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Research Article

Soil quality evaluation under Khat (*Catha edulis*), Enset (*Ensete ventricosum*) alone and Enset-Khat intercropping in Hanshika sub-watershed, South Ethiopia

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Abstract

Agricultural land use type affects the physical, chemical, and biological properties of soil. This study was designed to evaluate the impact of different agricultural land use types: Khat (*Catha edulis*), Enset (*Ensete ventricosum*), and Enset-Khat on the physical and chemical properties of soils in Hanshika subwatershed, Southern Ethiopia. Twenty seven (3 treatments* 3 replications * 3 sample plots) composite soil samples were collected from the top 0-30 cm depth. Undisturbed soil samples were also collected for bulk density determination. The result showed that bulk density (BD) varied significantly with land use types, and was smaller in soil under Enset (*Ensete ventricosum*) than the rest of land use types. The soil pH (H2O), soil organic carbon, total N, available P, available K and cation exchange capacity were higher in soils under Enset (*Ensete ventricosum*) than in Khat (*Catha edulis*) mono-cropping land use type. Exch. K, Ca and Mg also varied with land use types while exch. Na did not show any trend of variation among the land use types. Cultivating Enset (*Ensete ventricosum*) alone or intercropping with Khat (*Catha edulis*) have improved most of the investigated soil qualities than Khat (*Catha edulis*) alone. Further studies might be required to fully understand and clarify the influence of these management practices on soil properties and soil qualities for valid generalization.

Keywords: Soil health, land conversion, land uses, intercropping, soil properties

1 Introduction

From the point of view of agriculture, it is a basic interest to evaluate soil quality (Carter et al. 2004). Maintaining soil quality provide economic benefits in the form of increased products and productivity (USDA-ERS, 1997). Soil quality (Karlen et al. 1997), which is the capacity of a soil to function, within natural or managed ecosystem boundaries, to sustain biological productivity, maintain or increase water and air quality, and promote human health. Soil quality started to be interpreted as a sensitive and dynamic way to document soil conditions, as resistance to stress imposed by land use changes (Karlen et al. 2001). From the view of soil quality, the dynamic soil nature describes the condition of a specific soil due to land use types and management practices which is measured by using various chemical, physical and biological indicators (Karlen et al. 2003). 1 In natural processes of soil, reference values represent the inherent capacity of a soil to function by the soil forming factors in its native state and can be used to compare effects of land use types or different management practices on similar soils. Management of the inherent soil health can enhance sustainable production of high quality products with little or no external inputs (Mausbach and Seybold 1998).

Agriculture is the backbone of the Ethiopian economy and special attention has been given by the government to transform the sector. It represents 42% of the GDP and 85% of the population gain their livelihood directly or indirectly from agriculture. About 64% of agricultural value addition comes from different crops. The most important constraint limiting crop yield in developing nations, and especially among resource-poor farmers, is the decline in soil quality (CSA 2015) primarily due to lack of land use planning, inappropriate cropping system with lower levels of fertilizer application, reduction in the length of fallow periods, complete removal of crop residues from fields and lack of adequate soil conservation practices (Elias 2002). Ethiopia is one of the countries that experience the highest rates of nutrient depletion in Sub Sahara Africa (FAO 2010). UNDP-ERS (2002) reported that loss of 30 kg N/ha and 15-20 kg P/ha annually. A field level investigation in southern Ethiopia revealed even higher rate of nutrient depletion amounting -102 N and 26 kg K particularly in distant fields planted to cereals (Elias 2002). The ever increasing soil degradation and nutrient loss from cultivated fields result in declining soil quality that urgently call for actions before reaching at an irreversible stage. The uncultivable lands of the country (hilly, stony and marshy lands) which constituted a significant proportion of the total land size, currently are converted into cultivated land due to high population pressure. Such practices are more widely observed in the southern Ethiopia particularly in Gedeo, Sidama, Gurage, Kambata and Walaita Zones where cultivated lands are converted into Enset (*Ensete ventricosum*), Khat (*Catha edulis*) and Khat-Enset intercropping. However, there is no detail research conducted on the impacts of such conversion practices on soil quality. Hence, this study was proposed to evaluate soil quality as impacted by different agricultural land use types: Enset (*Ensete ventricosum*), Khat (*Catha edulis*) and KhatEnset, in Hanshika subwatershed, Southern Ethiopia.

2 Materials and methods

2.1 Description of the study area

The study area, Hanshika Subwatershed, is located at about 268 kms Southeast of Addis Ababa, in Wondo Genet District of the Sidama Regional State. Geographically, Wondo Genet District is located between 380 37' to 380 42' E longitude and 70 02' to 70 07' N latitude (Fig. 1). It is part of the L. Hawassa watershed situated in the eastern boundary of the southern rift valley.

2.2 Climate and agro-ecology

The climate of the area belongs to the Ethiopian rift valley and characterized by subtropical agro climatic zone. The minimum and maximum annual temperature of the area is 17oC and 19oC, respectively. The mean annual rainfall of the study area is 1214mm (EOSA 2007).

2.3 Geology, soil and vegetation

According to Makin et al. (1975) the main parent materials are volcanic deposits of ignimbrite, ash, lava and tuff. The geological bedrock of the area consists of mainly acidic rocks, sometimes inter bedded with lavas of basaltic composition, probably of terrain origin (Eriksson and Stern 1987). The soils around Wondo Genet District are classified as andosols with sandy loam - loam to silt loam textures (Fantaw 2017) and are naturally fertile soils except phosphate limitations (Makin et al. 1975). Montane forest species such as Celtis africana, Cordia africana, Croton macrostachys, Albizia gumifera, Podocarpus gracilor, Milletia sp. And Phonix spp. are the most dominant tree species (Eriksson and Stern 1978). Currently, the landscape has been changed to different cultivated land use types for the production of both cereal and perennial crops such as sugar cane, Khat (*Catha edulis*), Enset (*Ensete ventricosum*), Coffee and various fruit trees. The study area, Hanshika Subwatershed, is particularly characterized by Khat (*Catha edulis*), Enset (*Ensete ventricosum*) and Enset-Khat intercropping.

2.4 Site selection, soil sampling and analyses

Reconnaissance survey has been carried out to record the land use history, cropping sequences, and have some field observation in the study area followed by identification of representative soil sampling plots. Although data was not presented, topographic attributes such as altitude, landscape position, and slope percent were also recorded. Three replicates of dominant cultivation practices (here after land use types): Khat (*Catha edulis*), Enset (*Ensete ventricosum*) and Enset-Khat intercropping, were selected and three sample plots were randomly assigned and replicated in each land use type. Fifteen sub-samples, five from each plot, were collected from each land use type to pool one homogenized representative composite soil sample. A total of twenty seven (3 land use types *3 replications*3 sample plots* 1 soil depth: 0-30 cm) bulk soil samples were collected. The soil samples were air-dried, grounded and made to pass through a 2 mm diameter sieve. For soil bulk density determination, a total of twenty seven separate undisturbed soil samples were also collected from 0-30 cm soil depth with three cylindrical cores (10 cm height and 7.2 diameter) per depth. Finally, the prepared soil samples were brought to Wondo Genet College of Forestry and Natural Resorce and Batu Soil Laboratory Centers to analyse selected physical and chemical parameters. The soil physical parameters considered were particle size distribution, bulk density and total porosity while the soil chemical parameters include soil pH, organic carbon content, total nitrogen, available phosphorus, available potassium, cation exchange capacity and exchangeable bases (Na, K, Ca, and Mg). Soil textural fractions were determined by hydrometer after dispersion

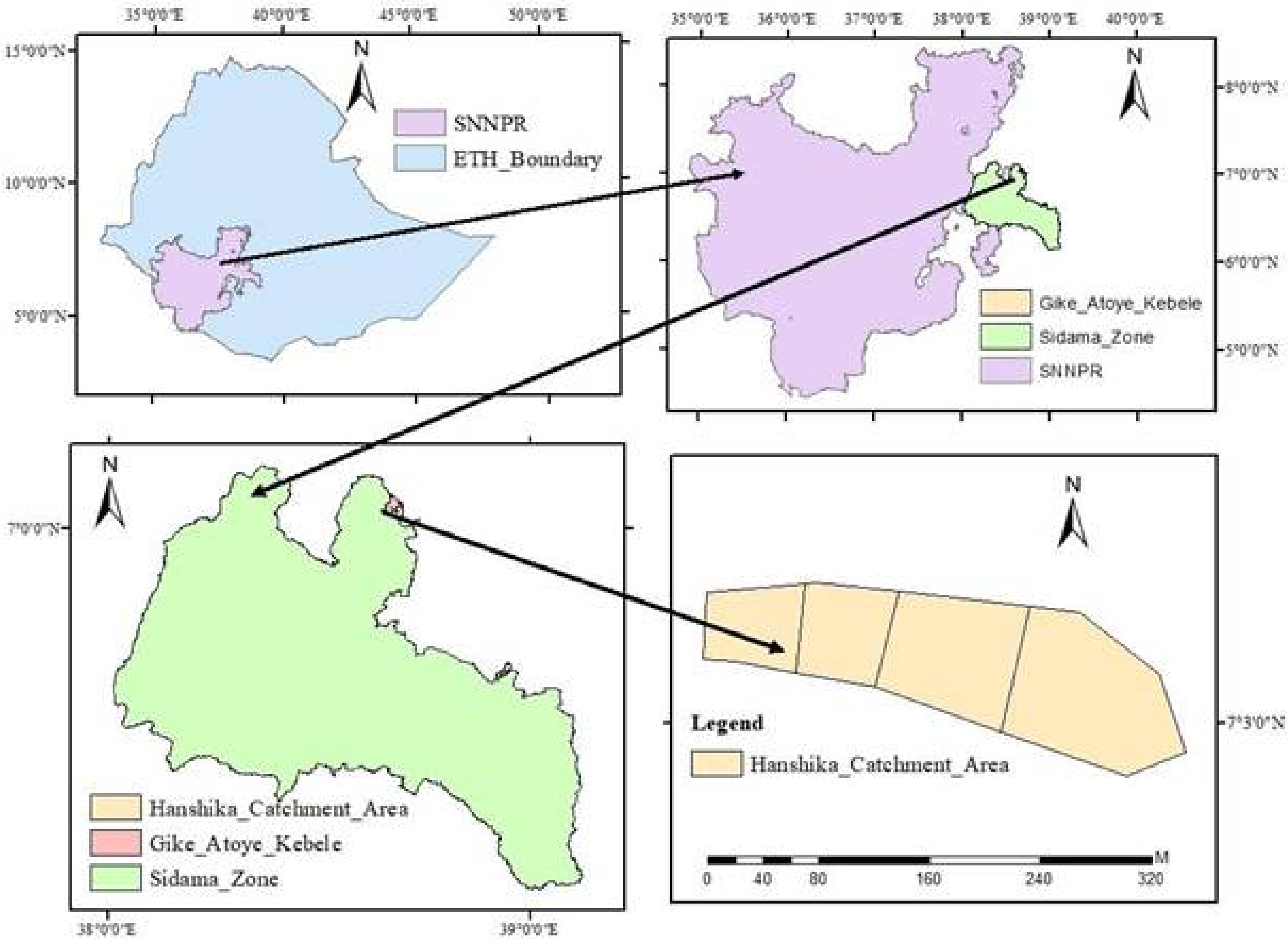

Figure 1: Location map of the study area

in a mixer with hexametaphosphate. Soil bulk density was determined after drying the soil samples in an oven at 105oC to constant weights method (Blake 1965). Total porosity was computed from the values of bulk density (BD) and particle density (PD) considering 2.65g/cm3

$$\text{Total porosity (\%)} = \left(1 - \frac{\text{BD}}{\text{PD}}\right) \times 100$$

The soil pH-H2O was measured in water suspension in a 1:2.5 (soil: liquid ratio) potentiometrically using a glass-calomel combination electrode (Reeuwijk Van 1993). The Walkley and Black (1934) wet digestion method was used to determine soil organic carbon content and percent soil OM was obtained by multiplying percent soil OC by a factor of 1.724 following the assumption that OM is composed of 58% carbon. Total nitrogen was measured titrimetrically following the Kjeldhal method as described by Jackson (1973). The carbon-nitrogen ratio of the prepared compost was determined from the quotient of soil organic carbon to total nitrogen (Martin 1991). Available phosphorus was determined colorimetrically using spectrophotometer after the extraction of the soil samples with 0.5M sodium bicarbonate (NaHCO3) at pH 8.5 following the Olsen extraction method (Olsen et al. 1954). The exchangeable basic cations (Ca, Mg, K and Na) were extracted with 1N ammonium acetate at pH 7 (Chapman 1965). Exchangeable Ca and Mg were determined from this extract with atomic absorption spectrophotometer, while exchangeable K and Na were determined from the same extract with flame photometer. Cation exchange capacity (CEC) of the soil was determined from ammonium acetate saturated samples that was subsequently replaced by sodium from a percolated sodium chloride solution after removal of excess ammonium by repeated washing with alcohol (Chapman 1965). Percentage base saturation (PBS) was calculated by dividing the sum of the charge equivalents of the base-forming cations (Ca, Mg, Na and K) by the CEC of the soil and multiplying by 100.

2.5 Data analysis

The collected data was subjected to completely randomized design analysis of variance (ANOVA) (CRD) using the General Linear Model (GLM) of the Statistical Analysis System software (SAS Institute 2002). Mean separation was done using Duncan's Multiple Range Test (DMRT) at 5% probability level.

3 Results and discussion

3.1 Soil Physical Properties

3.1.1 Soil texture

Analyses of the soil textural fractions showed that there was no significant variation $(p > 0.05)$ in all fractions across all land use types (Table 1). Even though there was no significant difference between them, relatively higher mean sand fraction was observed in soil under Khat-Enset intercropping (56%) followed by Khat (*Catha edulis*) (52%). The lowest sand percent (49%) was in soil under Enset (*Ensete ventricosum*). The highest silt (21%) proportion was observed in soils of the Enset (*Ensete ventricosum*) whereas the lowest (13%) was in Khat-Enset intercropping of cultivated land use types. Across all land use types, the soil textural class is sandy clay loam (Table 1). The similar textural class across all land use types indicates the homogeneity of soil forming processes and similarity of parent materials (Foth, 1990) and not influenced considerably by land use types and soil management (Brejda et al. 2000).

3.2 Soil bulk density

The soil bulk density showed significant variation with land use types (p 0.05). The highest mean soil bulk density was recorded under Khat (*Catha edulis*) (0.98 g/cm3) while the lowest was under the Enset (*Ensete ventricosum*) (0.86 g/cm3) land use type (Table 1). The highest mean soil bulk density obtained in Khat (*Catha edulis*) land use type could be attributed to the lower level soil organic matter content and total porosity (Tables 1 and 2). Sintayehu (2006) also reported variation in soil bulk density with land use types due to differences in the land management and land use histories. The smaller bulk density in soils under Enset (*Ensete ventricosum*) land use type is an indicative of better soil physical quality as it is less compacted and does not limit root penetration (Landon 1991).

3.3 Total porosity

The soil total porosity results of the three land use types were significantly $(p \leq 0.01)$ different. The largest mean value of soil total porosity was observed under the Enset (*Ensete ventricosum*) (67.54%) land use type while the lowest was under the Khat (*Catha edulis*) (63.02%) land use type (Table 1). The highest mean total porosity under the Enset (*Ensete ventricosum*) land use type might be due to the high organic carbon (4.98%) or organic matter (8.58%) contribution from the Enset (*Ensete ventricosum*) (Table 2). However, the total porosity of soils of the study area falls within the normal porosity range (30 and 70%) for most mineral soils and can be used as a very general indication of the degree of compaction in a soil in the same way as bulk density is used (Landon 1991).

3.4 Soil Chemical Properties

3.4.1 Soil pH (H2O: 1:2.5)

The soil pH also varied significantly $(p \leq 0.05)$ with land use types (Table 2). The highest soil pH was recorded in the soils under Enset (*Ensete ventricosum*) (pH 5.76) followed by the

KhatEnset (pH 5.75) land use types and both fall under medium ratings and preferred range for most crops (Landon, 1991). The lowest pH (pH 5.49) was observed in soil under Khat (*Catha edulis*) land use type. However, according to Tekalign (1991) rates for Ethiopian soils, the soil pH of the study area was medium (5.3-5.9) acidic across all land use types.

3.5 Soil organic carbon (OC, %)

The soil organic carbon showed significant $(p \leq 0.01)$ differences with land use types (Table 2). The highest (4.77%) mean OC was observed in soil under Enset followed by the Khat-Enset (4.12%) land use type while the lowest (2.67%) mean value of OC was found in the Khat. The lower SOC content under Khat than in Enset and Khat-Enset intercropping could be due to the reduced amount of organic materials (green leaves) being returned to the soil system (Girmay et al. 2008).

On the other hand, the soil organic matter content under Enset land use type was also higher than under Khat (*Catha edulis*) land use type due to addition of enset residues after harvest. According to the soil OC rating scale of Tekalign (1991), the soil OC values under Khat land use type fall within the medium (1.5-3.0) range and the soil carbon under Enset and Khat-Enset were high (¿ 3.0).

3.6 Total nitrogen (N,%) and C:N ratio

Total N and C:N ratios showed significant $(p \leq 0.05)$ differences. The highest mean (0.42%) soil total N was observed under the Enset and the lowest (0.23%) in the soils under Khat land use type (Table 2). In all land use types considered in this study, total N decreased consistently from Enset (*Ensete ventricosum*) to Khat-Enset then to Khat. The variation seem parallel with the change in organic carbon content (Table 2). Moges and Holden (2008) reported that total nitrogen is associated with the relatively higher organic carbon which in turn resulted from plant and root biomass as well as residues being returned to the soil system. The C:N ratio did not significantly vary with land use types and found to be within the range of 8:1-15:1 which is commonly cited as an indicator of intermediate organic

Table 1: Mean (±SEM) of soil texture, soil bulk density and total porosity at Hanshika Subwatershed

Land use type (0-30 cm depth)	Soil texture (%)			Textural class	BD (g/cm^3)	TP (%)
	Sand	Silt	Clay			
Khat	52 ± 0.33^a	18 ± 0.23^a	30 ± 0.06^a	SCL	0.98 ± 0.00^a	63.02 ± 0.09^a
Enset	49 ± 0.28^a	21 ± 0.25^a	30 ± 0.06^a	SCL	0.86 ± 0.01^c	67.54 ± 0.06^b
Khat-Enset	56 ± 0.30^a	13 ± 0.20^b	31 ± 0.07^a	SCL	0.92 ± 0.01^b	65.28 ± 0.08^b
LSD (0.05)	6.45	0.82	NS		0.05	1.55

LSD = Least significant difference; SEM = Standard error of mean; OC = Organic carbon; N = Nitrogen; C:N = Carbon to nitrogen ratio; Av. P = Available phosphorus; Av. K = Available potassium; Means within a row for the same factor followed by the same letters in superscripts are not significantly different from the p=0.05

Table 2: Mean (±SEM) of selected soil chemical properties at Hanshka Sub-watershed

Land use	**pH-H_2O**	**OC (%)**	**Total N**	**C:N**	**Av. P**	**Av. K**
	type (0-30 cm depth) (mg/kg)		(%)		(mg/kg)	(mg/kg)
Khat	5.49 ± 0.02^b	2.67 ± 0.02^b	0.23 ± 0.01^c	11.6 ± 0.30^a	2.02 ± 0.03^c	154 ± 0.03^c
Enset	5.76 ± 0.01^a	4.77 ± 0.03^a	0.42 ± 0.00^a	11.4 ± 0.28^a	2.44 ± 0.02^a	333 ± 0.49^a
Khat-Enset	5.75 ± 0.30^a	4.12 ± 0.02^a	0.36 ± 0.01^b	11.40 ± 0.27^a	2.15 ± 0.03^b	298 ± 0.48^b
LSD (0.05)	0.25	1.40	0.05	0.09	0.24	10.47

LSD = Least significant difference; SEM = Standard error of mean; OC = Organic carbon; N = Nitrogen; C:N = Carbon to nitrogen ratio; Av. P = Available phosphorus; Av. K = Available potassium; Means within a row for the same factor followed by the same letters in superscripts are not significantly different from each other at p=0.05

matter mineralization (Prasad and Power 1997). The narrow variations in C/N ratios across all land use types suggest less variability in the degree of humification of organic matter.

3.7 Available phosphorus (P, ppm)

The analysis of variance revealed that the available phosphorus showed significant ($p \leq 0.05$) difference with land use types (Table 2). The highest (2.44 mg/kg) mean available P was observed in soils under Enset (*Ensete ventricosum*) land use type compared with the rest land use types. Girma and Endalkachew (2013) reported low available phosphorus resulted from absence of biomass addition to the soils and P- fixation by Al and Fe (Eylachew 1999). However, according to the soil quality rating scales of Cottenie (1980) and Landon (1991), soils of the study area are generally deficient (¡ 4 ppm) of available P. Consequently, low available P in the soils became one of the major soil fertility limiting factors to crop production (Fantaw 2017).

3.8 Available potassium (K)

The available K showed significant ($p \leq 0.05$) variation with land use types. The highest (333 mg/kg) mean value of available K was observed in soil under Enset (*Ensete ventricosum*) while the lowest (154 mg/kg) was under Khat (*Catha edulis*) land use type (Table 2). The observed highest concentration of available potassium under the Enset (*Ensete ventricosum*) land use type was attributed to the application of organic wastes (Bohn et al., 2001). According to FAO (2006) ratings, the available K was medium (117.2-234.6 mg/kg) in soils under Khat (*Catha edulis*) to high (234.6-469.2 mg/kg) ratings both in soils under Enset (*Ensete ventricosum*) and Khat-Enset land use types.

3.9 Exchangeable sodium (Na, meq/100g) and potassium (K, meq/100g)

The exchangeable Na showed no significant ($p \leq 0.05$) variation with land use types but, the exchangeable K varied significantly with land use types (Table 3). The mean exchangeable K was the highest (8.97 meq/100gm) under Enset (*Ensete ventricosum*), while it was the lowest under Khat (*Catha edulis*) (4.87meq/100gm). According to the FAO (2006) ratings, the observed mean values of exchangeable K of the studied soils fall in the range of very high (¿ 1.2 meq/kg) across all land use types.

3.10 Exchangeable calcium (Ca, meq/100g) and magnesium (Mg, meq/100g)

According to the FAo (2006) ratings for of Ca in soil under Enset (*Ensete ventricosum*) exchangeable Ca and Mg, the mean concentration and Khat-Enset were rated as high (10.0-20.0Ca and Mg were the principal base cations in the exchange complex of studied soils which significantly varied with use types (Table 3). The highest (12.45meq/100gm) mean concentration of Ca was observed un-

Table 3: Mean (±SEM) exchangeable bases, CEC, and base saturation at Hanshka Subwatershed

Land use	Na	K	Ca	Mg	CEC	BS (%)
			(meq/100g)			
Khat	3.46±0.02	4.87±0.28^{b}	8.76±0.05^{b}	7.34±0.09^{b}	46.58±0.50^{c}	52.45±0.34^{b}
Enset	3.66±0.01	8.97±0.14^{a}	12.45±0.04^{a}	10.42±0.04^{a}	59.46±0.13^{a}	59.70±0.05^{a}
Khat-Enset	3.62±0.01	5.72±0.12^{ab}	10.90±0.08^{a}	8.50±0.04^{b}	52.78±0.27^{b}	54.45±0.26^{b}
LSD (0.05)	NS	3.64	1.76	1.14	6.04	4.34

LSD = Least significant difference; NS = Not significant; SEM = Standard error of mean; CEC = Cation exchange capacity; BS = Base saturation; Means within a row for the same factor followed by the same letters in superscripts are not significantly different from each other at P = 0.05

der Enset (*Ensete ventricosum*) and followed by Khat-Enset (10.90 meq/100gm) while the lowest exchangeable values of Ca (8.76 meq/100gm) were recorded in soils under Khat (*Catha edulis*) land use type. The highest exchangeable Ca in soil under Enset (*Ensete ventricosum*) and Khat-Enset could be due to the relatively higher OM content in these land use types. The concentration of Ca and Mg generally follow the pH trend, in agreement with the findings of Young and Hammer (2000). Exchangeable calcium in a soil has an important relation to soil pH and to the availability of several nutrient elements (Thompson and Troeh 1993). meq/100gm), and very high Mg concentration (¿ 8.0 meq/100 gm) indicating that the two concentrations were sufficiently available in the soils.

3.11 Cation exchange capacity (CEC, meq/100g)

The variation in CEC was significant ($p \leq 0.05$) with the land use types. Accordingly, the highest mean CEC value was observed in soils under Enset (*Ensete ventricosum*) (59.46 meq/gm) land use type while the lowest (46.58 meq/gm) was under Khat (*Catha edulis*) land use type (Table 3). This might be due to high OM contents recorded under the Enset (*Ensete ventricosum*) land use type (Table 2). Similar result was reported by Gao and Chang (1996) that the organic matter plays an important role in exchange process as it provides more negatively charged surfaces than clay particles do. According to the Landon's (1991) ratings, the investigated soils have a very high level (¿ 40 meq/100 gm) of CEC for agricultural crop productions. The very high CEC values may be attributed to the predominance of high surface area clay minerals such as allophane and imegolite (Wada, 1985; Southard and Southard, 1989) and organic matter (Voundi Nkana et al. 1998; Fantaw 2017). CEC of a soil is determined by the relative amount and/or of two main colloidal substances; humus and clay (Gao and Change 1996).

3.12 Percent base saturation (PBS)

The percent base saturation (PBS) varied with land use types (($p \leq 0.05$) Table 3). It was higher (59.7%) in soil under Enset (*Ensete ventricosum*) compared to the rest of land use types (Table 3), attributed to the exchange sites with less amounts of organic matter (carbon) and more base cations leading to higher base saturation (Fantaw, 2017). The investigated soil the different land use types had high PBS of greater than 50 percent values and were generally considered fertile according to Landon (1991) ratings.

4 Conclusion

Soil quality indicators are affected by several physicals, chemical, and biological parameters of the different land use types. Accordingly, statistically significant differences in soil quality indicators such as bulk density, total porosity, soil pH (H2O), CEC, exchangeable bases (Ca, Mg, K and Na), PBS, OC, total N, available P and available potassium were mainly impacted by the management practices. Thus, the low soil quality results in the Khat (*Catha edulis*) cultivation should be corrected through appropriate integrated soil management practice mainly focused on organic residue management. Further research is recommended need for valid generalization and knowledge on the soil quality indicators in relation to different local soil management practices.

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Competing interests

The authors declare that they have no competing interests.

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Research Article

Households' willingness to pay for the services of watershed management in lake Hawassa watershed, southern Ethiopia

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Abstract

Watershed provides vast economic benefits within and beyond the management area of interest. But most watersheds in Ethiopia are increasingly facing the threats of degradation due to both natural and man-made factors. To reverse these problems, communities' participation in sustainable management programs is among the necessary measures. Hence, this study assessed the households' willingness to pay for the services of watershed management through a contingent valuation study approach. Double bounded dichotomous choice with open-ended follow-up format was used to elicit the households' willingness to pay. Based on data collected from 275 randomly selected households, descriptive statistics results indicated that most households (79.64%) were willing to pay for the services of watershed management. A bivariate Probit model was employed to identify determinants of households' willingness to pay and estimate mean willingness to pay. Its result shows that age, gender, income, livestock size, perception of watershed degradation, social position, and offered bids were important variables affecting their willingness to pay. The study also shows that the mean willingness to pay for the services of watershed management was calculated to be 58.41 Birr and 47.27 Birr per year from the double bounded and open-ended format, respectively. The study reveals that the aggregate welfare gains from the services of watershed management were calculated to be 931581.09 Birr and 753909.23 Birr per year from double bounded dichotomous choice and open-ended format, respectively. Depending on the double bounded dichotomous format result, the policymakers should design an approach to make households pay for the services of watershed management.
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Keywords: Bivariate Probit model, Watershed management, Services of watershed Management, Willingness to pay

1 Introduction

The economy and environment are now jointly determined systems linked in the process of co-evolution, with the scale of economic activity exerting significant environmental pressure. 1There is a dynamic interdependency between economy and ecosystem, but the fundamental point is that economic systems are underpinned by the ecological system and not vice versa (Bateman and Wills, 1999).

Due to this, in the majority of developing countries, the quantity and quality of environmental resources are decreasing and resulting in more severe floods and droughts (Fikru, 2009). In terms of weather and naturerelated disasters and climate change, Ethiopia was ranked the ninth most climate-vulnerable country in the world (Merkine et al., 2017), and this resulted in diminishing productivity of agriculture and increasing problems in water quality. Specifically, due to this, the natural resources are under influence of many interrelated factors and result in unsustainable farming practices, lower vegetative cover, severe soil loss, and migration of wildlife (Simachew, 2020). The estimated average annual soil loss rate of Ethiopia is to be 42tons/hectare/year which resulted in two percent of crop loss and it may be higher in steep slopes and places where there is lower vegetation cover (Biniyam, 2013).

Watershed is a geographically delineated area that is drained by a stream system. Currently, watersheds in Ethiopia are undergoing severe degradation. Lake Hawassa watershed is one of the watersheds which have faced problem of degradation. During the pre-1974 period, the watershed had high vegetation abundance and richness, low population, high soil infiltration rate, and normal temperature and rainfall. Since 1991, there is accelerated deforestation despite a small portion of planted exotic trees, increased severity of erosion and common gullies, warmer and erratic temperature and rainfall. The major causes for this degradation are inappropriate land-use systems such as extraction of sand and stone, removal of forests and woodlands in upper stream areas, lower adoption of indigenous and introduced soil and water conservation practices (Yericho, 2019; Zenebe, 2013). Soil bund and check dam were implemented by public participation, while soil bund and Fanya-juu were implemented in private land for management of the watershed. The structures were appropriate for the catchment but their layouts were not as standard. In addition, the regular maintenance and management of structures after implementation was also minimal and the effective and efficient management options undertaken in tackling the problem of degradation were also not satisfactory (ibid).

Degradation of the watershed is manifested, in landslides, lower productivity of land, lower crop production and productivity, soil erosion and gullies, deterioration in the quality of the lake, and overuse of natural resources in the watershed (SARI, 2017). In addition, these may result in malnutrition of children, extra loads on women and poor, absence of medicinal plants, lack of water and forage, health problems, and lack of recreation areas (Hagos et al., 2014). Thus, communities within the watershed will be one of the primary beneficiaries from good watershed management thus their involvement in sustainable management is critical (Wolfgramm, 2015). This ensures fair and equitable sharing of costs and benefits as well as co-management of surface and sub-surface water resources for improving water productivity (Gebrehaweria et al., 2017). On top of the reduction of watershed degradation, the integrated management may improve soil productivity and other ecosystem services and ultimately results in the local community's livelihood improvements (Simon, 2016).

One of the environmental friendly approaches of community involvement in sustainable natural resource management is paying for its services and improvements (Sharma et al., 2005). According to the study conducted by Zenebe (2013), the communities within the watershed have the interest to participate and cooperate in the programs which are working on rehabilitation of the watershed, but their participation in terms of payments was not clear. Due to this, this study was conducted to assess households' willingness to pay for the services of watershed management in the study area. The findings of the study can be used as a source of information for policymakers, natural resources, and watershed management-related project implementers to overcome the challenges of watershed degradation.

2 Research Methodology

2.1 Description of the Study Area

Lake Hawassa is one of the eight major Ethiopian Rift Valley lakes, which is situated in Southern Ethiopia. It receives water from only perennial Tikurwuha River and runoff from the catchment areas (Mallampati and Osman, 2015). It is a topographically closed lake in the central main Ethiopian Rift Valley and its watershed has an area of 1436.51 km2 proportion of which is in the Eastern sub-watershed (Mulugeta et al., 2017). The eastern escarpment is found partially in the Central Rift Valley of Ethiopia, at about 263 Km South of Addis Ababa. Geographically, it is located between 38°37'E to 38°42'E and 7°02'N to 7°07'N. The watershed covers an area with a wide altitudinal range of 1690 to 2700 meters above sea level. Plantation forests of exotic species such as different species of Eucalyptus, Grevillea Robusta, Cupressus Lusitanica are common. Homestead agroforestry is commonly practiced in the area (Kebede et al., 2014).

Soil characteristics of the area are very porous, sandy loam, shallow at top and along the slope length of the hills and deep at hill base. Auguring can bedone up to 150 cm without difficulty, but soil is susceptible to erosion by water and grey in appearance (Zenebe, 2013). The production system in the area are mainly mixed farming in which maize, enset, and teff are major crops, and cattle, sheep and goat, and equines are major livestock reared.

2.2 Method of Data Collection

The primary data were collected from selected farm households in the study area through a structured questionnaire. Before the collection of main data, PRA tools such as Focused Group Discussion (FGD) and Key Informant Interview (KII) were conducted to gather information. The participants during KII are experts that have long years of experience in development works within the watershed. During FGD, the participants were member of the kebele administration and selected farmers. During the discussion, the bid values for the services of watershed management were determined and cross-checked with previous studies. Accordingly, four (9, 18, 36, and 72) bid values (in Birr) were determined with their respective higher and lower follow-up bids. A double bounded dichotomous choice elicitation method was used because of its advantages over controlling biases that arise during the CV study. It also minimizes

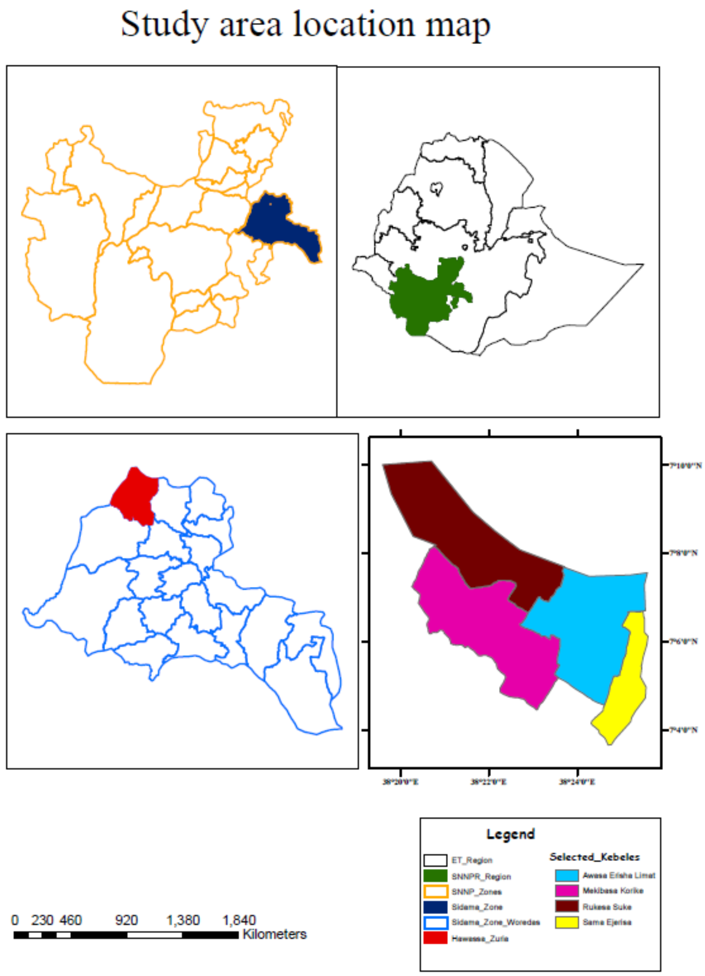

Figure 1:
(Source: Own GIS Mapping (2020))

nonresponses and avoids outliers, and it is more efficient than other elicitation methods. Indeed, it has efficiency gains because additional questions, even when they do not bound WTP completely, further constrain the part of distribution where respondents' WTP lies (Haab and McConnel, 2002).

2.3 Sampling Techniques

From five Lake Hawassa sub-watersheds, Hawassa Zuria Woreda (Dorebafena-Shamena) sub-watershed was selected purposefully because of its severe degradation problem. This watershed includes sixteen kebeles and it has 16931 total households. In this study, four kebeles were selected for final data collection based on the need for watershed management. For sampling, the list of the population was accessed from the woreda office of agriculture and natural resource. The sample size was determined by the rule of thumb that every explanatory variable in the model to have at least 10 (ten) sample respondents. A total of 275 households were selected using simple random sampling techniques. The total number of households were distributed among the four Kebeles in proportion to their size. Households were then selected by using Stat Trek's random number generator procedure .

2.4 Theoretical Framework

Let an individual household's utility function depends on marketable good x and some of the non-marketable services of WSM practices which are valued. The corresponding indirect utility function depends on the individuals' income 'y', the services of watershed management (WSM) practices 'q', and various other arguments including the price of market goods, attributes of market goods, and attributes of an individual that shifts his/her preferences (Hanemann, 1999). For simplicity, we suppress all of these arguments except (q,y). In random utility model (RUM) it assumed that, while a respondent knows his or her preferences with certainty, and does not consider them stochastic, they contain some components that are unobservable to the econometric investigator and are treated by the investigator as random. These unobservable could be characteristics of households or attributes of WSM practices services can stand for both variation in preferences among members of a population and

Table 1: The sample number of households from each kebeles

Kebeles	Number of households	Sample households
Sama Egersa	549	46
Rukessa Suke	717	60
Makibassa Korke	1278	106
Uddo Wotate	754	63
Total	3278	275

Source: Own computation from woreda office of agriculture.

measurement error. For now, we represent the stochastic component of preferences by ε without yet specifying whether it is a scalar or a vector, and we write the indirect utility function as $v(q, y, \varepsilon)$. Thus, the individual is confronted with the possibility of securing a change from q_0 to $q_1 > q_0$. We assume the household regards this as an improvement, so that $v(q_1, y, \varepsilon) > v(q_0, y, \varepsilon)$.

The household is told this change will cost *Birr A*, and he or she is then asked whether they would be in favor of it at that price. By the logic of utility maximization, the household answers 'yes' only if:

$$v(q_1, y - A, \varepsilon) \geq v(q_0, y, \varepsilon),$$

and 'no' otherwise. Hence,

$$\Pr(\text{response is 'yes'}) = \Pr\{v(q_1, y - A, \varepsilon) \geq v(q_0, y, \varepsilon)\}.$$

An equivalent way to express this same outcome uses the compensating variation measure, which is the quantity C that satisfies:

$$v(q_1, y - C, \varepsilon) = v(q_0, y, \varepsilon).$$

Thus, $C = C(q_0, q_1, y, \varepsilon)$ is the household's maximum willingness to pay (WTP) for the change from q_0 to q_1. It follows that he/she answers 'yes' if the stated price is less than this WTP, and 'no' otherwise. Hence, an equivalent condition to the one above is:

$$\Pr(\text{response is 'yes'}) = \Pr\{C(q_0, q_1, y, \varepsilon) \geq A\}.$$

In a random utility model (RUM), $C(q_0, q_1, y, \varepsilon)$ itself is a random variable. While the household's WTP for the change in q is something that he/she knows, it is something that the investigator does not know and treats as a random variable.

2.5 Methods of Data Analysis

2.5.1 Descriptive statistics

Descriptive statistics were used to analyze the socio-economic characteristics of respondents. These are means, percentages, and frequency distributions. Different characteristics of sample respondents were compared to the desired characteristics. Ch-squared and t-test were used to test whether or not there is a strong relationship between the dummy and continuous variables, respectively with households' willingness to pay for the services watershed management.

2.5.2 Econometric Model

Assuming that each household has some unobserved true point valuation for the services of watershed management in question, at the moment the first dichotomous choice contingent valuation (CV) question is posed. Let this unobserved value be Y_{1i}, and the first offered threshold assigned arbitrarily to this individual be denoted by t_{1i}. We will assume that the individual will state that they are willing to pay the offered amount ($I_{1i} = 1$) if $y_{1i} \geq t_{1i}$. They will be unwilling to pay this amount ($I_{1i} = 0$) if $y_{1i} < t_{1i}$.

Now let the unobserved valuation y_{1i} consist of a systematic component $X_{1i}\beta_1$, which is a function of vector X_{1i} of observable attributes of the respondent, plus an unobservable random component ε_{1i} (distributed $N(0, \sigma)$), which absorbs all unmeasured determinants of the value of the resource to the individual. Once an individual has been randomly assigned their initial offered value, the follow-up offer will take on one of two alternative predetermined values (one higher and one lower). The probability of receiving the predetermined higher offer is just the probability of responding "yes" to the first willingness-to-pay (WTP) question and vice versa.

We must, therefore, develop the model in the context of the joint distribution of (y_{1i}, y_{2i}). We assume a Bivariate Normal Distribution, BVN$(X_{1i}\beta_1, X_{2i}\beta_2, \sigma, \sigma, \rho)$, for these two implicit valuations. There are four possible pairs of responses to these questions: $(I_{1i}, I_{2i}) = (1, 1), (1, 0), (0, 0), (0, 1)$.

Using $Y_1 = X_{1i}\beta_1 + \varepsilon_1$, this condition can be expressed equivalently as:

$$\frac{\varepsilon_1}{\sigma_1} > \frac{t_1 - X_{1i}\beta_1}{\sigma_1},$$

where $\frac{\varepsilon_1}{\sigma_1}$ is a standard normal random variable. Similarly, using $Y_2 = X_{2i}\beta_2 + \varepsilon_2$, this condition can be expressed equivalently as:

$$\frac{\varepsilon_2}{\sigma_2} > \frac{t_2 - X_{2i}\beta_2}{\sigma_2},$$

where $\frac{\varepsilon_2}{\sigma_2}$ is also a standard normal random variable.

Denote the standardized normal error $\frac{\varepsilon_1}{\sigma_1}$ as z_1 and $\frac{\varepsilon_2}{\sigma_2}$ as z_2. The analysis can proceed in terms of probabilities associated with regions in the domain of the standard bivariate normal distribution, where the pair (z_1, z_2) is distributed BVN$(0, 0, 1, 1, \rho)$ (Cameron and Quiggin, 1994).

Accordingly, the equation becomes:

$$\text{WTP}_{ij} = \mu_i + \varepsilon_{ij},$$

where WTP$_{ij}$ represents the jth respondent's willingness to pay, and $i = 1, 2$ represents the first and second answers. μ_1 and μ_2 are the means for the first and second responses, and ε_{ij} are unobservable random components.

After running a regression of the dependent variable (yes/no indicator) on the constant and the independent variable consisting of bid values, the mean WTP is determined as follows, depending on the normality assumption of the WTP distribution (Haab and McConnell, 2002):

$$\text{MWTP} = -\frac{\alpha}{\beta},$$

where MWTP is the mean willingness to pay for the services of watershed management, α is the intercept of the model, and β is the coefficient of bid values.

The independent variables used to compute MWTP are the initial (Bid1) and follow-up willingness-to-pay values (Bid2). After that, from two regression outputs, the average value is calculated to estimate the mean willingness to pay.

2.6 Definition of Variables and Hypothesis

The dependent variable: The dependent variable is a binary choice variable (WTP1 and WTP2) measuring the willingness of households to pay for the services of watershed management. The response 1 represent willing households who responded 'yes' for offered bids, and 0 otherwise. Independent variables: The following variables were hypothesized to determine the households' willingness to pay for watershed management. These are explained below.

Age: This is a continuous independent variable. According to previous studies, young household heads may have a longer planning horizon and may be more likely to invest in watershed management activities like SWC practices than older age (Gebrelibanos, 2012). So, it is hypothesized that it negatively affects WTP for the services of watershed management

Gender: It is the sex of the household head which is measured as a dummy variable taking a value of 1 for male-headed household and 0 otherwise. Male-headed households are more willing to pay for the services of watershed management than female-headed households (Calderon et al., 2013; Gebrelibanos, 2012). So, it is hypothesized that the probability of male-headed respondents' WTP is more than female-headed respondents.

Extension contact: It is a discrete variable depending on the number of households' yearly contact with the extension agent. The variable hypothesized that it increases awareness of the services of watershed management and increases willingness to pay (Gebrelibanos, 2012). Initial and follow-up bids: these are continuous variables and measured in cash and included in the regression analysis to check whether starting bias exists or not. For every increase in bid amount, holding other variables constant, households willingness to pay for the services of watershed management decreases.

Educational status: It is a continuous variable representing the number of years that the respondent household spent in school. This variable has a positive and strong relationship with WTP because as the education level of household heads increases, willingness to pay for WSM practices increases because education provides information about watershed degradation and its effect (Calderon et al., 2013; Gebrelibanos, 2012). So, it is hypothesized to positively affect willingness to pay for watershed management.

Distance from the mountain: This is a continuous variable measured in kilometers and expected to affect willingness to pay for the services of watershed management negatively because if the household is far from the upland mountain within the watershed, he or she is less willing to pay for the management of watershed including upland mountain rehabilitation.

Household income: It is a continuous variable and measured in Ethiopian Birr and contains the amount of income that the household collected last year from agriculture like livestock and crop production. The households' WTP increases with a unit increase in agricultural income assuming other variables constant (Calderon et al; 2013, Lewis et al., 2017). So, it is hypothesized that it has a positive effect on a households' willingness to pay for watershed management.

Family size: It is a discrete variable and indicates the number of people living in one house. It is hypothesized that; the higher family size has a negative effect on WTP for the services watershed management because the larger number of households need more money for their expenses; including expenses for schooling and clothes for children. Hence, affects WTP negatively.

Landholding: It is a continuous variable and indicates the size of land in hectares owned by farm households. It is hypothesized that farmers who own large plots are more willing to pay for watershed management than the smaller ones. Because farmers who own large plots generate higher income than the smaller ones (Gebrelibanos, 2012) and thus expected to benefit more from watershed management. .

Total livestock unit: It is a continuous variable indicating the number of livestock that respondent households have in terms of tropical livestock unit (TLU). TLU is one of the wealth indicators and should have a positive contribution to a willingness to pay (Gebrelibanos, 2012). It is hypothesized that it has a positive effect on WTP for watershed management.

Farming experiences: This is a continuous variable. This variable represents the total number of years the respondent household head has spent on farming. Wider knowledge and experiences will be gained on the issue of watershed degradation with longer experience in farming (Calderon et al., 2013). So, it is hypothesized that it has a positive effect on respondents' willingness to pay for watershed management.

Perception of watershed degradation: It is a dummy variable that takes the value 1 if the respondent household perceived watershed degradation and 0 otherwise. It is hypothesized that the household that has perceived the problem of watershed degradation are more willing to pay than farmers who haven't perceived watershed degradation (Gebrelibanos, 2012).

Social position: This is a dummy variable that takes 1 if households have a certain position within the community, and 0 otherwise. Those positions are being a member of kebele administration and recognized elder. So, it is hypothesized that it has a positive effect on the respondent's WTP for watershed management

3 Results and discussion

3.1 Socio-economic characteristics of sample households

This analysis is based on data collected from 275 sample households. Overall, the descriptions of the socio-economic characteristics of sample households are presented below. Table 2 and 3 show the summary statistics of dummy and continuous variables, respectively. According to the result of the chi2 test, willingness to pay is associated with gender, social position, and perception of watershed degradation are .

Gender: A great majority of non-willing households (83.93%) were female headed households while male-headed households constitue a great majority (85.8%) of the households who were willing to take offered bids for watershed management . The Chi-square test reveals that there is a significant difference in willingness to pay between male and female household heads at a 1% probability level. This might be due to differences in access to information about natural resource management.

Social position: Concerning social position, 66.5% have no position in the community and 33.45% have a position in the community. Close to 90% of the non-willing households have no any social position in the community. On the other hand, the group that accepted the offered bid is relatively better distributed between those with social position (60.7%) and without social position (39.3%). Based on chi-square test analysis, there is a strong relationship between social position and willingness to take offered bids. This also might be due to differences in access to information.

Perception of watershed degradation: From the total households interviewed, 74.55% of respondents perceived the problem of degradation and 25.45% did not perceive it. As expected a large majority (82.2%) of households willing to pay for watershed management perceived the problem of degradation. For the non-willing group, there was not a large difference in the proportion of households that perceived (55.4%) and didn't perceive (44.6%) the problem of degradation. The chi-square test statistics also show that there is a strong relationship between perception of watershed degradation and willingness to pay.

According to the t-test, there is no significance difference between willing and non-willing households in terms of age, education status, family size, distance from the mountain, landholding, and farming experiences. But TLU and annual farm income are significantly different between willing and non-willing households.

Tropical Livestock Unit (TLU): On average, respondents have 3.6 TLU of livestock. The t-test statistics also show that there is a significant mean difference in livestock size between the willing (3.78) and the non-willing (2.91) households.

Farm income: The average annual farm-level income of respondents is 3310 Ethiopian birr. The mean annual income of willing respondents is signficantly greater than non-willing respondents. This might be due to the direct influence of income on the amount of payment for watershed management.

3.2 Description of Households' Willingness to Take Initial and Follow-up Bids

Table 4 shows that one of the four initial bids were presented for each of the respondents – 9 Birr (22.91%), 18 Birr (25.82%), 36 Birr (26.91%), and 72 Birr (24.36%). Out of 275 respondents, 20.4% respondents were non-willing and 79.6% were willing to take initial bids and contribute to the implementation of watershed management as indicated in Table 5. This was based on randomly asking them to respond to pre-determined initial bids

In terms of willingness to take the initial bids, households' probability to say 'yes' for offered bids percentage decreases as the bid amount increases. This implies the respondents answer positively as the bid amount goes down. In addition, out of 275 respondents, positive responses for higher follow-up bids were 35.64% and negative answers were 24.73% as indicated in Table 5 below.

Therefore, even though the payment amount is high, a large number of the households were interested to pay more to halt watershed degradation problems. The reverse is true for lower bid amounts. This might be due to households' annual level of income. This implies that the severe problem of degradation pushes respondents to take offered bids.

3.3 Determinants of Households' Willingness to Pay

Thirteen (13) explanatory variables were used in the bivariate probit model to identify determinants of willingness to pay based on the hypothesis made (Table 6). The result of the model shows that the probability of chi-square distribution (162.61) with less than the tabulated counterfactual is 0.000, which is less than1significance level. This implies the variables included in explaining WTP for WSM practices fit the bivariate probit model at less than 1probability level. Also, it means that the joint null hypothesis of coefficients of all explanatory variables included in the model was zero should be rejected. This implies the data fits the model. As indicated in Table 5, out of thirteen (13) variables used in the model, seven (7) variables affecting households' willingness to take initial bids were significant at less than 1% and 5% significant levels. These are age,

Table 2: Categorical Variables and Their Distributions

	Category		Statistics			
Variable	**Group**	**N**	**Col 1**	**Col 2**	**Col 3**	**Col 4**
Have position 6	-	-	10.71	86	39.27	92
	-	-	33.45	-	44.63***	-
Perception of WS degradation	Not Perceived	31	55.36	39	17.81	70
	Perceived	25	44.64	180	82.19	205
			74.55	-	33.14***	-
Physical property of land	Not Prone	13	23.21	53	24.20	66
	Erosion prone 43	76.79	166	75.80	209	76.00
					0.024	-
Awareness on role of forest	Not Aware	3	5.36	9	4.11	12
	Aware	53	94.64	210	95.89	263
			95.64	-	0.17	-

Table 3: Description of discrete and continuous variables by the willingness to pay status

Continuous and discrete variables	**Non-willing (N=56)**		**Willing (N=219)**		**t-test**	**Total mean**
	Mean	**St. Err**	**Mean**	**St. Err**		
Age	36.45	1.29	33.87	0.66	1.76	34.39
Education Status	5.38	0.54	5.21	0.27	-0.28	5.24
Family size	5.54	0.37	5.81	0.19	-0.66	5.75
Distance from mountain	3.38	0.38	3.2	0.22	0.38	3.24
Land holding	0.79	0.05	0.84	0.03	-0.71	0.83
Farming experiences	18.19	1.41	19.69	0.865	-0.85	19.39
TLU	2.91	0.22	3.78	0.11	-3.46***	3.60
Farm income	3158.93	0.43	3348.86	0.29	-3.11**	3310.18

** and *** imply statistical significance at less than 5% and 1% levels. Source: Own survey, 2020.

gender, initial bid, farm income, livestock size, perception of watershed degradation, and social position. Age and initial bid affect negatively and the remaining five (5) variables affect the willingness to pay for watershed management positively. In addition, four (4) variables were affecting households' willingness to take follow-up bids at less than 1% significant level. These are gender, follow-up bid, perception of watershed degradation, and social position. Follow-up bid affects WTP negatively and the remaining three (3) variables affect the willingness to pay for watershed management positively.

Age of household head: It had a negative and significant effect on households' willingness to pay for the services of watershed management at less than 1% level of significance. The major reason for the negative effect of age on willingness to pay is that the older aged households may have a short planning time horizon and reduce WTP for future sustainable management of watershed. Thus, older age households were less likely to pay for WSM practices as they expect they would benefit less from investment in WSM compared to young household heads. This negative relationship between age and investment in natural resource conservation is also consistent with the finding of Calderon et al. (2013) and Gebrelibanos (2012). Keeping other variables constant, on average the age of household head has been found to reduce the probability of accepting offered initial bid by 1.7 percent.

Gender of household head: This variable is found to have a positive effect on willingness to pay for watershed management. The result of the bivariate probit model shows that male-headed households were found to have more likely to say 'yes' for offered initial and follow-up bids than female-headed households. This is because agricultural activities are most of the time performed by males and it is known that they have a better awareness of watershed degradation. Concerning its joint marginal effects on willingness to pay, the probability of male- headed households saying 'yes' for offered initial and follow-up bids were more than 51 percent compared to female-headed households.

Initial bid and follow-up bids: Initial and follow-up bids offered were found to negatively and significantly affect WTP. This implies the households' probability to say 'yes' for offered bids increases

Table 4: Distribution of amount of initial bids

Bid1 (ETB)	Frequency	Percentage	Willingness responses	
			No (%)	Yes (%)
9	63	22.91	14.29	85.71
18	71	25.82	14.04	85.92
36	74	26.91	24.32	75.68
72	67	24.36	28.36	71.64
Total	275	100.00	20.36	79.64

Table 5: Response rates of follow-up questions

Initial bids	Follow-up bids (ETB)		Responses for Higher Follow-up		Responses for Lower Follow-up	
(ETB)	Follow-up	Bids	No	Yes	No	Yes
9	20	4	12	38	9	4
18	40	10	18	29	11	13
36	72	18	19	19	18	18
72	140	36	19	12	19	17
Total	–	–	68 (24.73%)	98 (35.64%)	57 (20.73%)	52 (18.91%)

with a decrease in the bid amounts. This is consistent with economic theory, as price level increases demand decreases. With respect to its marginal effects, as bid amount increases by a unit, keeping other variables constant, on average the probability of willingness to take both bids for watershed management decreases by 0.3 percent.

Farm Income: The annual farm-level income of household head was found to positively and significantly affect willingness to pay for WSM practices at less than 1% probability level. This implies that the probability to say 'yes' for offered bid amount increases with increase in the annual farm income of the household head, which is consistent with economic theory. Keeping the effect of other explanatory variables constant, a unit increase in annual farm income of household increases the probability to say 'yes' for offered initial bids is 5.9 percent. This implies that households say 'yes' to offered bids, if and only if the amount of bid is less than they can afford to pay.

Tropical livestock unit (TLU): The size of livestock ownership was found to positively and significantly affect willingness to pay at less than 1% probability level. This implies increased possession of livestock increases willingness to pay because it is one of the wealth indicators and should have a positive contribution to willingness to pay. This finding is in line with a study conducted by Gebrelibanos (2012). Its marginal effect implies when possession of tropical livestock unit increases by a unit keeping other variables constant, it increases the probability of saying 'yes' for offered initial bids by 7.7 percent.

Perception of Watershed degradation: Perception of watershed degradation was found to positively and significantly affect willingness to pay for WSM, which is consistent with prior expectations. That is the probability of willingness to pay by households that perceived the problem of watershed degradation is higher than the households who do not perceive the problem of watershed degradation. In addition, the joint marginal effect shows the likelihood to say 'yes' of households who perceived the watershed degradation problem is 34.4 percent more than households who have not perceived. This result is consistent with the study of Gebrelibanos (2012) for the relationship between perception of soil erosion and WTP.

Social position: Households who have any position in kebele or community have been found to positively and significantly affect willingness to pay for WSM. The result is consistent with the findings of Genene and Anteneh (2015) which indicated that farm households who have a social position have better access to different capacity- building training and social affairs in the community which creates a better awareness of the management of resources. The joint marginal effect reveals that households who have a social position in the community were 52.7 percent more likely to say 'yes' for the offered first and second willingness to pay questions.

3.4 Estimation of Mean Willingness to Pay

One of the aims of this study was to estimate the amount of willingness to pay. The bivariate model was applied to estimate MWTP by using response dummy variables for two responses and their respective bid amounts. Table 7 shows the bivariate probit model result of two responses of willingness to pay questions

LR test of rho=0: chi2(1)=10.3701   prob¿chi2=0.0013.

In the above bivariate probit model output, rho is positively and significantly different from zero at less than a 1% probability level, implying there is a positive correlation between the two responses.

In addition to this, the correlation coefficient of the error term is less than one which implies the random component of WTP for the first

Table 6: Explanatory variables affecting the households' willingness to pay

Variables	WTP1 Coeff (St. Err)	WTP2 Coeff (St. Err)	WTP1 marginal effects	Joint marginal effects
Age	-0.051 (0.014) ***	-0.003 (0.009)	-0.017	-0.013
Gender	1.14 (0.298) ***	1.41 (0.24) ***	0.406	0.51
Extension contact	-0.027 (0.02)	-0.016 (0.014)	-0.009	-0.01
Initial (follow-up) bid^2	-0.012 (0.005) **	-0.009 (0.003) ***	-0.004	-0.003 (-0.003)
Education	-0.052 (0.039)	-0.006 (0.026)	0.017	0.013
Distance from mountain	-0.045 (0.038)	0.042 (0.031)	-0.015	0.003

Note: Initial bid was used for WTP1 estimation and follow-up bid was used for WTP2 estimation.

Variable	**Coefficient (SE)**	**Coefficient (SE)**	**Marginal Effects**
Farm Income	0.18 (0.039) ***	-0.015 (0.024)	0.059
Family size	-0.0035 (0.055)	-0.05 (0.043)	-0.001
Farm size	-0.039 (0.272)	-0.18 (0.202)	-0.057
TLU	0.235 (0.073) ***	-0.06 (0.057)	0.077
Farming experience	-0.019 (0.013)	-0.016 (0.009)	-0.007
Perception of WS degradation	0.766 (0.296) **	0.727 (0.224) ***	0.273
Social position	1.88 (0.29) ***	0.60 (0.20) ***	0.568
Cons	-5.38 (1.38) ***	-0.397 (0.86)	0.527

Observations = 275
Loglikelihood = -193.29
Wald χ^2 (26) = 162.61
Prob ¿ χ^2 = 0.000

*** and ** are significance at 1% and 5% respectively.

question is not perfectly correlated with the random component of follow-up questions. According to the formula of Habb and McConnell (2002) , the estimated willingness to pay is 58.41 Ethiopian birr per year for WSM practices. This double- bounded willingness to pay ranges from 57.42 to 59.4 birr per year.

In addition to the double bounded dichotomous choice elicitation method, an open-ended format was used to cross-check the estimated value by two formats. Accordingly, from the open-ended format mean maximum willingness to pay per year is 47.27 birr, which ranges from 0 to 300 birr per year. This result is different from the double bounded question, which has a mean WTP is 58.41 birr per year. Table 8 reveals that 89.45% of households were willing to pay some amount of birr for WSM and only 10.55 percent were not willing.

During the survey, each willing respondent was asked to state the reasons for their maximum willingness to pay. Out of 246 willing households, 46 (18.69%) stated that they think the watershed management is worth the bid amount asked, and 200 (81.31%) stated they did not afford to pay more than the amount they are willing. The possible reason for this might be their annual level of income.

In most valuation of environmental services studies, some respondents were not interested to pay and participate in the management of natural resources due to many reasons. Similarly, in this study, out of the 275 sample respondents, 29 (10.55%) were not willing to pay some amount of birr for WS management. From them, 16 (55.17%) responded that the government should pay for it and are considered as protest zero bidders, which were excluded from the estimation of aggregate demand estimation and 12 (41.38%) and 1(3.45%) responded they can't afford to pay and they do not use the good, respectively are considered as true zero bidders. Hence, these protest zeros are considered as free riders on services of watershed management.

3.5 Welfare Measure and Aggregation of WTP

Aggregation of willingness to pay for environmental resources is important in the CV study. Random sampling technique with face-to-face interviews was used in this study and protest zero responses were excluded from the estimation of aggregate benefit for watershed management services.

Table 10 reveals aggregate willingness to pay for watershed management. This was calculated by multiplying the mean willingness to pay from open-ended and dichotomous choice responses result by the total number of populations within a watershed with 16931 households. Accordingly, the total willingness to pay from dichotomous choice responses is 931581.1 birr per year whereas, from the open-ended format, the total willingness to pay is 753909.2birr per

Table 7: Mean willingness to pay from double bounded dichotomous responses

Dependent variables	Explanatory variables	Coefficients	St. Error	Z-value	P-value
WTP1	Bid1	-0.012	0.0033	-3.69	0.000
	Cons	0.689	0.138	5.00	0.000
WTP2	Bid2	-0.0085	0.0024	-3.59	0.000
	Cons	0.5049	0.131	3.87	0.002
Anthro		0.429	0.141	3.05	0.002
Rho		0.404	0.118		

LR test of rho=0: chi2(1)=10.3701 prob¿chi2=0.0013.

Table 8: Table 8. Open-ended willingness to pay responses

Maximum WTP in Birr	Mean	St. Error	Min	Max	Obs	Non-willing (=0)	Willing (¿0)
47.27	45.04	0	300	275	10.55	89.45	

year. This implies the result from dichotomous choice is greater than the open-ended format.

4 Conclusion

The result of the study revealed that the majority of households were concerned about the problem of watershed degradation in the study area and the households in the area were willing to pay for watershed development. The bivariate probit model was employed to identify the effect of explanatory variables on households' willingness to pay for WSM. In the model, the age of the household head and offered initial and follow-up bids were significantly and negatively affecting WTP for WSM. On the other hand, gender, income, tropical livestock unit, perception of watershed degradation, and social position were found to positively and significantly affect willingness to pay for WSM. With this, the mean willingness to pay for WSM was calculated to be 58.4 Birr and 47.3 Birr, from the double bounded format and open-ended format, respectively per annum. Indeed, the aggregate welfare gain from watershed management in the study area was estimated to be 931581.09 and 753909.23 Birr from the double bounded dichotomous choice format and open-ended format, respectively per annum. This shows that the value of WSM from an open-ended format was underestimated as compared to a double bounded format. This indicates that there may be the existence of free- riding problems and a lack of base for households for valuing WSM in an open-ended format. This implies that, in the valuation of environmental resource services, using a double bounded dichotomous choice format is preferable to an open-ended format. In general, the study found the higher gain from services of WSM in the study area from a double bounded dichotomous format.

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Conflict of interest

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Table 9: Table 9. Reasons for not willing and willing to pay

Reasons for willingness to pay	Freq.	Perc.	Reasons for not willing to pay	Freq.	Perc.
I think it is worth that amount	46	18.69	I do not use the good	1	3.45
I couldn't afford more	200	81.31	I can't afford to pay	12	41.38
			The government should pay	16	55.17
Total	246	100	Total	29	100

Table 10: Table 10. Aggregate willingness to pay

Elicitation procedure	Total No of samples HHs	No of protest	HH with of protest zero	Proportion protest zero	Expected valid	HHs with responses	Mean WTP	Total WTP
Double bounded Dichotomous	16931	275	16	0.058	981.998	15949	58.41	931581.09
Open ended	16931	275	16	0.058	981.998	15949	47.27	753909.23

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Research Article

Exploring the current status of forest stock in the areas bordering Dinder Biosphere Reserve, Sudan

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Article Info

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Abstract

Dinder Biosphere Reserve (DBR) is one of the first protected areas in Sudan. It hosts diversified populations of plants and animals species ranging from annual plants and grasses to mature and over mature trees, as well as, birds and herbivores to large carnivores. However, with all this diversity, information about the current status of forest resources around the reserve is lacking. Therefore, the objective of the study was to explore the current status of forest stock in the study areas surrounding the DBR, in order to bridge the current information gap for attaining sustainable management of natural resources. Six forest reserves were selected for data collection due to their nearest position and importance to the DBR. For data collection, a systematic sampling method was applied with a 10 % as sampling intensity across the six forest reserve sites. Spiegel Relaskop was used for measuring the basal area per hectare in each sample plot in order to determine the tree density per hectare. After determination of tree species within sample plot of a hectare, variables that included number of trees per hectare, diameter at breast height, total tree height were measured. Paired samples T test in Minitab (Version 17) was used to compares between the various growth parameters. The results of the study revealed that the minimum value of tree density per ha was 20 trees in Remila riverine forest reserve while the highest one was 743 trees in Fazara natural forest reserve. The probability value (P) results revealed that growth parameters differed significantly between riverine forest reserves as 0.032 for DBH, 0.012 for Height, 0.024 for Basal Area and 0.011 for volume with no significant differences among natural forests. Fazara natural forest reserve revealed the maximum value of tree density. Badous riverine forest reserve showed the highest mean value for tree density throughout the study area. Besides, the study findings also distinguished Acacia seyal var fistula, Adansonia digitata and Tamarindus indica as rare tree species in all six-forest reserves. It is that urgent protection measures are needed in the study areas in order to conserve these rare tree species before they disappear from their natural ranges.

Keywords: Biosphere reserve; natural forest; rare species; riverine forest; species density

1 Introduction

Sustainably managed forests have multiple environmental and socio-economic functions at global, regional, and local scales (Fox 2000; Ruddell et al. 2007; Virah-Sawmy 2009). Natural forests and protected areas play a vital role in sustainable development and poverty alleviation in many developing countries across the world (Brockington 2007; Gustafsson et al. 2012; Pfeifer et al. 2012). FAO estimated that 1.6 billion people depend on forest resources for at least part of their livelihood (FAO 2001). For example, in Viet Nam in 2002, the national assessment confirmed that more than 25% of Vietnamese were living in or around the natural forests and protected areas (de Jong. et al. 2006). There are more than 60 million indigenous communities of Latin America, Southeast Asia, and West Africa who are heavily dependent on forests and forest resources (Ennals et al. 2003).

Therefore, to fulfil the requirements of sustainable management of forest resources in a given forested area, it is very important to assess the status of the present stock the exiting forest. An accurate assessment of forest resources is essential for formulating sound forest management strategies and decision-making (Mati and Dawaki 2015). Forest inventory is a key component for this process through which we can gather reliable information for planning, conservation and protection processes (Bohn and Huth 2017). Reliable and up-to-date information about the growing stock, wood and non-wood products, change in vegetation cover, biodiversity, and recreation value, are mainly achievable through forest inventory (Mati and Dawaki 2015; Romijn et al. 2015). DBR is one of the oldest protected areas in Sudan which is of great importance to the country, particularly for local communities in and around the reserve (Ahmed 2005; Elmekki 2008; Mahgoub 2014). However, information about the status of existing forest stock in this area is lacking; therefore, this study is also intended to provide the needed information that will contribute to the sustainable management of forest resources in the study area.

The main aim of this study was to investigate the current status of forest stock in the areas surrounding the DBR, explore the characteristics of growth parameters for different tree species, determine the tree density for each surveyed reserve forest and to identify the rare tree species in the study areas for further conservation.

2 Material and methods

2.1 Study area

DBR was established in 1935 as a national park. It was declared as a biosphere reserve in 1978 and as a Ramsar site in 2002 (known as 'The Rasar Convention on Wetlands 1993'cited by Elmekki 2008). Its area is currently expanded to 10292 Km². It has three ecosystems: Riverine, Meadows (Mayas) and woodland ecosystems (Mahgoub 2014). The biosphere management is the mandate of Wildlife Conservation General Administration (WCGA). For protection and easier management, the reserve was divided into three zones, which included; transition, buffer and core zones. Most human activities are carried out in transition zone, while most carnivores are in core zone (Elmekki 2008; Elmoghraby and Abdu 1985; Mahgoub 2014). Moreover, the buffer zone acted like a barrier between transition and core zones (Fig. 1). For the purpose of this study, three forest reserves were selected within each bordering state depending on their proximity and importance to the DBR. These forests reserves are; Fazara natural forest reserve and Remila riverine forest reserve in Gedaref state border, Wad Ayies natural forest reserve and Okalma natural forest reserve in Sinnar state border as well as, Abu Gadaf natural forest reserve and Badous riverine forest reserve in Blue Nile state border.

2.2 Remila riverine forest reserve

It is a riverine forest reserve found in Gedaref State, Rahad locality, between latitudes $12°57'30''$ N and $12°59'0''$ N, and longitudes $35°01'0''$ E and $35°02'0''$ E, with a total area of 86.19 ha (Fig.2A). The main tree species in this forest is *Acacia nilotica*, and the topography is flat with clay to silt soil. Administratively and technically, the forest belongs to federal forests management (Hassan, 2015).

2.3 Badous riverine forest reserve

Badous forest is a riverine reserved forest located in Blue Nile State, Rosaries locality bordering Badous village, between $12°00'00''$ N and $12°10'00''$ N, and $34°15'00''$ E and $34°20'00''$ E. The total area of the forest is 76.98 ha (Fig. **??**). The main tree species in Maya (the bottom of the flood basin characterized by dark cracking clays and flooded for a period of 6 months or more each year) and Geref (the flood basin slopes that separate the Maya from the river) are *Acacia nilotica*, while the Karab area (the flood basin slopes between the Maya and the vast clay plains of the central Sudan) is dominated by *Azadirachta indica* and *Sterculia africana*. Other scattered tree species in Karab were *Combretum aculeatum*, *Grewia tenax*, *Grewia mollis*, *Capparis decidua*, *Acacia senegal*, *Acacia seyal*, *Acacia oerfota*, *Acacia mellifera*, *Hyphaene thebaica*, and *Lonchocarpus laxiflorus*. Soil types in this reserve are clay soil in Geref and Maya, while in the Karab area the soil type is a mixed sandy clay soil (Ibrahim, 2018; Ibrahim, 2019).

2.3.1 Fazara natural forest reserve

It is located in Gedaref State, Basonda locality, at latitudes 12º 41 0 N and 12º 48 0 N and longitudes 35º 37 0 E and 35º 44 0 E, with a total area of 7,095.76 ha (Fig. 3A). The dominant tree species in the flatlands are Acacia seyal var seyal, Acacia senegal, and Combretum

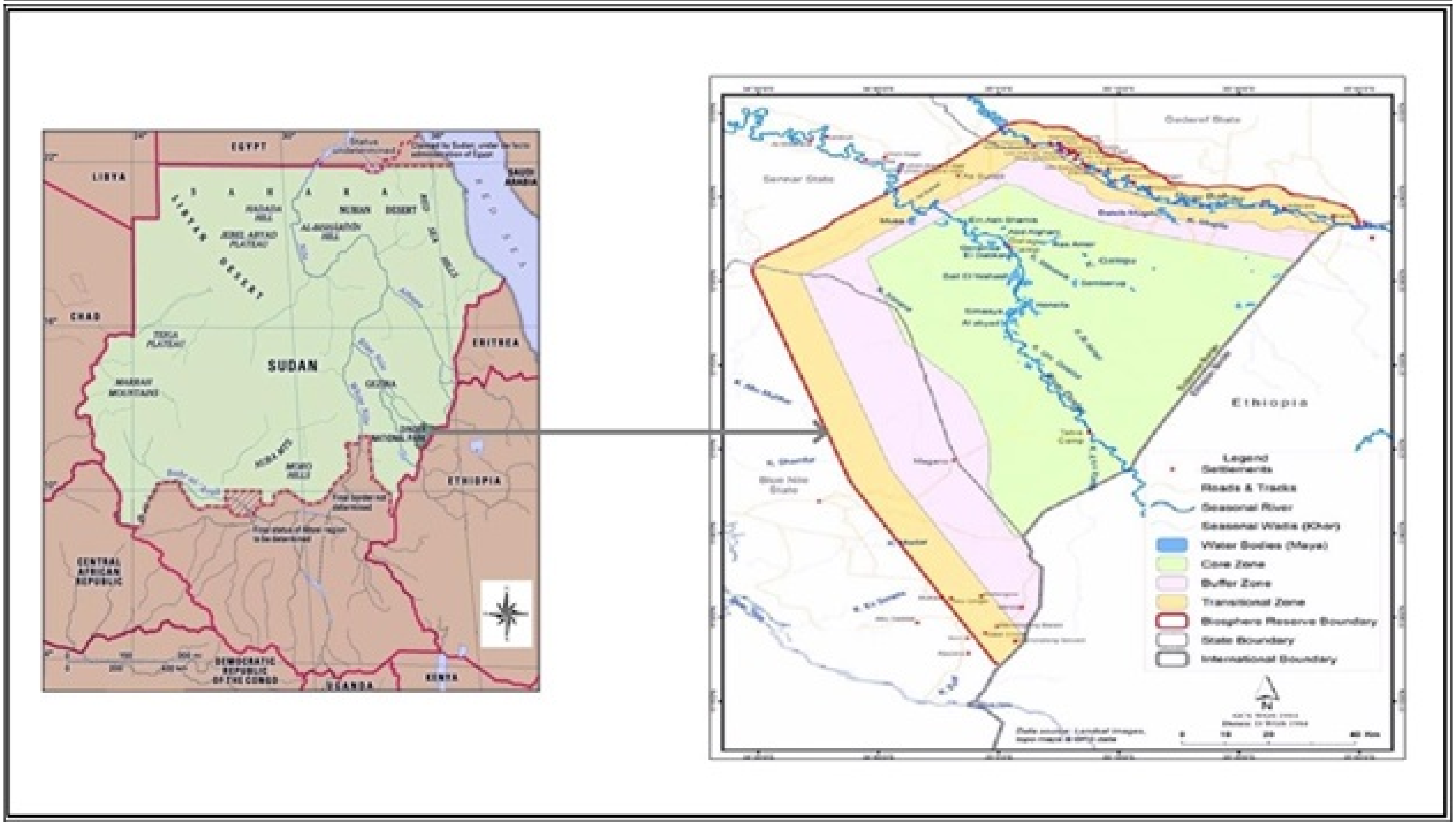

Figure 1: Map of the Dinder Biosphere Reserve in Sudan, including three zones of different protection status and some villages inside and around the reserve. Sources: https://en.unesco.org/biosphere/arab-states/dinder (Last updated: May 2019)

hartmannianum. While the common tree species on mountainous areas are Anogeissus leiocarpus, Terminalia brownii, Terminalia laxiflora, Lannea fruticosa, Sterculia africana, Lonchocarpus laxiflorus, Sclerocarya birrea, Ziziphus spina-christi, Maerua angolensis, and Pterocarpus lucens. The general topography of the forest is flat except in the western area of the reserve around the Fazara Mountain. The elevation of Fazara Mountain is 561 m above sea level with fine and coarse sandy soil. The soil types are crack dark clay soil in the northern and southern parts, and sandy clay in the mid area of the forest (Ibrahim 2019).

2.3.2 Abu Gadaf natural forest reserve

Abu Gadaf forest is the last reserved forest in the eastern part of Wad Almahi locality, Blue Nile State, at Kadalow area near the international boundary between Sudan and Ethiopia. It is located between latitudes 11º 25 00 N and 11º 31 00 N, and longitudes 34º 50 00 E and 34º 55 00 E, with a total area of 4413.78 ha (Fig. 3B). The forest is characterized by high diversity in tree species, soil types and topography. It hosts more than 46 tree species ranging from those of gum production and edible fruits to that of building construction materials and fuel wood. Gum producing species in the forest include; Acacia senegal, Acacia seyal var seyal, Acacia polycantha, Boswellia papyrifera, Commiphora africana, Sterculia africana and Sterculia setigera; while the tree of edible fruits are Balanites aegyptiaca, Diospyros mespiliformis, Grewia bicolor, Grewia flavecuns, Grewia mollis, Grewia tenax, Hyphaene thebaica, Lannea fruticosa, Sclerocarya birrea,Tamarindus indica, Ziziphus abyssinica, and Ziziphus spina-christi. For building/construction purposes the preferable tree species by local communities include Anogeissus leiocarpus, Dalbergia melanoxylon, Acacia seyal var seyal, Combretum hartmannianum, Lannea fruticosa, Lannea schempri, Pterocarpus lucens, and Lonchocarpus laxiflorus. All tree species are used as firewood; however, the preferable one for charcoal production is Acacia seyal var seyal.

Other tree species are: Boscia senegalensis, Combretum aculeatum, Combretum ghazalense, Combretum glutinosum, Combretum micranthum, Combretum molle, Crateva adansonii, Dichrostachys cinerea, Entada africana, Ficus sycomorus, Gardenia lutea, Lannea kerstignii, Maerua angolensis, Piliostigma reticulatum, Pseudocedreca kotschyi, Stereospermum kunthianum, Strychnos innocua, Syzygium guineense, Terminalia brownii, Terminalia laxiflora, Terminalia macroptera, Xeromphis nilotica, and Ximenia Americana (Hassan 2019).

The topography of the forest varies from mountainous one in the northern, north eastern and north western parts to the semi flat in eastern and western parts, and flat one in southern part. The soil types are coarse sand in north western, sandy in north eastern, sandy-clay in northern and crackly-clay soils in southern parts (Ibrahim et al. 2018; Ibrahim and Hassan 2015).

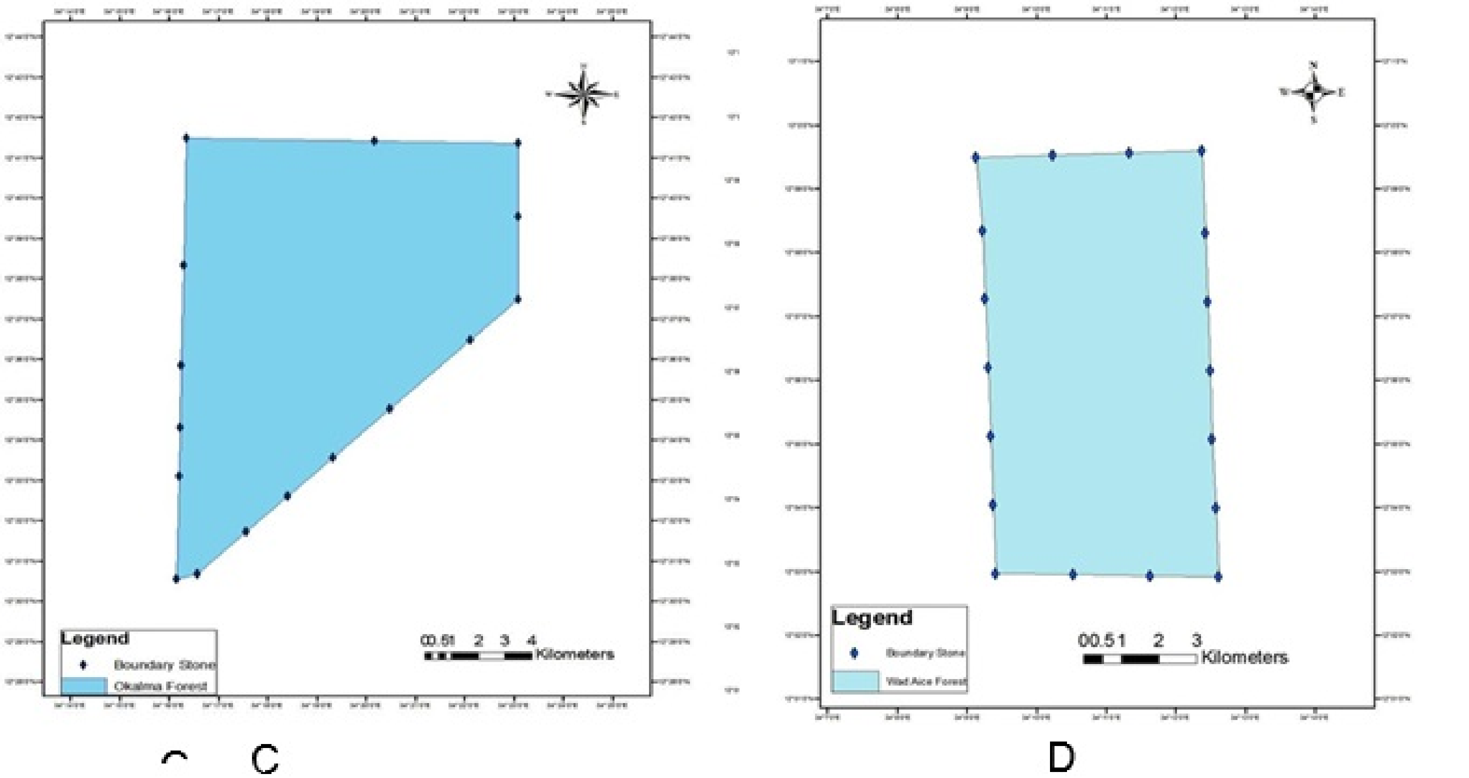

Figure 2: Maps of selected natural forest reserves in the study area (A: Fazara natural forest reserve, B: Abu Gadaf natural forest reserve, C: Okalma natural forest reserve and D: Wad Ayies natural forest reserve

2.3.3 Okalma natural forest reserve

This forest reserve is located in the southern east part of Sinnar State at latitude 12º 30 00 N and 12º 40 00 N, and longitude 34º 16 00 E and 34º 24 00 E (Fig. 3C). It is the largest forest in the State with total area of 17639.65 ha (Hassan 2019). The forest includes different tree species, which are dominated by Acacia senegal, Acacia seyal var seyal, Lannea fruticosa, Ziziphus spina- christi, Acacia mellifera, and Acacia oerfota. Some tree species like Sterculia setigera, Anogeissus leiocarpus, Dalbergia melanoxylon, and Acacia nilotica are present in small quantities. The forest topography is flat to semi flat with crack clay soils alternating with deeply cracked clay soils in the Mayas and sand soil in mountainous and bare land.

2.3.4 Wad Ayies natural forest reserve

This forest located at latitudes 12º 52 00 N and 13º 00 00 N, and longitudes 34º 09 00 E and 34º 13 00 E, with an area of 7160.86 ha (Fig. 3D). It is dominated by Acacia seyal var seyal, Acacia senegal and Balanites aegyptiaca with scatter numbers of Acacia oerfota and Acacia mellifera. Acacia nilotica, Tamarindus indica, and Ziziphus spina-christi are present in small quantities along the valleys and Mayas. Generally, the forest is characterized by flat topography with clay soil in area covered by Acacia seyal, and sandy clay soil in Acacia senegal areas (Mohammed et al. 2021).

2.4 Data collection

Point sampling (spot less sampling) design was used for data collection, whereby each forest reserve was systematically divided into survey lines for grid formation from which the sample centers were recorded and entered into a GPS device map 62s GARMIN. To create this grid layout (Fig. 4), Arc GIS version 9.3 was used. The sample plot size was 1 ha and the sampling intensity was 10% throughout the study area [except under topographical circumstances (such as mountain/hills, meadows . . . etc) where the percent 10 deferred]. Table 1 illustrates the number of samples per forest reserve, survey lines and forest area for each selected forest reserve in the study area. The tree variables measured were: Diameter at Brest Height (DBH at 1.30 m above the ground) and Total Tree Height (TTH), while Basal Area/ha (BA) and Tree Volume (V) were computed from the measured variables. The Spiegel Relaskope was used to count the number of trees/ha as recommended by other researchers (e.g., Ueno 1978). DBH was measured using diameter tape, while, height was measured using Suunto Clinometer as recommended by other scientists (e.g., Ibrahim et al. 2015; Ibrahim and Osman 2014). The total number of measured trees in this study was 8,014 trees from the six forests.

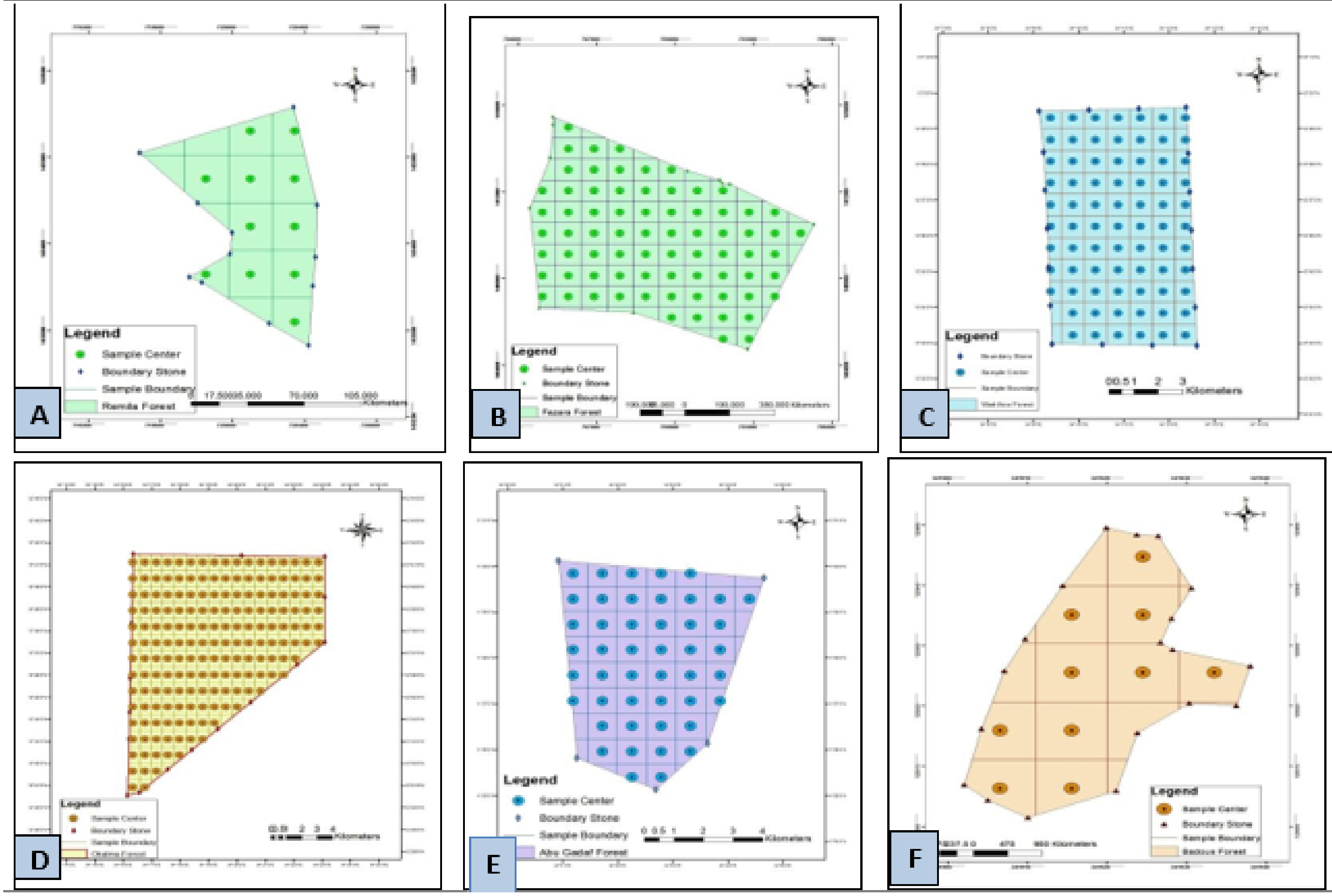

Figure 3: Sampling layout for the six forest reserves (A. Remila, B. Fazara, C. Wad Ayies, D. Okalma, E. Abu Gadaf and F. Badous)

2.5 Data analysis

The following equations were applied to calculate the Tree Basal Area (BA), Volume (V), and Density per ha as recommended by Ibrahim and Hassan (2015).

Tree Basal Area = $\pi \times \frac{(DBH)^2}{4}$
Basal Area per Sample Plot $= \sum$(Trees Basal Area in a plot)
Basal Area per ha $= \left(\frac{\text{Basal Area per Sample Plot}}{\text{Area of Sample Plot}}\right) \times 10000$
Volume per ha $=$ (Basal Area per ha) $\times FF \times$ Average Height

Where Basal Area is in m^2, Volume is in m^3, and FF is the form factor (a correction factor for the taper of a tree). Paired samples T-test in Minitab 17 (HUSCH 1971) was used to compare between the calculated parameters.

2.6 Results

2.6.1 Characteristics of the Growth Parameters and Tree Density

Riverine forest reserves showed better performance than natural forest reserves, where all growth parameters were higher in riverine than natural forest reserves. Growth parameters differed significantly between Badous and Remila riverine forest reserves with probability values (P) of 0.032 for DBH, 0.012 for Height, 0.024 for Basal Area, and 0.011 for Volume (Table 2). However, the same parameters indicated no significant differences between the four natural forest reserves (Table 3).

On the other hand, the minimum value of tree density per ha was 20 trees in Remila riverine forest reserve, while the highest one was 743 trees in Fazara natural forest reserve (Table 4). In terms of average values, riverine forests attained good density values compared to natural forests, where Badous riverine forest reserve has an average density of 356 trees/ha (Table 4).

2.7 Rare tree species in the study areas

Six tree species appeared as rare species in both Badous and Remila riverine forest reserves, beside other four species distinguished independently. Local communities around the two riverine reserves used Adansonia digitata, Balanites aegyptiaca and Ziziphus spina-christi for food, fodder and medicinal uses (Table 5). For natural forest reserves, Abu Gadaf showed the highest number of rare tree species (13) followed by Fazara, Wad Ayies and Okalma forest reserves as 8, 8 and 7, respectively (Tables 5).Species like Acacia seyal var seyal, Adansonia digitata and Tamarindus indica are shared as rare species in all four natural reserves, while others like Acacia

Table 1: Table 1: forest area size No. of survey lines, and sample sizes in the studied area

Forest name	Forest area (ha)	Survey lines (No.)	Samples (No.)
Remila Riverine Forest Reserve	86.186	3	11
Fazara Natural Forest Reserve	7,095.758	11	74
Wad Ayies Natural Forest Reserve	7,163.866	7	75
Okalma Natural Forest Reserve	17,647.059	17	178
Abu Gadaf Natural Forest Reserve	4,413.784	7	46
Badous Riverine Forest Reserve	76.984	4	10
Total	36483.637	49	394

Table 2: Characteristics of the trees parameters in selected riverine forest reserves

Parameter	**Badous Riverine Forest Reserve**					**Remila Riverine Forest Reserve**				
	Min	Mean	Max	SE	CV%	Min	Mean	Max	SE	CV%
DBH (cm)	10.8	28.4	58.2	0.495	35.3	11.2	23.9	58.2	0.376	36.7
Height (m)	12.0	18.1	18.6	0.165	18.3	5.6	10.0	26.1	0.168	39.1
Basal Area (m^2)	0.01	0.071	0.266	0.003	72.1	0.01	0.051	0.266	0.002	76.3
Volume (m^3)	0.05	0.55	2.50	0.023	84.6	0.04	0.24	1.53	0.011	105.

Note: Min, Max, SE, and CV are Minimum, Maximum, Standard Error, and Coefficient of Variation, respectively. P is the probability value.

polyacantha, Dichrostachys cinerea and Sterculia setigera are rare in only three reserves. Reasons that make species in the study areas to be rare were illicit grazing, illegal harvesting trees and growing demand for the NTFPs in the forest reserves.

3 Discussion

Riverine forest reserves characterized by a good management system and well-scheduled plans, that is why they attained good performance of growth parameters particularly in Badous forest. Tree diameter and height are key indicators for healthy growth and fertile stand, which is well recognized in this study. Variation in the stand spacing and density, as well as the site characteristics, guided the observed significant differences between Badous and Remila forest reserves. These findings are similar to (Ibrahim et al. 2018). On the contrary, other natural forest reserves are exposed to a continuous livestock browsing/grazing and illegal harvesting (FNC 2011), which negatively affected the natural regeneration of the tree species and their growth performance. Probably, that is why tree diameter, total height, basal area and volume exhibited no significant differences between natural forest reserves. This finding is supported by the results obtained by other researchers (e.g., Ibrahim and Hassan 2015 and Osman and Idris 2012).

The formal national accounts show a limited contribution of the Sudan forestry sector to the GDP. These accounts register figures of 1- 2% contribution, which equals the value of wood produced from government forest reserves or registered in the format of royalty collection (CBoSTAT 2014). This accounting deficiency attributed to the lack of data on different forest products obtained from different forest areas in addition to the difficulty of assessing the indirect benefits of trees and forests. Excluding Gum Arabic, most of the non-wood forest products not accounted for GDP (FAO 2014 b). Sudan forestry sector differ significantly before and after the separation of South Sudan to form an independent country on 9 July 2011. However, according to the Forest National Corporation (FNC) – Sudan - report for the year 2011 (year of separation/referendum), the percentages of forest cover was 11.60%. Thus, the reduction in percentage was from 29.4% to 11.6% with reduction of 17.8%, which categorizes Sudan as one of the low forest cover countries with deforestation rate of 2.46% annually (FNC 2011).

The various forms of forest destruction was carried out in the form of illegal felling of tree branches and debarking up to complete tree logging. Overgrazing is another key factor that eliminates the forest stock and degrades many rangelands (Chaturvedi et al. 2012; Hassan and Tag 2017; Lempesi et al. 2017; Nicu 2018; Yousif and Mohammed 2012). These two factors (overgrazing and illegal harvesting) are the main reasons for the remarkable reduction of tree species in these natural forests. These results are supported by the findings of different researchers (Alvarez-Aquino and Williams-Linera 2012; Mahgoub 2014; Pour et al. 2012).

Twenty-one NTFPs trees and shrubs species surrounding the two forest reserves in Gadarif state were utilized. However, disappeared and rare species, record a total of 34 and 36, respectively (Hassan 2019). The same study stated that from the tree species that disappeared due to dust bowl, 2013 in Kadalow area was Cordia sinensis. More investigation could be carried out to roadmap forest trees resilient or vulnerable to climate change/climate variability processes. Abu Gadaf natural forest reserve revealed the highest number of rare tree species, which directly related to the high anthropogenic pressure coming from the local communities and firewood traders in these remote areas.

The study results indicated that the number of tree species among the six studied forests ranges from 3 to 49 tree species per forest. The results of the study showed that the average growing stock for one ha (one sample plot) was ranging between 2 m3 ha-1 to 28.6 m3 ha-1 (the overall average was 10.5 m3 ha-1). This was 2% to 26% compared to the global average (110 m3 ha-1). The global average for growing stock is 110 m3 per hectare (11 000 m3 per km2) and has not changed significantly over the last 15 years. Growing stock is a measure of the volume of stem wood in a given area of forest or wooded land, usually measured in solid cubic meters (m3). Forest growing stock has traditionally been a key indicator of wood production and is used as a basis for estimating biomass and carbon stocks in most countries. The results also indicated that the overall average for measured variables: Basal Area (m2); Tree number per ha (No); Form factor (f); Tree height (m) and Volume per ha (m3) between the three states were significantly different (P 0.000). The results revealed that the minimum value of tree density per ha was 20 trees in Remila riverine forest reserve while the highest one was 743 trees in Fazara natural forest reserve. The probability value (P) results revealed that growth parameters differed significantly between riverine forest reserves as 0.032 for DBH, 0.012 for Height, 0.024 for Basal Area

Table 3: Characteristics of the trees parameters in four selected natural Forest Reserves

Parameter	**Fazara Natural Forest Reserve**				**Wad Ayies Natural Forest Reserve**				**Okalma Natural Forest Reserve**				**Abu Gadaf N**	
	Min	Mean	Max	SE	CV%	Min	Mean	Max	SE	CV%	Min	Mean	Max	SE
Mean	Max	SE	CV%											
DBH (cm)	6.7	23.1	36.6	0.44	23.3	15.5	23.5	38.0	1.09	23.5	17.0	25.6	39.7	1.56
25.4	42.7	1.47	27.2											
Height (m)	6.2	8.3	11.8	0.43	17.7	6.9	8.6	11.9	0.24	15.0	7.1	9.6	12.7	0.39
9.1	13.9	0.34	19.3											
Basal Area (m^2)	0.03	0.05	0.12	0.01	48.8	0.03	0.05	0.13	0.01	49.4	0.03	0.06	0.14	0.01
0.06	0.16	0.01	56.4											
Volume (m^3)	0.07	0.18	0.38	0.03	62.3	0.08	0.20	0.67	0.13	51.5	0.08	0.25	0.77	0.20
0.22	0.97	0.17	51.7											

Table 4: Characteristics of the tree density/ha in the studied forest reserves

Forest Reserve	**Mean**	**Min**	**Max**	**SE**	**CV%**
Badous Riverine Forest Reserve	356	160	614	3,909	42.53
Remila Riverine Forest Reserve	157.8	20	298	5,182	73.43
Abu Gadaf Natural Forest Reserve	257.2	168	422	2,378	29.24
Fazara Natural Forest Reserve	184.1	16	743	7,519	129.2
Wad Ayies Natural Forest Reserve	219.6	65	424	3,733	53.75
Okahna Natural Forest Reserve	219.6	71	424	3,733	53.75

Note: Min, Max, SE, and CV represent Minimum, Maximum, Standard Error, and Coefficient of Variance, respectively.

and 0.011 for Volume with no significant differences among natural forests. Fazara natural forest reserve revealed the maximum value of tree density, however, Badous riverine forest reserve showed the highest mean value for tree density throughout the study area. Besides that, the study findings also distinguished Acacia seyal var fistula, Adansonia digitata and Tamarindus indica as rare tree species in all six-forest reserves. Hence, urgent protection measures are needed in the study area in order to conserve these rare tree species before they disappear from their natural ranges.

Although, Badous is a riverine forest reserve with good management system and well- scheduled plans, it has a highest percent of the rare species. So, considerable managerial works should take place. The study made in the transitional zone of DBR has shown that the highest number of disappeared tree and shrub species were 21 species in Sinnar side followed by Blue Nile 11 species and Gedaref 9 species (El-Mugheira 2019). The lowest number of rare species was 12 in Sinnar while the highest one was 20 species in Gedaref side. These findings indicate that the over utilization is very apparent in Sinnar forest reserve compared with Blue Nile and Gedaref where disappeared species were observed in the area. The highly affected area by agricultural expansion was that part of transitional zone bordering Sinnar State followed by Gedaref State and Blue Nile State, while for reserved forests; the worse situation was in Blue Nile followed by Gedaref and Sinnar. The results of the study have revealed that the inadequate stocking density and growing stock per ha in the study area. The above mentioned finding was in line with e.g. Badi and Abdel Magid (2013) for Blue Nile (Sunt) and Hassan (2015) assessment of the forest resources in the transitional zone of the DBR and the forest reserves around the zone.

4 Conclusion

Stocking density and growing stock per ha in the study area was poor (only 9.5% as compared to the global average). The study concludes that riverine forest reserves are well stocked compared to natural forest reserves. However, all forest reserves have a significant number of rare tree species that need urgent intervention to conserve and protect these vulnerable species. Acacia seyal var fistula, Adansonia digitata and Tamarindus indica were documented as rare tree species throughout the study area, while Acacia seyal var seyal and Acacia nilotica were dominant in all natural forests and riverine forests, respectively. Special attention should be devoted to the planting and conservation of Balanites aegyptiaca, Tamarindus indica and Adansonia digitata, which have growing importance within the climate change context and multi-utilizations throughout the country. The study recommends increasing the stocking density to increase the quantity and quality of forest reserves to fulfil the environmental and socio- economical requirements in order to improve livelihoods of the communities and sustain the DBR.

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Conflict of interest

The authors declare no conflict of interest

Table 5: Rare tree species in the studied riverine and natural forests reserves

Species	Uses	Forests Reserves
Acacia mellifera	Fodder, building materials, and firewood	B; R
Acacia polyacantha	Fodder and firewood	Abu; Wada
Acacia seyal var fictula	Fodder and charcoal	B; R; Abu; Fazara; Wada; O
Acacia sieberiana	Fodder and firewood	R
Adamsonia digitata	Food, fodder, and medicine	B; R; Abu; Fazara; Wada; O
Balanites aegyptiaca	Food, fodder, medicine, firewood, and furniture	B; R; Fazara; O
Combretum aculeatum	Fodder and firewood	B; Wada
Combretum microtratum	Fodder, building materials, and firewood	Fazara
Commiphora africana	Medicine and fodder	Fazara
Dalbergia melanoxylon	Furniture and building materials	Abu
Dichrostachys cinerea	Fodder and firewood	B; R; Abu; Wada; O
Grewia bicolor	Food and fodder	Abu
Grewia flavescens	Food and fodder	Abu
Grewia mollis	Food and fodder	Abu
Grewia tenax	Food and fodder	Abu
Hyphaene thebaica	Food and building materials	O
Pseudocedrela kotschyi	Building materials, furniture, and firewood	Abu
Stereospermum kunthianum	Medicine and fodder	B; Fazara; Wada; O
Tamarindus indica	Food, fodder, and firewood	B; R; Abu; Fazara; Wada; O
Terminalia macroptera	Firewood, furniture, and building materials	Abu; Fazara
Ziziphus spina-christi	Fodder, furniture, food, medicine, and firewood	B; Abu; Wada

Note: B for Badous; R for Remila; **Abu** for Abu Gadaf; F for Fazara; **Wada** for Wada Ayies; and O for Okahna.

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Research Article

Pastoralists' willingness-to-pay for rangeland improvement: A case of Yabello District, Southern Ethiopia

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Abstract

Rangeland degradation remains a major concern for pastoralists' livelihoods in Ethiopia. Several studies about rangeland resource management in Ethiopia hitherto focused on the biophysical aspects without considering the societal and cultural needs of the people. However, insights about pastoralists' demand for the improvement of rangeland environment using acceptable environmental valuation techniques remained a research gap. Thus, this study was aimed at estimating mean willingness to pay (WTP) for rangeland improvements in Yabello District, southern Ethiopia. A total of 172 households from two Kebeles were randomly selected. Bivariate probit model was used to estimate mean willingness to pay (MWTP) and binary logistic model was used to estimate the factors influencing pastoralists' willingness- to-pay. The estimated mean willingness-to-pay for the improvement was 11.86 man-days/month, which is equivalent to 830.2 ETB/month (17.93 USD). The aggregate WTP for the improvement was 38,426 man- days/year, which is 2,689,820 ETB/year (58,117.84 USD). Sex, age, family size, major livelihood activities, livestock holding and initial bid value have significant influence on pastoralists' willingness to pay. Hence these factors need to be considered in policy-making regarding rangeland rehabilitation projects involving pastoral communities. This study enlightens an entry point for future research in rehabilitation of degraded rangelands in Ethiopia.
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Keywords: Binary logistic, bivariate probit, contingent valuation, rangeland degradation, willingness to pay

1 Introduction

Rangelands cover a large proportion of the world and are a very important source of livestock feed as well as livelihood assets for pastoralists (Suttie and Reynolds 2003; Upton 2004). They provide the least costly feed resources to domestic and wildlife ungulates in arid and semi-arid parts of the world (Zerga Belay 2015). The values of rangelands resources range from providing primary materials for feed and food, shelter and medicines to "linking humanity to the sun and eventually to God" (Sabiiti 2004). In Africa, rangelands are the major source of feed, which support 59% of all ruminant livestock and constitute about 65% of the total land area (Friedel et al. 2000).

In Ethiopia, rangelands are located around the border line of the country. The majority of them are found below 1500m.a.s.l and estimated to cover an area of 78 million ha (Dawit Abebe 2000). The rangelands of Ethiopia are home to many important plant species which contribute greatly to daily sustenance of local communities. These plants, which are diverse in nature, are primary source of fodder, fuel wood, resins, traditional medicines, etc., and in some cases, contribute significantly to food security in terms of wild food in marginal areas (Zerga Belay et al. 2018). Climatic condition in pastoral areas varies greatly based on the geographical and temporal setting. Several studies in Ethiopia revealed that rangelands have been degraded at an alarming rate (Asrat paulos et al. 2004; Berry and Campbell 2009). They need to be properly managed and utilized to optimize the benefits of the pastoral community and the country at large.

Borana rangeland is among the most important rangelands for the cattle production which is located in the southern part of Ethiopia (Oba et al. 2000). Borana rangeland are facing enormous natural and anthropogenic problems such as recurrent drought, floods, bush encroachment and pastoral-related conflict from resource competition.

Many development interventions were initiated to reverse the process of degradation and re-establish healthy grasslands. However, they focused more on the experimental work and biological aspects, and did not involve local communities to extend the research findings through social lens (Mohammed Musa et al. 2016; Kusse Kutoya et al. 2018). Additionally, attempts to rehabilitate degraded rangelands have failed as they placed more value on the physical and technical details of the interventions than the socioeconomic and cultural needs of the people (Mureithi et al. 2014). Hence, valuable strategies to improve the self-reliance and resiliency of the pastoral community are required.

The pastoral communities possess indigenous knowledge in managing their grazing lands acquired through extensive observation and continuous herding practice (Oba and Kotile 2001;). To stop and reverse the effects of rangeland degradation, an appropriate improvement strategy should be designed and implemented. Thus, in this study, rangeland improvement is understood as a range of activities, such as clearing invasive bushes, planting grass and permanent trees to provide shades and fodder, constructing permanent sources of water, building fundamental infrastructures (schools, health center, roads) in the area, to make suitable place to stay permanently. All these activities need direct involvement, contribution and participation of pastoral communities, so as to solve their primary problems. The contribution could be in terms of cash payment or labor contribution. As a result, understanding the willingness-to-pay (WTP) of the pastoralists and the factors influencing their WTP is a first step towards realizing rangeland rehabilitation.

The scholarly attention given to estimate the economic value of rangeland rehabilitation in the study area is, thus far, very low. Particularly, pastoralists' willingness to pay decision and determinants that affect their willingness to pay in terms of cash and labor had hitherto not been studied in Borana area. Therefore, this study was conducted with the aim of estimating mean willingness to pay and identifying the determining factors that affect the pastoralists' decision on willingness to pay for the rangeland improvement in Yabello district, using double- bounded contingent valuation method (CVM).

2 Material and Methods

2.1 Description of the study area

The study was conducted in Yabello district of Borana Zone, southern Ethiopia (Error! Reference source not found.). Borana Zone shares international boundary with Kenya to the south, regional boundary with Somali Regional State in the east and Southern Nations Nationalities and People's Region (SNNPR) in the north, northeast and Zonal boundary with Guji Zone in the northeast (Figure 1). The rangelands of Borana are located in the southern part of Ethiopian lowlands and cover a total area of 95,000 km2 (Coppock, 1994). The area extends from 30 N to 60 N latitude 360 E 420 E longitudes. The altitude ranges from 1000 m.a.s.l to 1700 m.a.s.l having peaks up to 2200m. The region is dominated by a semi-arid climate with annual mean temperatures varying from 19 to 24°C. The rainfall pattern of the study area is bimodal with the long rainy season between March and May and the short rainy season between September and November. There is variability in both the quantity and distribution of rainfall with an average annual rainfall ranging from 400 mm in the south to 600 mm in the north (Negasa Bikila et al., 2014). The Borana Plateau represents part of the remaining core area or cradle land of the southern highlands and rangelands from which the original Oromo culture expanded and conquered half of present-day Ethiopia during the 1500s (Teshome Abate, 2016). The core rangeland area contains historical Oromo shrines still worshipped by the population. The area has been reportedly shrinking since the early 1900s, largely because of induced habitat change and Somali encroachment from the east (Coppock, 1994).

The main livelihood strategy of the community is livestock production. Production units are defined as typically consisting of a male household head, one wife, two to three children

and perhaps several other live-in relatives dependent upon the livestock for which the household head assumes management responsibility. Men are largely the strategists for livestock production, while women carry out day-to-day management and retain primary responsibility for dairy-related activities. Labor allocation is profiled on a daily basis for married women in different seasons. Herding and watering animals dominate labor requirements overall. Labor budgets suggest that labor is likely to be a common constraint in dry seasons. Land use type in the Borana rangelands is largely known to be communal, but in recent decades, crop cultivation and private enclosures have been increasing (Negasa Bikila et al. 2014). In this extensive communal semi-arid rangeland of Borana, herbaceous plants are the major feed sources of grazers. Households in the area are highly dependent on livestock production as they are pastoralists and daily labor in different farming season.

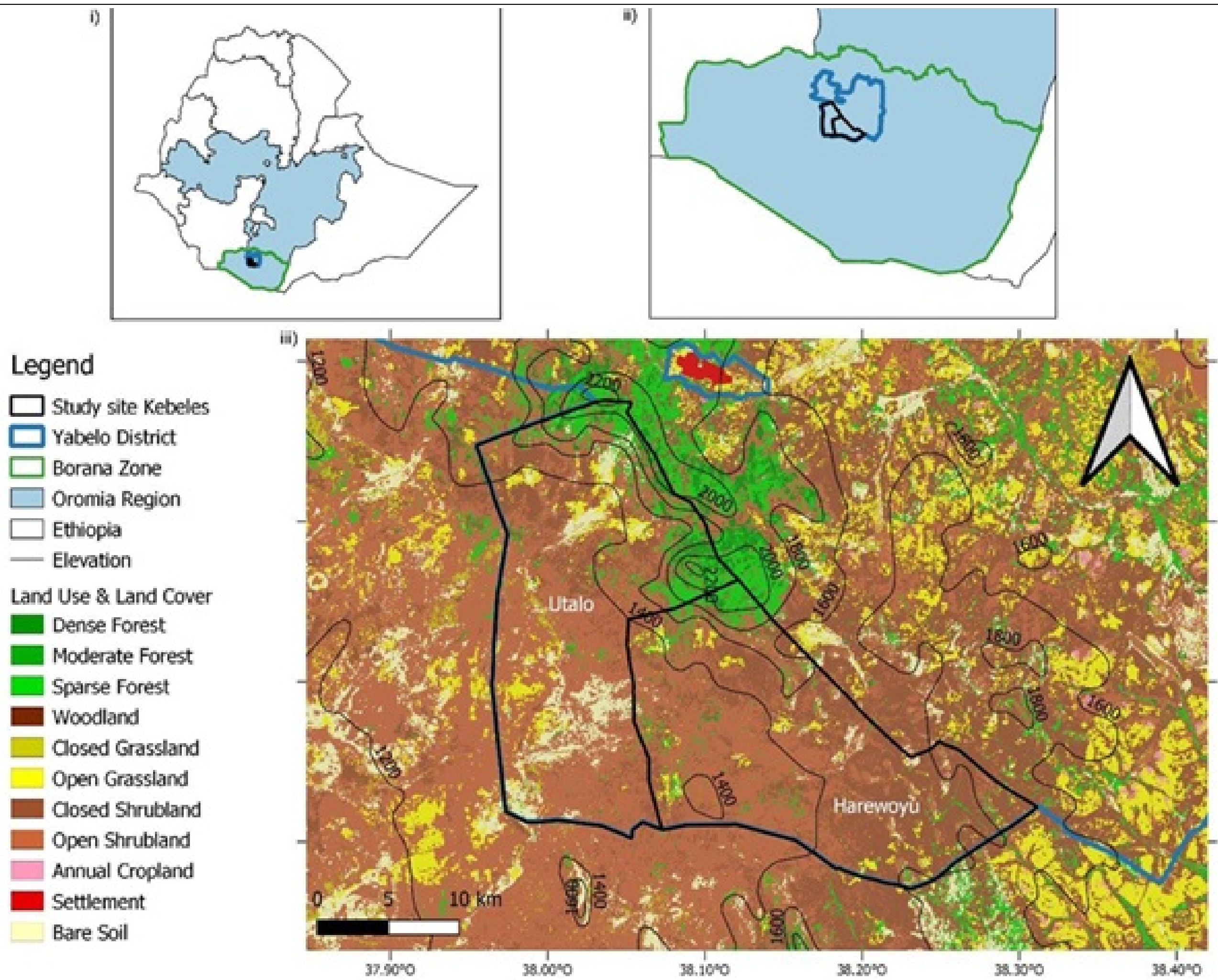

Figure 1: Location map of the study area showing i) Oromia region, ii) Borana Zone, and iii) the study site Kebeles

2.2 Sampling design and sample size

The study employed the embedded case study design, with the pastoralists as the unit of analysis (Yin 2018). We used multistage sampling technique. First, the study district was selected purposively based on people's rangeland access and use. Second, the study Kebeles (the lowest administration unit in Ethiopia), namely Harewoyu and Utalo, were randomly selected from Yabello district, which is considered as the representative of lowland areas of the Borana zone, southern Ethiopia. Due to large area coverage of Kebeles, only two Kebeles were selected from the district. Then the number of sample household respondents from each kebele were determined proportionally. Finally, each sample household was selected by simple random sampling. The number of sample respondent households was determined using the formula developed by (Yamane, 1967) cited by (Israel, 2012).

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

where n is the sample size, N is the total population, and e is the level of precision (7%). The total household count of the two kebeles is 1080 according to the Socio-demographic information of Yabello district (2019).

2.3 Data type, source and collection techniques

Both primary and secondary data were used for this study. The primary data were collected from sample respondents through household survey key informant interview (KII) and focus group discussions (FGD) using a structured questionnaire via face to face interview with the heads or working members of households. The developed questionnaire was tested before conducting the survey and was translated into the local language (Oromiffa), in order to have a clear understanding for the enumerators as well as respondents. Prior to the household survey, FGDs and KIIs were done to gather complementary data thereby enhancing the understanding of the context of the study. The FGD involved elders, women, men and youth who are native in each of the two kebeles. KIIs were conducted with Kebele officials, development agents, and elders who have a deep knowledge on environmental issues. Moreover, secondary data were collected from journals, books and pastoralist office of the Yabello district.

Contingent valuation method (CVM) in the form of double-bounded dichotomous choice elicitation method with open ended follow up question was employed to elicit households' willingness to pay (WTP) for rangeland improvements in terms of labor contribution/day. The double-bounded dichotomous choice format (yes-no, no-yes responses) makes clear bounds on unobservable true WTP. According to Hoyos and Mariel (2010), pre-test survey with open ended questions can help to provide some information on the bounds of respondents' WTP. Besides, the yes-yes, no-no response sharpens the true WTP (Haab and McConnell, 2002). The double-bounded dichotomous choice format help to elicit more information about respondent's WTP than single bounded format.

2.3.1 Preliminary survey and bids

Before conducting the final survey, a pre-test survey was held to determine initial bids in terms of cash and labor using open-ended contingent valuation format with 24 randomly selected households for FGD. In addition to that, two Development Agents and two Chief Administrators of the two kebeles participated as key informants with other elders (long-lived residents) in the area to give supporting ideas about the payment vehicle suitable for the study regarding rangeland improvement. Indeed, the choice of the payment vehicle can be varied depending on the socio-economic characteristics of the communities where the research is being conducted. According to Ahlheim et al. (2010) money as a payment is not a good measure of valuation in developing countries, since WTP is harshly restricted by households' tight budget constraints. In this case also, the pre-test survey accepted and agreed only labor contribution as a payment vehicle for rangeland improvement in the context of the area. This is because of the genuine nature of Borana pastoralist communities who prefer to contribute for development intervention measures on an in- kind basis and labor rather than on cash. The discussion with focus groups also confirmed that the labor they are willing to contribute has high degree of respect to the rangeland improvement than willing to contribute on cash basis.

During the pre-test survey, respondents were openly asked to state their maximum willingness to pay in labor. Then, four starting bid values (frequent responses) determined in terms of labor days were 4, 8, 12 and 15 labor days per month and the group participants agreed for these initial bids (labor days) per month. In addition to this, they were reminded that the contribution of labor for the improvement will only work for one working season (winter) per year, meaning that every willing person will contribute predetermined labor days per month only for three months per year. Then, the total sampled households were divided randomly into four groups corresponding to the four initial bids (labor days) for the final survey. After the bids were designed, the respondents were asked a yes/no question to elicit their willingness to pay. If one's answer was yes for the first bid, the next higher amount (pre-determined amount) was asked to state his/her answer. Finally, the respondents were asked their maximum willingness to pay both for the bounded and unbounded values using open-ended questions to state the maximum amount they are willing to pay. If his/her answer was no, the next minimum amount followed by open-ended question was also employed to elicit his/her maximum amount. The field survey was successfully completed without protest responses/zeros' .

2.4 Methods of Data analysis

The primary data collected from the survey were analyzed using STATA software to estimate the mean willingness to pay for the improvement (MWTP) and to identify the factors influencing the likelihood of the WTP responses. The major data categories collected at the survey level included pastoralists' decisions on WTP for rangeland improvement.

The logit transformation has good properties, as it is linear in its parameters, continuous, and ranges from $-\infty$ to $+\infty$ depending on the scale of the independent variables. Maximum likelihood estimation (MLE) is used to estimate the parameters of the variables assumed to influence the payment decision.

2.4.1 Dependent and independent variables

The dependent variable to be estimated was pastoralists' willingness to pay for rangeland improvement in the study area given the explanatory variables. WTP is a powerful tool used for assessing the perception and acceptability of a social-ecological service. Many studies employed the method in various social-ecological settings in a similar manner. For instance, Köhlin (2001) used WTP for provision of social forestry in Orissa, India. Shyamsundar and Kramer, (1996) used willingness to accept format for land use restriction associated with a newly established national park in Madagascar. All respondents were asked if they were willing to pay if the rangelands were rehabilitated for purposes of providing pasture and maintaining the environment. For the respondents who are willing to pay, questionnaires with both payment vehicle, either in monetary or in labor were prepared and given. Bidding system was used to determine the minimum and maximum amounts which the respondents are willing to pay. The dependent variable, as a function of given set of explanatory variables, was as follows:

WTP =f (age, sex, marital status, family size, education level, cultivated land size, number of herds owned, satisfaction with status quo, type of housing, rangeland ownership and initial bid value). Error! Reference source not found. lists the hypothesized effect of the explanatory variables on the dependent variable.

2.4.2 Empirical model specification

Logit and probit models are popular statistical techniques in which the probability of a dichotomous outcome is related to a set of explanatory variables that are hypothesized to influence the outcome (Nupane et al. 2002). However, Pindyck and Rubinfeld (1981) acknowledged logistic probability function as computationally easier to use than the other types. Thus, logistic regression model was used

Table 1: Explanation, type, and expected sign of the independent variables

Independent variables	Explanation	Types of variable	Expected sign
sex	Sex of the respondent	Dummy variable	Positive
Age		Continuous variable	Positive/negative
Marital	Marital status of the respondent	Categorical variable	Positive
Totfam	Total family size of the respondent	Continuous variable	Positive/negative
Educat	Education of the respondent	Dummy variable	Positive
Major	Major livelihood activities of the respondent	Categorical variable	Positive
Totland	Total cultivated land size of the respondents	Continuous variable	Negative
TLU	Total livestock in tropical livestock unit	Continuous variable	Positive
Housing	Type of housing	Dummy variable	Positive
bid1	Initial bid value	Continuous variable	Negative
cons	Constant		-

for this study. The logistic regression analysis is a uni/multivariate technique which allows for estimating the probability whether an event will occur or not through the prediction of a binary dependent outcome from a set of independent variables (Bamlaku Ayenew et al.2019). The model was adopted and used by Hanemann

(1989); Branka and Kelly (2001); Yusuf et al. (2007); Adepoju and Omonona (2009). The pastoralists' responses to willingness to pay questions were regressed against the prices that they are willing to pay and other socioeconomic characteristics of the household. Thus, in this study we used two econometric models, Binary logistic and Bivariate probit model to answer the objectives of the study. The study used binary logistic model to identify the factors affecting pastoralists' decision on willingness to pay for the rangeland improvement and bivariate probit model to estimate the mean willingness to pay for the improvement. The regression logistic model is specified as:

The probability P_i is given by:

$$P_i = E(Y = 1 \mid X_i) = \frac{1}{1 + e^{\beta_0 + \beta_1 X_1}}$$

where:

- Y = pastoralists' response of willingness to pay question, which is either 1 if Yes or 0 if No,
- β_0 = constant,
- β_1 = coefficient of the bid price that the households are willing to pay for the improvement,
- X_1 = the bid price that the households are willing to pay for the improvement.

The response Y is modeled as:

$$Y = \frac{1}{1 + \exp(-Z)}$$

where:

- Y = responses of household WTP, which is either 1 for Yes and 0 for No,
- $Z = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n$,
- $X_1, X_2, X_3, \ldots$ = explanatory variables,
- $\beta_0, \beta_1, \beta_2, \ldots$ = coefficients of explanatory variables.

The mean willingness to pay (WTP) for the improvement of degraded rangeland with no covariates was calculated using the formula adopted by Yusuf et al. (2007):

$$\text{Mean WTP} = \frac{1}{\beta} \ln(1 + \exp(\alpha))$$

where:

- α = coefficient for the constant term,
- β = coefficient for offered bids to the respondents.

Aggregation of benefit is an important issue related to the measurement of welfare using CVM or WTP (Mekonnen Alemu 2000). There are four important issues to be considered regarding sample design and estimating a valid aggregation of benefits:

- Population choice bias,
- Sampling frame bias,
- Non-response bias,
- Sample selection bias (Mitchell and Carson 1989).

None of the above biases were observed in the investigation. The study used face-to-face interviews, and there was no protest zero response, even though the expected protest zero was accounted for in the estimation of the total aggregate benefit of rangeland improvement in this study. Mean WTP was used as a measure of the aggregate value of rangeland improvement in this study.

3 Results and discussion

3.1 Sociodemographic characteristics of respondents

All of the 172 sample households had no data discrepancy. Thus all observations were included in the analysis. The summary statistics was computed for the total sample and compared with the willing and not willing respondents. The average age of the respondents was 44.9 years. The mean age of willing households was lower than the average age, so the willing pastoralists tend to be younger than non-willing households. The average family size of the willing respondents was 7.6, which was higher in comparison to the average family size of non- willing respondents which was 4.5. Respondents with large number of family size would contribute more labor for the improvement which is in line with Bamlaku Ayenew and Yirdaw Meride (2015). The average cultivated land of willing respondents was more than that of non-willing individuals. The average livestock holding of the willing and non-willing respondents were 13 and 4, respectively, meaning that those with more livestock tend to contribute more for rangeland improvement, which is in accordance with the finding of Getachew Belay et al. (2020). Error! Not a valid bookmark self-reference. summarizes the above-mentioned continuous variables.

In addition to that, the result revealed that 90% of the respondents were male-headed households of which 82% of them were willing to pay for rangeland improvement. About 19.7% of the respondents were literate households. Out of 34 literate households, 76.5% were willing to pay for the rangeland improvement. Literate households were more willing to pay for rangeland improvement, which is consistent with the finding of Bamlaku Ayenew and Yirdaw Meride (2015). Almost 93% of the willing respondents were permanent residents in the area. Around 68% were married and 72% of respondents' major livelihood activity is livestock production. Regardless of the willingness of the respondents, no respondent was found to be satisfied by the status quo level of rangeland resources in the area.

3.1.1 Households' WTP for the rangeland improvement

The mean WTP from responses of both the first and the second bids were estimated using double bounded dichotomous choice format. The result revealed that the correlation coefficient of the error term was less than one, which implies that the random component of WTP for the first question is not perfectly correlated with the random component from the follow-up question. The mean WTP from an open ended response was computed at 7.98 labor days per month, which is approximately 8 man-days per month (See Table 3). At 95% confidence interval, the average WTP from double bounded question for rangeland improvement varied between 16.06 to 7.08 man-days per month for the initial bid and second bid amount, respectively(See Table 3).The mean WTP from the double bounded dichotomous question is 11.57, which is approximately 12 man-days per month. The result shows that the mean WTP from bivariate probit model was greater than the mean WTP value from the open ended response. This indicated that respondents either try to free ride or the double bounded elicitation method has anchoring effect. This result is consistent with the various studies, such as Mekonnen Alemu (2000), Köhlin (2001), Carlsson et al. (2004), Bamlaku Ayenew and Yirdaw Meride (2015).

3.2 Estimation of the bivariate probit model

The results revealed that about 75.6% of the total sample households were willing to pay for rangeland improvement and their WTP is positive. To estimate the mean WTP from responses of both the first and the second bids offered, double bounded dichotomous choice format was used. The analysis was done using seemingly unrelated bivariate probit model (the equations are called seemingly unrelated because they are only related through the error terms). The estimation result of the model is reported in Table 4 below. The mean WTP from bivariate probit model was computed using the formula specified by Haab and Mconnell (2002).

3.3 Aggregate WTP for rangeland rehabilitation

As indicated in Table 5, the aggregate WTP was calculated by multiplying the mean WTP by the total number of households who were expected to have a valid response in the study area. Since there was no protest zero response from sampled households, there might not be expected protest zero response from the population as well. Based on the double bounded dichotomous questionnaires, the aggregate WTP for rangeland rehabilitation was computed at 38,426 labor days per year which is equivalent to 2,689,820 Birr (61435.49 USD). In terms of per household basis, it translates to 35.58 labor days per year. In contrast, based on the open ended questionnaires, the total WTP for the rangeland improvement was computed at 25,596 labor days which is equivalent to 1,791,720 Birr per year, or 23.7 labor days per year per household.

3.4 Determinants of pastoralists' willingness to pay

3.4.1 The binary logistic model estimation

The estimated result on factors affecting the households' WTP for rangeland improvement is presented in annex 1. The actual sign of most of the explanatory variables were as expected. Ten explanatory variables were included in the model to predict willingness to pay of the respondents in labor contribution. Table 6 shows the sign, magnitude, statistical tests significance level and odds ratio of each explanatory variable. Out of the total variables hypothesized to influence willingness to pay of the respondents in terms of labor, six variables were statistically significant at less than 1% (p-value ¡0.01) significance level. These variables are sex age, family size, major source of livelihood, livestock holding in tropical livestock unit and initial bid value. Marital status, land size, educational level and type of housing did not show statistical significance. The coefficients associated with sex, major livelihood activity, total family

Table 2: Definition, expected sign, and summary of the continuous variables

Variable name	Definition of variables	Measurement sign	Expected	Descriptive statistics (mean)		
			Willing n=130	Not willing n=42	Total n=172	
Age	Respondent's age	Continuous	-	44	51	44.9
Totfam	Total family size	Continuous	+	7.6	4.5	6.3
Tot land	Total cultivated land	Continuous	+	-	0.25	0.76
TLU	Livestock number in TLU	Continuous	+	13	4	12.5

Table 3: Pastoralists' WTP from Open-Ended Questions

Max WTP	Freq.	Percent
<10	72	41.86
11-14	69	40.12
15-18	31	18.02
n=172, Mean = 7.98, Std. Dev. = 6.81		

size and livestock holding are positive, while the coefficients associated with the age and initial bid value are negative.The results imply that variable sex is statistically significant and the coefficient is positive, which means that male household would be more likely willing to pay for the rangeland improvement. Female-headed households may have less resources and time, as they are fully responsible for more jobs other than keeping the cattle on the pasture in pastoralists' area. During the survey, most of the female respondents had no time to give full information about the issues included in the questionnaire. It was found that being male increases the chances of one's willingness to pay by 198% than female and is significant at less than 1% (p-value 0.002). In other words, men were 19.8 times more likely to be willing to contribute in labor for the rangeland improvements than women, which could also be attributed to the physically-intensive labor work, as reported in Getachew Belay et al. (2020). The influence of male gender on the willingness to pay can also be explained by the male- dominated society, whereby households' income and wealth are mainly controlled by men. This was also observed by Sabiiti and Tegegne (2004) during their feasibility study for the dry land husbandry project in Ethiopia. This implies that since the majority of cattle keeping are dominated by the male gender, the prospects of obtaining willingness to pay responses from male respondents to the cost sharing rangeland management are high.

Age of the household head had negative and significant effect on households' WTP in man-days contribution at less than 1% (p-value=0.000) level of significance. This may be older aged people tend to use the service provided with free of payment. On the other hand, young farmers may have a longer planning horizon and, hence, may be more likely to be willing for the improvement. Besides that, old- aged households tend to refrain from labor intensive activities. Keeping the influence of other factors constant, an increase in household head age by one year reduces the probability of willingness to pay in labor days by 90%. The negative relationship between WTP and age is consistent with the finding of Bamlaku Ayenew and Yirdaw Meride (2015); Getachew Belay et al. (2020).

The results also show that total family size was found to be statistically significant with the expected positive sign (p¡0.01). This indicates that the probability of pastoralists' WTP to support the proposed rangeland improvement increases as the total household size increases under the hypothetical market scenario. Keeping the influence of other factors constant, an increase in household size by one unit increases the odds of willingness to pay by 187% for the rangeland improvement. This could be explained by the fact that, rangeland improvement practices like bush clearing and local water storing ponds are labor intensive; hence, households with large labor power are willing to contribute more in these practices. This result is consistent with the findings of Gebremariam Gebrelibanos (2012); Bamlaku Ayenew and Yirdaw Meride (2015). Livestock holding in tropical livestock unit has been found to relate to the probability of WTP for rangeland improvement positively and significantly at 1%. As the number of livestock increases, the chance of WTP will also increase. This is because the benefit obtained from rangeland improvement increases with the number of livestock owned. The odds ratio shows that, keeping the other explanatory variables constant, for each additional increment of livestock in TLU, the probability of the households' willingness to pay for the improvement will increase by 143%. Positive sign indicates that one unit increase in TLU is associated with an increase in likelihood of WTP for rangeland improvement. This is consistent with the findings of Mezgebo Alem et al. (2013); Gebremariam Gebrelibanos (2012); Bamlaku Ayenew and Yirdaw Meride (2015).

Livestock as the major livelihood activity also determines respondents' decision on their WTP for the rangeland improvement. Rangeland resource is the base for livestock production and livestock is the major source of livelihood for pastoralists' community. As a result, major livelihood activity is expected to be significantly affecting pastoralists' decision on their WTP for rangeland improvement. Result of the survey shows that livestock production as major livelihood activities had positive and significant effect on pastoralists' WTP at p-value 0.000. Therefore, respondents whose major livelihood activity was livestock are more likely to pay for the improvement of degraded rangeland than those whose livelihood depends on crop production and safety net. The finding further revealed that the coefficient of starting bid price has negative sign and significant at less than 1% level of significance. The negative sign and the significance of this coefficient indicated that, as the starting

Table 4: Result of Bivariate probit model

Variables	Coef.	Std. Err.	z	P¿z	[95% Conf. Interval]	
bid1	-0.1270165	0.0293995	-4.32	0.000	-0.1846385	-0.0693946
cons	2.040007	0.3402047	6.00	0.000	1.373218	2.706796
bid2	-0.1422015	0.04067	-3.50	0.000	-0.2219133	-0.0624898
cons	1.00715	0.4554578	2.21	0.027	0.1144694	1.899831

Log likelihood = -176.92552, No. obs = 172
Wald chi2(1) = 0.010862, chi2(2) = 31.73, Prob ¿ chi2 = 0.000
LR test of rho = 0
Mean WTP = 11.86 (at 95% CI, 7.08 to 16.06)

Table 5: Summary of aggregate benefit

Method	Total households (Y)	Expected households to have a protest zero (X)	Expected households with valid responses (Z)	Mean WTP	Aggregate benefit (in labor days)
Double bounded questions	1080	0	1080	11.86	38,426
Open ended questions	1080	0	1080	7.9	38,426

Aggregate labor days = MWTP × 1080 × 3, where MWTP is mean WTP obtained from bivariate probit model, 1080 is total households of both study kebeles (Harewoyu & Utalo) and 3 indicates the total number of months that *pastoralists'* are willing to contribute per year.

bid value increases by one unit, the log odds of household's willingness to pay in labor reduced by 75.5%. This is consistent with the findings of Carlson et al (2004) and Mousavi and Akbari (2011). Finally, the goodness of fit, R2 =0.6258, meaning that the dependent variable (WTP) is explained by the independent variables by 62.6%, and the remaining 37.4% of the WTP variation is left unexplained. Thus, based on the results, there are a lot more factors that can contribute to pastoralists' decision on WTP. Before analyzing the data by using binary logistic model, correlation and multicollinearity tests for independent variables were done (Table 7).

4 Conclusion

In Ethiopia, where the human and animal population grows rapidly, rangeland degradation occurs at an alarming rate and the land becomes fragmented and over utilized to meet the demand for pastoral livelihoods activities. However, little attention was given to improve degraded rangeland resources so far. The present study investigated pastoralists' willingness to pay for the rangeland improvement and factors influencing their decision on WTP by using bivariate probit analysis & binary logistic model.

The results of the CVM survey showed that the households were willing to pay for the rangeland improvement. The annual mean WTP value of households for improving rangeland resource based on the double bounded dichotomous choice was computed at 35.58 labor day per year, which is equivalent to 2,490.6 ETB (53.83 USD). The annual total WTP from open ended format was also computed at 23.7 labor days per year which is equivalent to 1,659 ETB per year (35.86 USD). The aggregate benefit or aggregate WTP for rehabilitation from double bounded dichotomous was found to be 38,426 labor days per year, which is equivalent to 2,689,820 ETB (58,121.06 USD). The aggregate WTP for rehabilitation from open ended format was found to be 25,596 labor days per year, equivalent to 1,791,720 ETB (38,707.69 USD). This implies that pastoralists could play a bigger role in contributing to rangeland rehabilitation efforts if supported by relevant policies and institutional support actors.

Moreover, the study found that the value of rangeland rehabilitation from open ended format was significantly lower than double bounded elicitation format. The empirical findings of the study on the determinants of WTP indicated that such explanatory variables as sex, age, family size, major source of livelihood, total number of livestock in TLU and initial bid value have statistically significant influence on WTP decision. Therefore, continued efforts need to be done in Ethiopia to acknowledge and include pastoralists' involvement in policy-making and rangeland rehabilitation efforts.

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Authors' contributions

All authors played crucial role during the study period. The corresponding author wrote the manuscript, collected, and performed statistical analysis, design to drafting the manuscript. Other authors participated in the study design and performed statistical analysis and finally, all authors read and approved the final manuscript.

Table 6: Correlation and multicollinearity tests for independent variables before analyzing binary logistic model

	sex	age	marital	educ	totfam	majorliv	totlan	TLU	housing
Sex	1.0000								
Age	-0.4234	1.0000							
Marital	0.0016	0.0564	1.0000						
Educ	0.1087	-0.1865	-0.2114	1.0000					
totfam	0.0275	0.4284	0.0350	0.0522	1.0000				
majorliv	-0.5003	0.3980	0.0189	-0.0664	-0.0948	1.0000			
totland	0.0571	-0.0015	-0.0579	-0.2020	0.0839	-0.0780	1.0000		
TLU	0.2252	-0.2904	-0.0081	0.1368	0.0745	-0.4480	0.0497	1.0000	
housing	0.0245	-0.0551	-0.0170	-0.0380	-0.0090	-0.0260	0.2225	-0.0260	1.0000

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Research Article

Effects of Elevations on Carbon Stocks of Kella Natural Forests in Konso Zone, Southern Ethiopia

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Abstract

Different anthropogenic and biophysical factors can affect woody species diversity and carbon stocks along the elevation gradients. This study, thus, was conducted to evaluate the impact of elevation on carbon stock potential in Kalla forest, Konso zone, Sothern Ethiopia. The study was undertaken along three elevation gradients, namely, low (LE) (1,605-1,690 m), middle (ME) (1,691-1,775 m) and high (HE) (1,776-1,860 m) elevations. A total of 60 sample plots (20 m x 20 m) were systematically laid down along the elevation gradients at interval of 200 m between transects and 50 m between sample plots. In each main plot a 5 sub plots (four from corners and one at the center) with 1 m x 1m were used to collect litter and soil samples. A total of 120 soil samples for soil chemical analysis and 120 samples for bulk density determination were taken separately. The total ecosystem carbon stocks (biomass plus soil, 0-60 cm) were significantly different ($p < 0.05$) across the three studied elevations. The LE showed higher ecosystem carbon stock (301.8 ± 171.6 t C ha^{-1}) than ME (255.6±88.2) and HE (190.8± 58.2). The SOC stock (0 - 60 cm depth), standing biomass and litter accounted for 90.8 %, 6.6 % and 2.6% respectively in the LE whereas 93.0 %, 5.1 % and 1.9 % in the ME and. 92.1%, 6.3% and 1.6% in the HE. *Juniperus procera* and *Euphorbia tirucalli* contributed altogether 81 % of the total biomass carbon stocks in the LE and both species shared 60 % in the ME whereas *Euclea racemosa* and *Juniperus procera* accounted for 48% of the total biomass carbon stock in HE. The total above ground biomass carbon stocks were significantly correlated with the species diversity. Finally, this study affirms that elevation affect woody species diversity and total carbon stocks in Kalla forest, Sothern Ethiopia.

Keywords: Biomass, Carbon stock, Elevation range, Woody species diversity

1 Introduction

The reductions of emission from deforestation and forest degradation by managing the existing forests sustainably bring financial and technical incentives from industrialized nations to developing countries through REDD+. To tap this opportunity, accurate and consistent data that meet international standards while creating favorable policy environment are the most important requirements (IPCC 2006).

In effect, reliable estimates of biomass, liter and soil carbon are needed to understand the contribution of forests to reduce atmospheric carbon dioxide. Measuring and estimating carbon stocks and changes in various pools are very important for carbon trading (Yitebitu et al. 2010). This calls researchers to direct their interests to quantify forest carbon stocks following standardized carbon stock accounting method. Currently the demand of reliable information regarding forest carbon stock both at national and global levels is growing (Genene et al. 2013).

However, several environmental factors such as temperature, precipitation, atmospheric pressure, solar and UV-B radiation, and wind velocity changes systematically with altitude affect the biomass productivity in forest ecosystem. An altitudinal gradient is among the most powerful ‘ ‘natural experiments’ ’ for testing ecological and evolutionary responses of biota to environmental changes (Fang et al. 2005). Although changes in species composition and distribution, biodiversity and community structure along altitudinal gradients have been well documented in the past few decades (Fang et al. 2005), the altitudinal patterns of carbon storage and partition among components (vegetation, detritus and soil) of forest ecosystems remain to be poorly studied (Fang et al. 2005).

Besides, in Ethiopia, as one of the country in the tropics, little is known about inter site and temporal variability of forest biomass compared to other parts of the tropics (Chave et al. 2001; Abel Girma et al. 2014). Periodic forest inventories and monitoring in the country are lacking even though they are most useful in order to evaluate the magnitude of carbon fluxes between aboveground biomass (AGB) and the atmosphere. Several reports affirm that Ethiopia has limited information about carbon stocks of forest in regional and local context (Adugna Feyissa et al. 2013; Abel Girma et al. 2014). In Konso wereda there are Kalla and Pamale forests, those are belong to Kalla and Pamale family respectively. These forests are rich in woody species diversity and managed culturally by family kings since ancient time. Similarly, in Konso specifically in Kalla forests there is limited studies that describe the effect of elevation gradient on woody species and carbon stock. The objective of this study, therefore, is to investigate the effect of elevation gradients on carbon stocks of Kalla Forest, southern Ethiopia.

2 Methods and materials

2.1 Description of Study Area

Kalla natural forest is located in Konso zone in the Southern Nations, Nationalities, and Peoples' Region (SNNPR) of Ethiopia. Konso district is found 356 km far away from Hawassa City to South, and 562 km far from Addis Ababa, Capital city of Ethiopia (Figure 1). Geographically, the study area is located at 5°19' 60” N and 37°19'60” E in the Great Rift Valley. Soil texture is sandy loamy and pH almost neutral (6.97).

2.2 Vegetation

According to zone agricultural office and personal observation, in Konso zone there are vegetation covers managed by government and clan king. Kings’ managed forest includes Pamale and Kalla forests. This forests are dry afromontane forests and located at elevation ranges between 1605 m and 1860 m.a.s.l and cover about 205 ha. Konso people are internationally known by traditional tracing, which is registered by UNESCO as world heritage. In crop production areas of the farms, *Moringa stenopetala* (Haleko) is the dominant woody species while *J. procera, Euphorbia tirucalli, Acacia senegal, Acokaathera schimpori* and *Euclea racemosa* are the most abundant woody species in natural forests.

2.3 Sampling techniques and sample layout

A systematic sampling technique was employed. The forest was divided into three elevation gradients, namely, low (here after referred as LE) (1605 m – 1690 m), middle (ME) (1691 m -1775 m) and high elevation (HE) (1776 m- 1860 m).

Narrow elevation ranges was fixed owing to steep slope nature of the studied forest. In each of elevation category, transect lines were laid along the contour at center of each elevation ranges 30 m away from the forest edge to avoid border effect. Sample plots of 20 m x 20 m were laid down along the transect lines at 200 m distance between them and at 50 m interval distance between sample plots. A total of 60 sample plots were surveyed (20 in each elevation category). The first sample plot was randomly assigned at the beginning of the transect line. Inside each main plot, five subplots (1m x 1 m), four at the corners, and one at the center were established to collect soil samples and litter.

2.4 Data collection methods

Inventory

The inventory of woody plants in sample plots included the measurement of stem diameter at breast height (DBH) $\geq$ 5 cm, diameter at stump height (DSH) and total height (H). The field survey was conducted during the dry season of December and January, 2017. DBH and DSH were measured at 1.3 m and 30 cm from the ground, respectively (Alamgir and Al-Amin 2008). Individual tree height in each plot was systematically measured using a clinometer and a graduated pole for low trees. In case of multi- stemmed woody species, each stem was measured separately and the equivalent diameter of plant was calculated as the square root of the sum of diameters of all stems per plant (Snowdon et al. 2002). Woody vegetation identification was done in the field using key informants and each vernacular name was translated to their botanical names using flora of Ethiopia and Eritrea (Hedberg et al. 1995; Edwards et al. 1997; Edwards et al. 2000); useful trees and shrubs for Ethiopia (Azene Bekele 2007) and Woldemichael et al. (2010).

Litter sampling

Litter samplings were collected from five 1 m x 1 m subplots from each main plot and mixed to make a composite sample. Fresh weight of litter samples were recorded in the field using string balance. Then a 100 g sub-sample was taken and transported to Hawassa University WGCFNR soil laboratory to determine dry to fresh weight ratios.

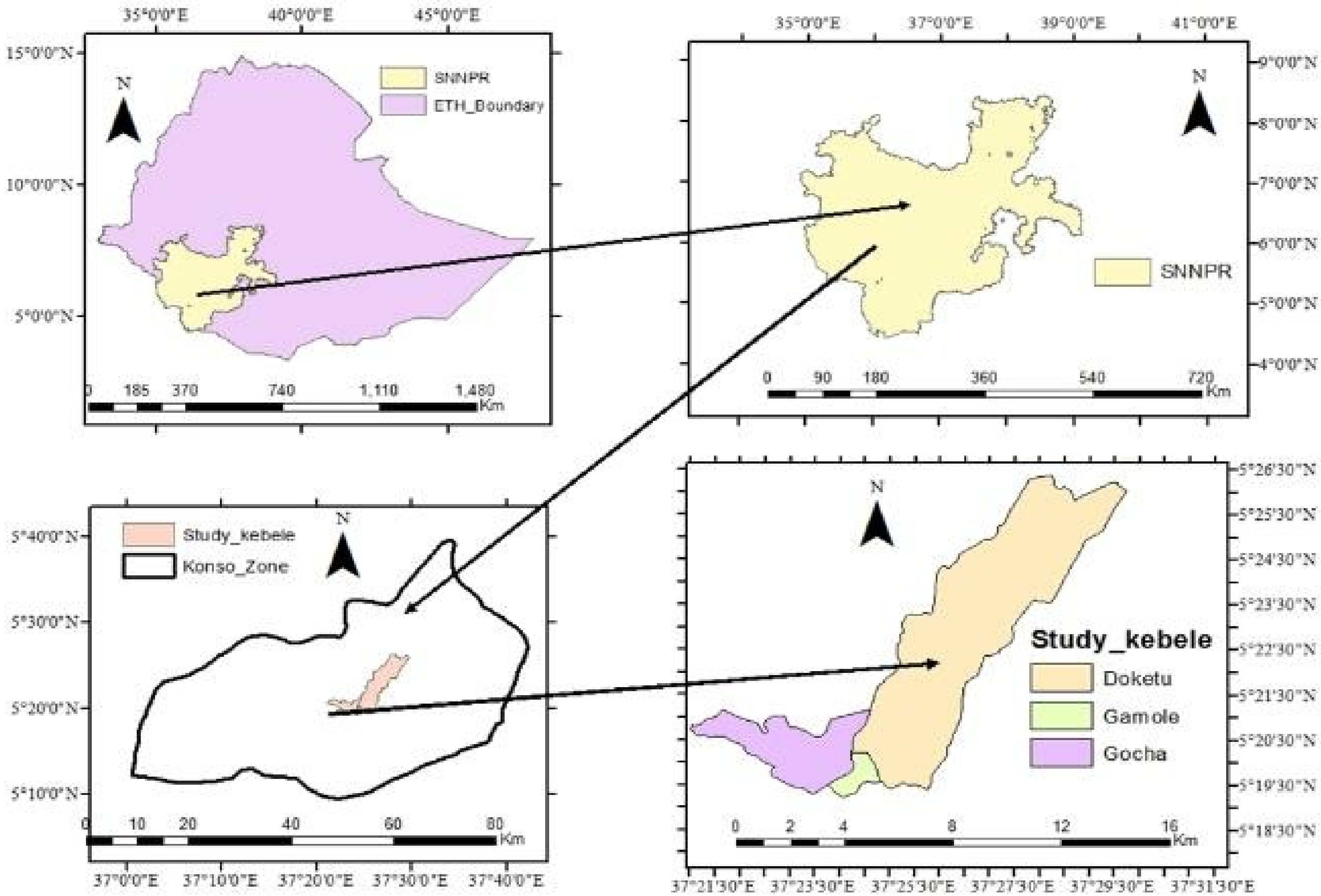

Figure 1: Study area map

Soil sampling

Soil samples were collected from five pits arranged within four corners and from central point. The pits were dug to 60 cm depth and soil samples taken uniformly along 0 - 30 and 30 - 60 cm soil depths by hand trowel. A total 120 soil samples (40 from each) from the two depths were taken along the three studied elevation gradients. Similar size of soil sample plots were collected separately for bulk density determination. A sharp edged steel cylinder corer (height 15 cm and diameter 7.2 cm) had been forced manually into the soil for drawing the samples for bulk density.

2.5 Laboratory work for litter and soil samples

Determination of litter dry biomass and carbon content analysis

The collected litter samples were air-dried first and oven-dried for 24 hours at 65 ºC until it attains constant weight. Then, the samples were weighed, ground using mortar and pesto then sieve with 2 mm mash. The loss on ignition (LOI) method was used to estimate percentage of carbon in the litter. From the oven dried grinded sample 3.00 g of each litter sub sample was taken in pre-weighted crucibles, and then put in the furnace at 550 ºC for two hours to ignite (Negash and Starr 2013). The crucibles were cooled slowly for two hours inside the furnace. After cooling, the crucibles with ash were weighed and loss of organic matter fraction was calculated according to Allen et al. (1986).

Soil analysis

The collected soil samples were air-dried, ground, homogenized and then sieved with a 2 mm mesh size sieve. Bulk density was estimated using oven dried samples at 105 ºC for 48 hours. Soil organic carbon was determined using Walkley & Black Method (Walkley and Black 1934), soil particle sizes for $<$ 2 mm fractions by Boycouos hydrometric method (Bouyoucos 1962), bulk density using core method (Blake and Hartge 1986) and soil pH using digital pH (Carter 1993).

2.6 Data Analysis

The above-ground biomass (AGB) of each elevation range with DBH $\geq$ 5 cm was estimated using the model developed by

(Chave,2014). This model was selected because it was developed for a wide range of climatic conditions and vegetation types. It uses the most important biomass predictor variables, such as diameter at breast height (DBH), wood density, and total height. This model is currently being proposed for inclusion in the IPCC Emission Factor Database and is used by REDD+ protocols.

The AGB (in kg) is calculated as:

$$\text{AGB (kg)} = 0.0673 \times (\rho \times \text{DBH}^2 \times h)^{0.976}$$

The AGB carbon stock is then derived as:

$$\text{AGB Carbon Stock} = \text{AGB} \times 0.5$$

where:

- AGB: Above-ground biomass (kg/tree)
- ρ: Wood density (g/cm^3)
- DBH: Diameter at breast height (cm), ranging from 5–158 cm
- h: Height (m)

Since direct measurement of below-ground biomass (BGB) is expensive and time-consuming, it is derived from AGB using the root-to-shoot ratio. The BGB is estimated to be 20% of AGB (Gibbs, 2007; Ponce-Hernandez, 2004):

$$\text{BGB} = 0.2 \times \text{AGB}$$

where:

- BGB: Below-ground biomass (kg/plant)
- AGB: Above-ground biomass (kg/plant)

Extrapolating carbon stocks from a per-plot basis to a per-hectare basis requires the use of expansion factors. This standardization is necessary to ensure that results can be easily interpreted and compared to other studies. According to (Pearson,2005), the expansion factor is calculated as:

$$\text{Biomass Expansion Factor} = \frac{10,000\,\text{m}^2}{\text{Area of plot, frame, or soil core (m}^2)}$$

Litter Dry Biomass and Carbon Estimation

The dry biomass of herbaceous litter was calculated using the following equation (Pearson,2005):

$$\text{LDM} = \frac{\text{Sub-sample dry mass} \times \text{Fresh mass of the whole sample}}{\text{Sub-sample fresh mass}}$$

where LDM is the litter dry biomass.

The expansion factor to hectare was converted using:

$$\text{Expansion Factor} = \frac{10,000\,\text{m}^2}{\text{Area of plot (m}^2)}$$

The percentage of organic carbon was calculated as:

$$\text{Ash} = \frac{(W_3 - W_1)}{(W_2 - W_1)} \times 100$$

$$\text{C\%} = (100 - \%\text{Ash}) \times 0.5$$

The percentage carbon content was estimated as 50% of organic matter ()Berhe,2013), where:

- C: Biomass carbon stock
- W_1: Weight of crucible
- W_2: Weight of the oven-dried ground sample and crucible
- W_3: Weight of ash and crucible

The carbon density of herbaceous plants was then calculated by multiplying the biomass of herbs per unit area by the percentage of carbon determined for each sample:

$$\text{CSL} = \text{LDM} \times \%C$$

where CSL is the total carbon stock in dead litter (t/ha), and %C is the carbon fraction determined in the laboratory (Pearson, 2005).

Soil Analysis

To determine the soil organic carbon (SOC), the bulk density was first calculated using the formula:

$$\text{Bulk Density} = \frac{\text{ODW}}{\text{CV} - (\text{RF}/\text{PD})}$$

where:

- CV: Core volume (cm^3)
- ODW: Oven-dry mass of fine fraction (< 2 mm) in g
- RF: Mass of coarse fragments (> 2 mm) in g
- PD: Density of rock fragments (g/cm^3), typically given as 2.65 g/cm^3

The SOC was calculated using Pearson (2007):

$$\text{SOC (t ha}^{-1}) = \left[\text{Soil Bulk Density (g/cm}^3) \times \text{Soil Depth (cm)} \times \%C\right] \times 1$$

In this equation, %C is expressed as a decimal fraction.

Statistical Analysis

A normality test (Kolmogorov-Smirnov test) and equality of variance test (Levene's test) were conducted to check the data. After confirming a normal distribution, further statistical analysis was performed. Elevation ranges (low, middle, and high) were treated as independent variables, while species richness, species diversity, density, basal area, DBH, height, soil organic carbon, biomass carbon stock, and ecosystem carbon stock were treated as dependent variables. The size and variation in species richness, diversity, and carbon stocks for each elevation were described using the mean and standard deviation. Descriptive statistics were used to test for differences in woody species richness, diversity, soil carbon stock (0–60 cm), and ecosystem carbon stock between elevation ranges. A two-way Analysis of Variance (ANOVA) was used to evaluate the effect of elevation ranges (low, middle, and high) and soil depths on soil organic carbon stock. A Kruskal-Wallis ANOVA was conducted to evaluate differences between elevation ranges in terms of woody species stand structure and biomass carbon stock. All statistical analyses were performed using IBM SPSS Statistics software (version 21) (IBM,2012).

3 Results

3.1 Biomass carbon stocks

Above and belowground biomass carbon stocks of woody species significantly differed among LE, ME and HE ($p<0.05$) (Table 1). The above ground biomass carbon stocks accounted for 80 % of the total biomass carbon stock of across the three studied elevations. The total biomass carbon stock recorded in LE was nearly 50% higher than ME and HE.

Similar letters show no significant differences among groups and different letters indicate significant differences

Also as depicted in figure 2 below, *J. procera* and *E. tirucalli* in LE contributed altogether 79% of the total biomass carbon stocks. While *E. tirucalli* and *J. procera* in the ME and *E. racemosa* and *J. procera* in HE contributed altogether 69 and 48 % of the total biomass carbon stocks, respectively.

3.2 Litter carbon stocks

There was no significant variation ($p > 0.05$) in the litter carbon stock among the three elevation categories. The average litter carbon stock estimated to be 4.74 ± 0.42 t ha^{-1} for HE, 4.86 ± 0.48 for ME and 5.04 ± 0.18 for LE.

3.3 Soil organic carbon stocks

The SOC stocks (t ha^{-1}) within 0 - 30 cm depth showed significant difference between the LE, ME and HE ($p < 0.05$). The surface layer (0 - 30 cm) contributed 58.5%, 61.3 % and 62.9% of the total SOC stock for the LE, ME and HE, respectively.

Similar letters show no significant differences among groups and different letters indicate significant differences

4 Discussion

4.1 Above and belowground biomass carbon stock

The higher biomass carbon stock in LE indicates that there is good comfort zone for woody species mainly due to better rainfall amount and temperature influence, stem density, diameter and height growth. Several studies in other parts of Ethiopia also reported similar findings (Hamere et al. 2015) and contradict with the findings of Thokchom and Yadava (2017). Moreover, the difference between HE and LE in above ground biomass carbon stock was comparable with those found by Alefu Chinasho et al. (2015). In contrast the total biomass carbon stock of this study also somewhat lower as compared with study conducted in highlands of Oromia, Ethiopia (Adugna Feyissa and Teshome Soromessa, 2017) and in mid highlands found elsewhere in Ethiopia (Hailu et al., 2014). This could be due to variation in tree dendrological parameters measured, allometric equations applied, carbon fraction and root: shoot ratio used. Outside from Ethiopia, this study is also in line with similar studies conducted in other countries (Shazmeen 2015).

4.2 Litter biomass carbon stock

Higher litter biomass carbon stock in low elevation might be due to high abundance of species. The amount of litter fall and its carbon stock of the forest can be influenced by the forest vegetation (species, age and density), climate and relatively fast decomposition rate in the tropics. In overall, the smaller litter carbon sock in the study areas may be associated with less amount of litter fall and fast litter decomposition rate. In this study result indicates there was no significant difference between HE and ME in litter biomass carbon stock. This result is consistent with the findings of Hamere et al. (2015) and contradicts with the findings of Alefu Chinasho *et al*. (2015).

4.3 Soil organic carbon stock

Soil organic carbon plays a vital role in the global carbon cycle and C pools (Sundarapandian et al. 2015). The rate of soil organic carbon stock was significantly affected by changing in elevation (Girmay et al. 2008; Zhang et al. 2009; Sundarapandian et al. 2015).

Table 1: Mean AGBC and BGBC t ha-1) along three studied elevation gradients of Kalla Forest, southern Ethiopia. The value in the parenthesis indicates standard deviation

Elevation category	AGBC	BGBC	TBC	p-value
HE ($n = 20$)	96 (48)^a	19.2 (9.6)^a	115.5 (57.6)^a	0.034
ME ($n = 20$)	108 (72)^b	21.6 (14.4)^b	129.6 (86.4)^b	0.033
LE ($n = 20$)	162 (108)^b	32.4 (21.6)^b	194.4 (129.6)^b	0.035

Values are mean (standard deviation). Superscripts indicate significant differences between groups (Tukey's HSD, p ¡ 0.05).

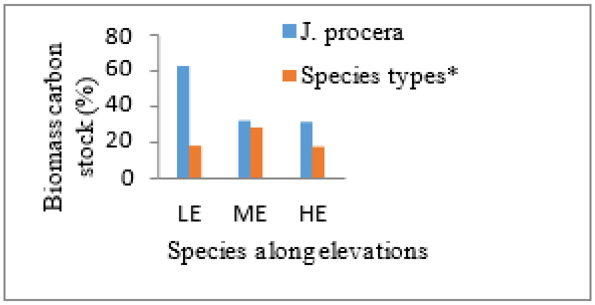

Figure 2: Proportion of biomass carbon stock contribution of the dominant tree species along the elevation gradients of Kalla Forest, southern Ethiopia Species types* represents for LE, ME and HE is E. tirucalli, E. tirucalli and E. racemosa respectively

The soil organic carbon in LE was higher than the adjacent ME and HE. This may be due to the accumulation of soil organic carbon on the quantity of litter and root activity such as rhizo - deposition and decomposition. This result was consistent with other studies in Ethiopia (Hamere et al. 2015) and in China (Biao et al. 2016). In contrast, (Alefu Chinasho et al. 2015) reported that elevation did not influence soil organic carbon. This study showed that SOC stock increased by 48 % through the low elevation over high elevation. This might be due to increased vegetation composition, reduced erosion loss and the subsequent production and decomposition of litter fall from vegetation.

In LE, there was higher litter biomass accumulation than middle elevation and high elevation. Litter fall contributes a major role for the return of organic matter to the soil (Liang et al. 2011). The higher soil organic matter accumulation in LE might also be related to the presence of *J. procera* for which the litter might be decompose and mineralized at slower rate. In contrast the mean SOC stock in the high elevation was lower owing to the low woody species abundance and the subsequent small litter fall that impacted the return of organic matter to the soil.

The present study showed soil organic carbon content decreases with soil depth. This might be due to the presence of lower accumulation of organic matter resulting from lower belowground root biomass in the sub- surface layer; which is similar with the justification of Yimer et al. (2015).

The total SOC stock (0-60 cm) in LE was higher than those reported from tropical dry forest that ranged between 33.36 and 48.82 t ha^{-1} (Sundarapandian et al. 2013). Our SOC stock in ME is substantially higher than those found in African savannahs and woodlands at middle elevation, SOC stock ranged between 30 and 140 t ha^{-1} (Williams et al. 2008). Also, higher than SOC stock reported by Woollen et al. (2012) in the central Mozambique middle elevation woodlands (40.1 ± 2.5 Mg C ha^{-1}). Maintaining of higher SOC levels ensures the productivity of degraded land as well as regulating the climate system.

4.4 Ecosystem carbon stock

The contribution of SOC stock in the present was higher than the total biomass carbon stock. Similar results were reported in other studies (Mekuria et al. 2009; Mekuria 2013). The total ecosystem carbon stock (in biomass plus soil, 0- 60cm) in the LE was higher than the report of Alefu Chinasho *et al.* (2015) and lower than other studies in Sothern Ethiopia (Mekuria et al., 2009; Mekuria 2013). The ecosystem carbon stock estimate with other sites may due to difference in the model used to estimate the biomass, variation in soil type, management of forest and topography.

5 Conclusion

The present study affirms elevation differences contribute to the variation in carbon stocks in the studied forest. The elevation effects mainly reflect the variation in climatic and edaphic factors. Total biomass carbon stock and soil organic carbon decrease as elevation increases. The low elevation in Kalla forest favors high accumulation of the carbon stocks in both the biomass and soils. In overall, our study show that Kalla indigenous forest can serve as a good candidate for REDD+ finical schemes.

Table 2: Mean soil carbon stock mean (t C ha^{-1}) of the three studied elevation categories of Kalla Forest, southern Ethiopia. The value in the parenthesis indicates standard deviation.

Depth, cm	N	HE	ME	LE	p-value
0-30	20	177.6 (58.8)^a	242.4 (87)^b	282 (171.6)^b	0.013
30-60	20	126.6 (60.6)^a	148.2 (71.4)^b	166.2 (85.2)^b	0.030
0-60	40	153 (64.8)^a	195 (91.8)^b	224.4 (145.8)^b	0.009

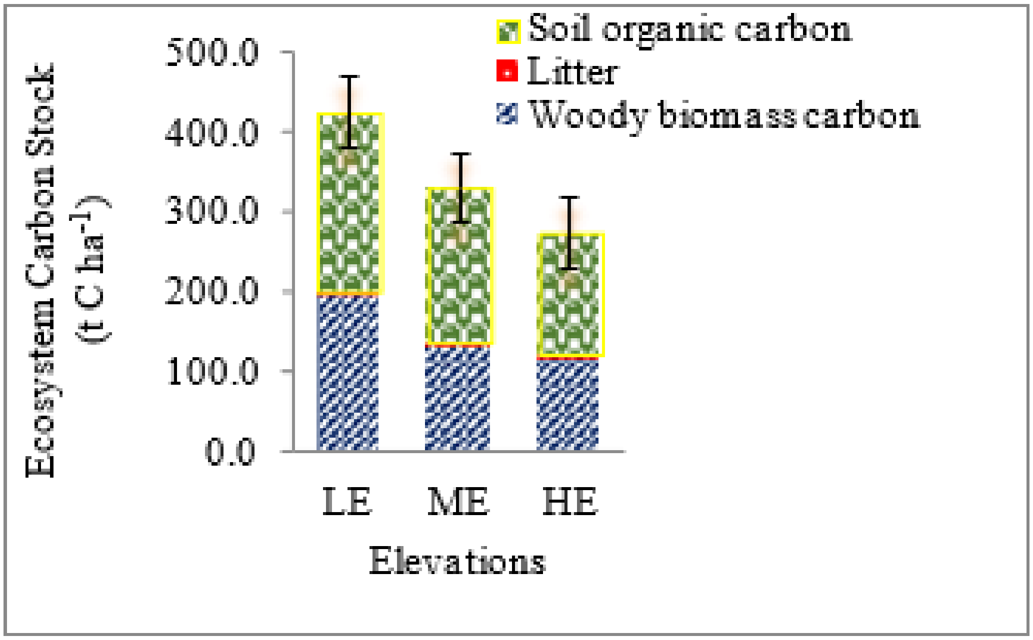

Figure 3: Ecosystem carbon stocks (in biomass plus soil) along elevation gradients of Kalla Forest, southern Ethiopia

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Conflict of interest

No conflict of interest

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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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- Publishing Frequency/Schedule: Bi-annual (December, June)
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- Physical Address: Wondo Genet College of Forestry and Natural Resources,
- P.O. Box 128, Shashemene, Ethiopia,
- Journal website: https://journals.hu.edu.et/hu-journals/index.php/jfnr
- Email of the journal: editorinchiefJFNR@hu.edu.et, maneditorJFNR@ehu.edu.et

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.

2.2. Review articles

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.

2.3. Featured articles

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:

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All necessary files have been uploaded:

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- Include keywords
- All figures (include relevant captions)
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- 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.

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3.5. Changes in Authorship

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.

4.1. Title:

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.

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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.

4.5. Results:

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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- In the case of Ethiopian names, the author's given (first) name precedes that of the
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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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Photographs and illustrations

Illustrations may be submitted in the form of black and white photographs or computer drawings or both.

Units

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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