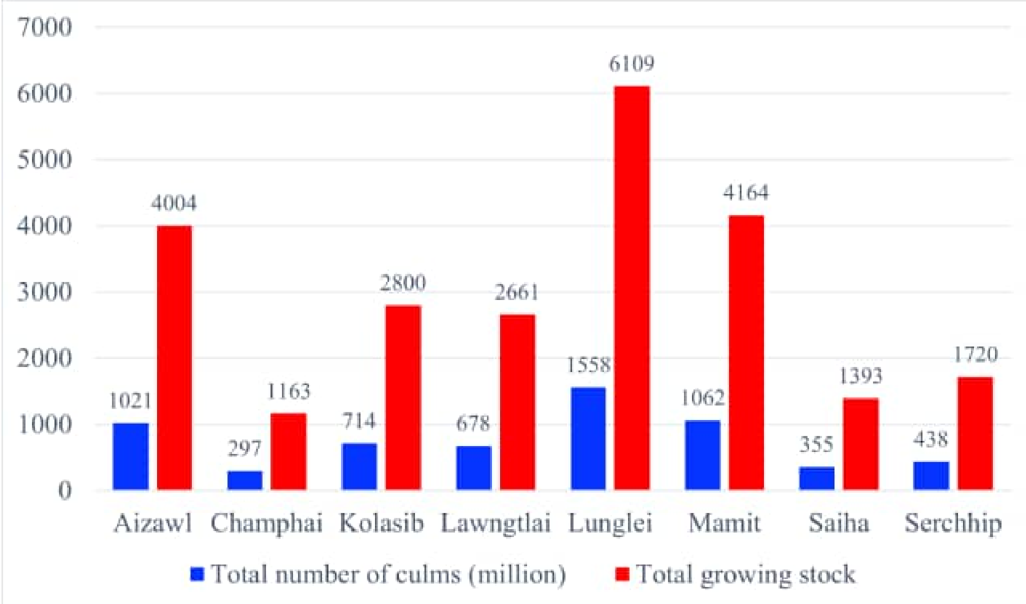

Figure 6: Total number of culms and the total growing stocks

Table 1: Number of estimated culms by soundness in recorded forests of Mizoram

S. No.	Estimated culms by soundness	Quantity (in m)	Quantity (%)
1	Green Culms	1953	88.57
2	Dry Culms	185	8.39
3	Decayed	67	3.04
4	Total	2205	100

Source: EFCC (2023), Government of Mizoram.

3.6 Economic Benefits of Bamboo Products

A case study was conducted involving 35 heads of households engaged in bamboo product manufacturing and 20 shopkeepers involved in selling these products (Table 6). The artisans produce bamboo items using traditional methods without modern technology and with limited facilities (Fig. 7). These products are sold in the local market, yielding modest profits. The study findings indicate that the per capita income from bamboo product manufacturing is INR 11,000 per month, while the income from selling these products is INR 9,000 per capita per month.

3.7 People's Perceptions of Bamboo Industry as an Option of Livelihoods

The perception of 60 households in Tanhril village regarding the bamboo industry and its role in livelihood enhancement was studied (Table 7). Several related questions were asked. About 16.7% of respondents were unaware of small-scale industries. Among the households, 58.3% were engaged in small-scale bamboo industries; however, only 41.7% were able to sustain their livelihoods through this work. Government subsidies are minimal, and market facilities are inadequate, though raw materials are readily available. Many respondents believe that small-scale bamboo industries can enhance livelihoods and that increased government support and subsidies could help make the bamboo industry more sustainable.

Mizoram has 10 major bamboo-related institutions. These institutions play a crucial role in promoting bamboo industries for sustainable livelihoods. They collaborate with industries, banks, foreign agencies, enterprises, research organizations, and social forums. Many individuals are employed in these institutions, contributing to the growth and development of the bamboo industry. Principal bamboo institutions in Mizoram promoting bamboo products for enhancing rural livelihoods are:

1. Mizoram Bamboo Mission
2. Mizoram Bamboo Development Agency
3. Department of Commerce and Industry
4. NABARD
5. Mizoram State Rural Livelihood Promotion Society
6. Rural Self Employment Training Institutes (RSETI)
7. Foundation of Micro Small and Medium Enterprises (MSMEs) Clusters
8. Evangelical Social Action Forum (ESAF)
9. PRIMAX Corporation, Taiwan
10. Advanced Research Centre for Bamboo and Rattan, Aizawl

Table 2: Correlation among bamboo area, total number of culms, and the total growing stock

Variables	**Bamboo Area (km^2)**	**Total No. of Culms (million)**	**Total Growing Stock (m^3)**
Bamboo Area (km^2)	1.000	0.951	0.951
Total No. of Culms (million)	0.951	1.000	1.000
Total Growing Stock (m^3)	0.951	1.000	1.000

Source: EFCC (2023), Government of Mizoram; analysed by the author.

Table 3: Bamboo area to district area and total bamboo area (n=8)

Statistic	Area (km^2)	Bamboo area (km^2)	% of bamboo area to district area	% of bamboo area to total bamboo area
Mean	2635.88	886.46	33.86	12.50
Maximum	4538.00	1956.59	52.81	27.59
Minimum	1382.51	345.68	10.85	4.87
Standard Deviation	1167.18	588.82	13.52	8.30
Sum	21 087	7091.67	270.92	100

Source: EFCC (2023), Government of Mizoram; analysed by the author

4 Discussion

This study reveals that Mizoram has abundant bamboo resources, a high number of culms, and significant bamboo stock. However, these vast resources have not yet been utilized sustainably. Mizoram is among the Indian states where infrastructural facilities, such as transportation and markets, remain limited. Bamboo forests are located in remote areas with steep and inaccessible terrain. Additionally, rural settlements are sparsely distributed, and population density is low. Furthermore, shifting cultivation is widely practiced in Mizoram, leading to the annual burning and clearing of bamboo forests for crop cultivation. As a result, two key factors contribute to the underutilization of bamboo resources. First, bamboo forests remain unutilized and gradually degrade over time. Second, large portions of bamboo forests are deliberately burned to make way for shifting cultivation.

A small proportion of the population is engaged in making and selling bamboo products. However, due to inadequate market facilities, these products are primarily sold in local markets and consumed domestically. This study highlights that Mizoram has a diverse range of bamboo species, with dense bamboo being the most dominant. Three northern districts—Kolasib, Mamit, and Aizawl—have the largest bamboo-covered areas, while Champhai district has the least bamboo forest coverage. In terms of the percentage of bamboo forest relative to district area, Mamit, Kolasib, and Lunglei rank the highest, indicating strong potential for establishing small-scale bamboo industries. Additionally, an analysis of the proportion of bamboo forests to the total bamboo area reveals that Lunglei has the highest bamboo coverage, followed by Mamit and Aizawl. The data suggests that four districts—Kolasib, Mamit, Lunglei, and Aizawl—possess the highest bamboo forest cover across all measured categories, making them key regions for bamboo-based economic activities.

There are 14 forest divisions, including national parks and wildlife sanctuaries, spread across all eight districts of Mizoram. Five forest divisions—Thenzawl, Kolasib, Lunglei, Darlawn, and Mamit—have particularly high potential for establishing bamboo industries and promoting sustainable livelihoods. In terms of the number of bamboo culms, Mizoram holds a significant position in India. At the district level, Lunglei, Mamit, and Aizawl rank the highest. Similarly, these three districts have the largest total growing bamboo stocks, highlighting their strong potential for bamboo-based industries, which can play a crucial role in livelihood sustainability. To support this, the State Government has established bamboo clusters in various locations to produce bamboo products. This study selected five key bamboo clusters, where numerous artisans are engaged in crafting and selling bamboo products in the local market. Each cluster specializes in specific products. The Government of Mizoram actively promotes these clusters by providing financial aid to support their growth.

Table 4: Total number of culms and total growing stock in Mizoram

Statistical Measure	Total no of culms (million)	Total growing stock (cubic meter)
Mean	765.47	3001.77
Maximum	1557.85	6108.97
Minimum	296.64	1163.26
Standard Deviation	401.45	1574.91
Sum	6123.74	24 014.14

Source: EFCC (2023), Government of Mizoram

Table 5: Key bamboo clusters in Mizoram

Cluster	Artisan No.	Major Products	Specialization
Hnam Cluster	360+ Artisans	Computer broom, floor broom, bamboo container, flower vase & tea coaster	Bamboo brooms & containers
Lengpui Cluster	75+	Bamboo Hanger	Bamboo Hanger
Sesawng Cluster	50+	Basket Coiled Bowls, Vases & Plates	Basket Coiled Bowls, Vases & Plates
Edenthar Cluster	50+	Bamboo container, Flower vase & Tea Coaster	Flower vase & Tea Coaster
Chite Cluster	50+	Bamboo container, Flower vase & Tea Coaster	Bamboo container

Source: Cluster observatory – FMC, Aizawl.

Table 6: Monthly income (INR) of people involved in making and selling bamboo products

Variables	Making ($n = 35$)	Selling ($n = 20$)
Input	35 000	540 000
Output	420 000	720 000
Net income	385 000	180 000
Per capita income	11 000	9000

Source: By author.

An input-output analysis of bamboo product manufacturing and sales reveals that small-scale bamboo industries can play a significant role in generating income, boosting the economy, and enhancing livelihoods, particularly in regions like Mizoram, where the economy primarily depends on traditional crop cultivation and the collection of non-timber forest products (NTFPs). However, this potential can only be realized if adequate market facilities and strong support from the State Government are provided. It has been observed that only a small proportion of the population in Mizoram is engaged in the bamboo industry, despite its substantial economic viability. Therefore, expanding participation in the bamboo sector could significantly improve livelihood sustainability. Public perception of the bamboo industry and its role in livelihood enhancement is generally positive. Although only a limited number of people are currently involved in the industry, they hold an optimistic view regarding the establishment of small-scale bamboo enterprises in rural areas. If adequate infrastructure, market facilities, and financial support from the State Government are ensured, bamboo could become an important source of sustainable livelihood in Mizoram.

Bamboo forests play a multifaceted role in generating income, boosting the economy, enhancing livelihoods, and conserving the environment. However, the economic condition of bamboo artisans remains poor, as they primarily belong to vulnerable communities. These artisans have limited ownership of and access to resources, markets, advanced production technologies, and insights into market trends. Most bamboo artisans are landless and do not own any farmland. As a result, their economic output remains low, with an estimated average monthly income of only INR 11,000, contributing to their continued financial hardship.

The bamboo industry presents both opportunities and challenges. The key opportunities include livelihood enhancement, revenue generation, entrepreneurship development, and sustainable growth. However, the industry also faces significant challenges, such as inadequate infrastructure, limited market access, and a lack of skill development. Government initiatives to establish bamboo industries and promote sustainable livelihoods remain limited. Some existing efforts include bamboo policies, financial assistance, research and development, skill development programs, infrastructure development, technology upgrades, market linkages, skill enhancement, and the promotion of sustainable practices. The Government of Mizoram has launched several measures for the promotion of bamboo industries in the state. However, frequent changes in government every five years disrupt these promotional efforts.

Only a few people in the state are involved in the promotion of bamboo-based industries. Most of them practice small-scale industries using traditional methods, without modern technology. As a result, the economic benefits are minimal. In comparison, other northeastern states of India have shown better performance in bamboo-based industries than Mizoram. However, there is considerable potential for developing small-scale industries in the state.

On the environmental front, the impact of bamboo depletion is severe. Large-scale cutting of bamboo on fragile slopes leads to significant soil erosion, which in turn reduces the fertility of the surface soil. In Mizoram, bamboo covers more than 50% of the total area, yet it remains largely underutilized. Additionally, bamboo is often cut and burned to prepare land for shifting cultivation. It was observed that shifting cultivation is mainly practiced in bamboo-covered areas, leading to serious environmental consequences.

(a) (b)

Figure 7: (a) an old artisan is making bamboo basket (b) bamboo handicrafts are hanging at the shop in Chanmari, Aizawl

Table 7: People's perception of bamboo industry and its role in livelihood enhancement (n = 60 HHs)

Questions	Yes (%)	No (%)	Don't know
Do you know about small-scale bamboo industry?	83.3	16.7	
Is there any small-scale bamboo industry in your village?	83.3		16.7
Are you engaged in small-scale bamboo industry?	58.3	41.7	
Is it sufficient to carry your livelihood optimally?	41.7	58.3	
Is there any government support/subsidy to small-scale bamboo industry in your village?	50.0	50.0	
Is market facilities enough for bamboo industries?	33.3	66.7	
Is raw material enough and free to bamboo industries?	58.3	41.7	
Do you think that more small-scale bamboo based industries can enhance livelihoods in the village?	66.7	33.3	
Can government support/subsidy make bamboo industry sustainable?	66.7	33.3	

Note: HHs = Households; – indicates no responses.

5 Conclusion

Bamboo is a vital resource that plays a significant role in promoting sustainable livelihoods, particularly in regions where the rural population relies on traditional agriculture and forest resources. This study reveals that Mizoram has abundant bamboo resources, distributed across almost the entire state. The region possesses a vast number of bamboo culms and substantial bamboo stock. However, the utilization of bamboo remains minimal. Only a small portion of the population is engaged in the bamboo industry, and the income generated from it is insufficient. Rural communities in Mizoram face significant economic hardships, with most people being marginal farmers who rely on traditional agricultural practices, primarily shifting cultivation, which yields low output. Many also depend on forest-based resources for their livelihood. This study suggests that Mizoram has immense potential to develop its bamboo industry by producing bamboo articles, furniture, and crafts. Currently, only a few artisans are involved in crafting handicrafts and agricultural tools for domestic use, which is not sufficient to fully harness the state's bamboo resources. Establishing small-scale bamboo industries at the village level could provide economic opportunities for rural communities. Collaboration between government agencies and local communities is essential to support sustainable livelihoods. Training programs can be introduced to enhance artisans' skills, and more individuals can be encouraged to participate in the bamboo industry. Additionally, providing adequate infrastructure and market facilities will help boost bamboo-based enterprises. Implementing these measures will significantly contribute to strengthening sustainable rural livelihoods in Mizoram.

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Journal of Forestry and Natural Resources (JFNR)

Authors Guideline

Abbreviation J. for. nat. resour.
ISSN 3005-4036

1. Editorial policy and Author's Guidelines

1.1. Background

The Journal of Forestry and Natural Resources (J. for. nat. resour., or JFNR) (JFNR) is a peer- reviewed online open-access published annually by the Wondo Genet College of Forestry and Natural Resources, Hawassa University. JFNR publishes original research findings in all subject-matter areas of forestry and natural resources. It seeks disciplinary and interdisciplinary research articles, review articles, featured articles, and short communication.

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1.2. Aims and Scope

Aims:

- serve as a communication medium among scientific communities in forestry, natural resources research, and other related fields
- publish original and innovative scientific works relevant to forestry and natural resources situation of Ethiopian as well as global problems
- encourage Ethiopian researchers, graduates, and postgraduate students to align their disciplinary and interdisciplinary researches in the direction of solving major problems in the areas of forestry and natural resources and conservation needs of the country, and
- serve as a platform to foster scientific knowledge sharing among researchers, scientists, policymakers, and practitioners working on sustainable forestry, green economy transition, issues of sustainable development goals, desertification, and dryland agriculture and forestry, combating desertification and drought, natural resource management, and conservation and other related topics.

Scope of the journal

The JFNR publishes scientific articles related to social, economic, policy, and environmental aspects: forestry, agroforestry, wildlife, soil, water and land resources, renewable energy, tourism, urban forestry, and greening, environmental science, GIS, and remote sensing.

2. Submission Guidelines

Submission system: Online

General contents of the journal JFNR uses the following format:

2.1. Research articles

These papers treat both disciplinary and interdisciplinary (thematic) types of researches encompassing basic and applied researches, graduate and postgraduate studies researches related to forestry and natural resources. JFNR will consider for publication articles from the regional and international forest and natural sources covering tropical and subtropical regions.

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Encompass critically reviewed scientific papers covering the state of the art knowledge in various aspects of forestry and natural resources. Review articles will be submitted by experts in the fields of forestry and natural resources with their expertise and experiences or invited by the editor-in-chief, associate editors, or editorial board.

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These include topics in forestry and natural resources management, conservation, utilization, education, and non-conventional research articles.

Technical papers in the areas of forestry and natural resources development encompassing different aspects of socio-economics, policy issues, wildlife, environment, rehabilitation efforts and forestry and natural resources inventory and surveys, biodiversity conservation, processing and value addition of forest products, agroforestry, non-timber forest products, medicinal plants and their domestication and commercialization, integrated watershed management, green economy transition, green initiative related studies, climate change and development, land degradation and drought, aquatic ecosystem management, fisheries, etc.

2.4. Short communications

This includes articles of brief scientific notes on preliminary results, scientific observations, experimental techniques, and recent technological advances in forestry and natural resources. It also included information on specific cases and limited applications. Manuscripts for this column should not be more than six typed pages. They should have a brief abstract and not contain more than two figures and/or two tables.

2.5. Book Reviews

A critical evaluation of recently published books in any discipline of forestry and natural resource sciences will be published under this column.

3. Manuscript evaluation process

The manuscript must be written and prepared in English. Grammar and language quality are the responsibilities of the authors to submit the manuscripts in clear and communicable language quality. Once manuscripts are submitted the editor-in-chief or associate editors will check the manuscript for possible plagiarism results, originality of the work and contents of editorial policy and scope, and authors' guidelines of JFNR. Submission of a manuscript to the Journal must be accompanied by a cover letter stating that no similar paper, other than an abstract or an oral presentation, has been or will be submitted for publication elsewhere. The manuscript should be submitted online or by email to the editorial manager, who gives the manuscript number and notifies the author of receipt of the manuscript. The manuscript number will be used in all correspondence regarding the manuscript. The editor-in-chief will consult associate editors to decide whether the manuscript is within the scope of JFNR and whether the contents are worthy of further review. Manuscripts that do not meet the minimum criteria will be returned back to the author within two weeks' time. Those that meet the minimum criteria will be passed to associate editors for quick check-ups and suggestions of potential reviewers. The associate editor is an expert selected in certain disciplinary areas and who has a wide network among professionals in their field of specialization.

3.1. Peer review process

The peer-review process will follow double-blind where the manuscript will first be evaluated by the editor-in-chief or associate editors, followed by at least two reviewers. The names of the authors will be kept anonymous while sending them to the reviewers. At least one of the reviewers will be out of the staff of the publisher institute. If the reviewers recommend publication without any change(s) and the associate editors agree(s), the manuscript and the reviewer's comments are sent to the editor-in-chief who will notify the author accordingly. If the reviewer and the associate editor recommend that the manuscript could be published after revision, the editor-in-chief will return the manuscript to the author for minor or major revision. If the reviewer and the associate editor recommend that the manuscript be rejected, the associate editor sends the manuscript and the reviewers' comments to the editor-in-chief, and the editor-in- chief will check the comments forwarded by reviewers and associate editor to make a decision and return to the authors. If very different comments and decisions are observed between or among reviewers, a third or fourth reviewer will be invited to resolve the issue. The author whose manuscript is released has the option of appealing to the editorial board. The first review process will take 6-8 weeks.

If a manuscript, sent to an author for revision, is not returned within the period specified by the editor-in-chief (normally a maximum of two months), the editor-in-chief will release it. Once released, the author must resubmit a manuscript as a new manuscript for reconsideration.

Authors whose manuscript has been accepted for publication will receive a letter of acceptance. The authors will also receive the proofreading to send their opinion in five days. The pdf version of the published manuscript will be sent to the author and co-authors via their email addresses and also will be available online on the website of the college and university. The hard copy of published articles will be dispatched to various institutions upon request free of charge.

3.2. Reviewers' Report

Reviewers are requested to evaluate the manuscript on originality of the work, state of the art and nobility of the study topic, relevant objectives, soundness, latest and appropriate methodology, results in quality to address the objectives, adequate discussion, and relevant conclusion made.

And also, the way references are presented both in the text and reference lists. Reviewers are expected to give their comments and suggestions clearly (referring to the line numbers in the paper) to the authors to assist the author (s) to address all comments and suggestions given. Language correction is not part of the review process but suggestions can be made by reviewers.

3.3. Submission checklist

You can use this list to carry out a final check of your submission before you send it to the journal for review.

One author has been designated as the corresponding author with contact details:

- E-mail address
- Full postal address

All necessary files have been uploaded:

- Manuscript:
- Include keywords
- All figures (include relevant captions)
- All tables (including titles, description, footnotes)
- Ensure all figure and table citations in the text match the files provided Further considerations
- The manuscript has been ‘spell checked’ and ‘grammar checked’
- All references mentioned in the Reference List are cited in the text, and vice versa

3.4. Authorship requirements

Where the family name may be ambiguous (e.g., a double name), please indicate this clearly. Present the authors’ affiliation addresses (where the actual work was done) below the names. Indicate all affiliations with a lower-case superscript letter immediately after the author’s name and in front of the appropriate address. Provide the full postal address of each affiliation, including the country name, and, if available, the e-mail address of each author.

Corresponding author: Clearly indicate who will handle correspondence at all stages of refereeing and publication, also post-publication. Ensure that telephone and fax numbers (with country and area code) are provided in addition to the the e-mail address and the complete postal address.

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Change in authorship requests is only made by the corresponding author to editor-in-chief.

4. Format for mansucripts

The manuscript should be prepared in Times New Roman with 11 font sizes, double space, and 2.5 cm marginal indentions on all sides. The maximum number of words should be 8000. The first page should contain the full title of the manuscript, the name(s) of the author(s) including address (es), and the institution(s) in which the research was carried out. For ease of communication, authors are requested to include their email addresses. For manuscripts with multiple authors, an asterisk should indicate the author to whom all correspondence is to be addressed.

Second and consecutive paragraphs after a heading should be indented while the first paragraph after a heading should start flush left. No space should be left between two consecutive paragraphs. Scientific names should be written in full when mentioned for the first time in the text. They should be italicized. Subsequent citations should abbreviate the genus name.

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The title of the manuscript should be concise, descriptive, in good order, and carefully chosen. It should clearly reflect the contents of the article.

4.2. Abstract:

This appears on the second page after the title. The abstract should reflect the concise contents of the paper. It should not exceed 250 words and must include a brief background on the study topic, the rationale for the study, objectives, methods used, results, and a conclusion. References and uncommon abbreviations should be avoided. Keywords should be up to five words, separated by a comma and in alphabetical order.

4.3. Introduction:

This section of the manuscript should include state of the art of background on the topic being studied, an in-depth description rationale of the study, objectives of the study, hypothesis, and significance of the study. It should provide a brief review of literature, limited to information essential to orient the reader.

4.4. Material and methods:

sub-headings under this section include specific study site description and selection, sample layout (experimental design) or survey methods, methods of data collection, and data analysis.

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The major findings in response to objectives set in the study. Be selective and focus on reporting your results.

4.6. Discussion:

It should follow your major findings. Interpret the findings, show relationships and implications, and compare with other studies in similar topics and relevant to the study. It should explore the significance of the results of the work and don't repeat what has been already described in the results. In some cases, results and discussion can be merged. (Results and discussion part could also be written as a separate chapter optionally)

4.7. Conclusions:

This can be written in a separate section or can be part of the discussion. It should also be concise, clear, and align to stated objectives and major findings.

4.8. Funding

Information that explains whether and by whom the research was supported

4.9. Conflicts of interest/Competing interests

Include appropriate disclosures

4.10. Acknowledgments

Collate acknowledgments in a separate section at the end of the article before the references and do not, therefore, include them on the title page, as a footnote to the title or otherwise. List here those individuals who provided help during the research (e.g., providing language help, writing assistance or proof-reading the article, providing finance, logistics, etc.).

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The manuscript should be prepared by Microsoft Word or an equivalent word-processing program. They should be submitted electronically according to JFNR Author's instructions.

4.12. References:

This follows author-year style taking the last author's last name in the text and alphabet refereeing system in the reference lists. As much as possible, recent references should be cited and the numbers kept to a minimum. It is the responsibility of the authors to check the accuracy of references. Papers by one or two authors are given as shown in the examples below:

- In the case of Ethiopian names, the author's given (first) name precedes that of the
- father's name; e.g., Mesfine Bekele and not Bekele, don't abbreviate Ethiopian names.
- (Kumar and Nair 2012)
- (Dhyani 2014; Kahiluoto et al. 2014; Lasco et al. 2014; Mbow et al. 2014a) - chrono- logically.
- For three or more authors, use et al. (no italics) i.e., Bekele Lemma et al. (2007), in the text (but spell out all authors' names in the reference list).

Examples of acceptable formats for listing references in the reference section are shown below.

Journal article

Kuyah S, Dietz J, Muthuri C et al (2012a) Allometric equations for estimating biomass in agricultural landscapes: I. Aboveground biomass. Agric Ecosyst Environ 158:216–224.

Assegid Assefa and Tesfaye Abebe (2014). Ethnobotanical study of wild medicinal trees and shrubs in Benna Tsemay district, Southern Ethiopia. J. Sci. Dev. 2, 17–33.

Book

Chapman DH and Pratt PF (1961) Methods of Analysis for Soils, Plants, and Waters. University of California, Riverside, California.(N.B. initials appear before the last author's family name).

Chapter in book

Cunningham AB, Shanley P, Laird S (2008). Health, habitats, and medicinal plant use. In: Pierce CJ (Ed.), Human Health and Forests: A Global Overview of Issues, Practice, and Policy.Earthscan, London, pp. 35–62.

Paper in proceedings

Tesfaye Awas, Sebsebe Demissew (2009) Ethnobotanical study of medicinal plants in Kafficho people, Southwestern Ethiopia. In: Svein Ege, Harald Aspen, Birhanu Teferra and Shiferaw Bekele, Trondheim (Eds.), Proceedings of the 16th International Conference of Ethiopian Studies. Addis Ababa, Ethiopia.

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Citation of unpublished and other source materials not readily available in libraries should not be included in the reference list but should be mentioned in parentheses in the text or as a footnote.

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Main headings and sub-heading should be numbered consecutively 1, 1.1, 1.1.1…, 2, 2.1, 2.1.1…. Main headings should be bold, capitalize the first letter, followed by lowercase letters. Sub-headings should be lower case letters. Minor sub-headings should be light font italics.

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Follow internationally accepted rules and conventions: use the international system of units (SI). If other quantities are mentioned, give their equivalent in SI.

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