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EXPLORING TRADITIONAL FOOD PRESERVATION METHODS OF WOLAITA PEOPLE, ETHIOPIA

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ABSTRACT: Postharvest food loss is significant in developing countries like Ethiopia, contributing to food insecurity. To address this issue, it is essential to leverage indigenous knowledge and practices related to food processing, preservation, and storage. This study assessed indigenous food preservation techniques among rural household heads in Wolaita Zone, Ethiopia. Using a cross-sectional survey design, 384 household heads were randomly selected and consented to collect data via structured questionnaires and observational checklists. The results indicated that 61.5% of respondents regularly preserve raw foods, 20.6% preserve cooked foods, and 16.7% preserve perishable items. The most commonly employed preservation methods were sun drying (33%), salting (23%), heating (18%), packing (9%), cooling (7%), fermentation (6%), and smoking (4%). Chi-square tests revealed significant associations between cooked food preservation and demographic factors such as sex, age, education, occupation, and monthly income ($p < .005$). Similar associations were observed for raw and perishable foods, highlighting the influence of demographics on preservation practices. The study reveals a significant association between food preservation practices and demographic characteristics. Sun drying, salting, and heating were the most prevalent methods for food preservation in the study area. A significant portion of participants did not practice food preservation methods, indicating the need for education and awareness. Indigenous food preservation methods within cultural context are vital to reduce postharvest food losses and ensure food security. Efforts should be made to promote traditional practices, which not only enhance food preservation but also contribute to cultural heritage and food security.

Keywords: Ethiopia, Food, Indigenous knowledge, Preservation, Wolaita.

INTRODUCTION

Ethiopia, the second-most populous country in Africa, grapples with a significant food deficit and alarming levels of food insecurity, affecting approximately 33 million people who suffer from chronic undernourishment, predominantly among rural residents who lack the resources to produce, purchase, or

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properly store food (FAO, 2014; Kuyu and Bereka, 2020). This dire situation is exacerbated by widespread poverty, with many individuals unable to meet their minimum nutritional requirements (Endalew et al., 2015). The rates of child malnutrition are particularly concerning, marked by high levels of stunting, underweight, and wasting (CSA, 2014).

Food insecurity in Ethiopia is not merely a consequence of inadequate food production; it is significantly compounded by high postharvest food losses, which are largely attributed to limited capacities for food processing and preservation (Kuyu and Tola, 2018). The postharvest losses vary widely among different food types, influenced by factors such as food characteristics, climatic conditions, and management practices. Unprocessed foods can be categorized into perishables and durables, with perishables including fruits, vegetables, dairy, and meats being particularly vulnerable to rapid deterioration (Teferra, 2022). In contrast, dry grains like cereals and pulses, while more stable; still face risks from pests and other factors (Teferra, 2022).

Extensive studies highlight the severity of postharvest losses in Ethiopia, with estimates ranging from 15% for cereal crops to as high as 80% for fruits and vegetables, and 40% for milk and its products (Getachew, 2003; Kuyu and Tola, 2018; Kuyu and Bereka, 2020). Addressing these losses is crucial for improving food security, and this can be achieved by recognizing and leveraging indigenous knowledge, skills, and practices in food processing, preservation, and storage (Asogwa et al., 2017). Indigenous knowledge, which encompasses practices honed over generations, has proven adaptable and innovative, offering sustainable solutions to combat hunger and malnutrition (World Bank, 1998; Oniang'o, 2004).

In Ethiopia, traditional food handling, preparation, and preservation methods represent a rich repository of knowledge that has been passed down through generations (Ethiopian Herald, cited in Kuyu and Tola, 2018). These practices not only provide accessible and sustainable food preservation methods but also reinforce cultural identity. By valuing and integrating indigenous knowledge systems, local communities can actively contribute to their food security strategies. However, documentation of these traditional

preservation methods remains scarce, with existing research primarily focusing on milk and dairy products (Fita et al., 2005; Alemu and Girma, 2018; Tola et al., 2018). There is a notable gap in research concerning traditional food preservation methods across various food types, such as raw food, cooked food, and easily spoiled foods, particularly in the Wolaita zone of southern Ethiopia, despite the region's rich diversity of traditional foods. Culturally, Wolaita is home to the Wolaita people, who possess a rich heritage and unique traditions. Traditional foods play a crucial role in the cultural identity of the Wolaita people and are regularly consumed, especially during celebrations and festivals (<https://wolaita.gov.et/en/>).

Therefore, this study aims to assess the indigenous food preservation techniques among residents of rural areas in the suburbs of Sodo town, Wolaita, southern Ethiopia. The findings will provide valuable insights for stakeholders seeking to enhance food security by modernizing and promoting the broader application of indigenous food preservation methods.

MATERIALS AND METHODS

Study area

The study was conducted from March 2018 to April 2018 in the rural kebeles of Sodo Zuria Woreda, Wolaita Zone, Ethiopia. Geographically, Wolaita Zone is situated between 7° N and 37° 45' E. It is bordered by the Central Ethiopia region to the north, the Sidama Region to the east, the Gamo and Gofa Zones to the south, the Southwest Ethiopia region to the west, and the Oromia Region to the northeast. The total area of the zone is 451,170 hectares. Sodo Zuria Woreda is one of the 16 rural Woredas and seven town administrations in Wolaita Zone. Its administrative center is Sodo town, located 383 km from Addis Ababa, the capital city of Ethiopia. According to data from the Sodo Zuria Woreda office, the total area of Sodo Zuria is 38,040 hectares. Administratively, Sodo Zuria Woreda is divided into 25 kebeles, comprising five urban kebeles and twenty rural kebeles. This study focused on three rural kebeles (Wachigabusha, Wajakero, and Tomegerera) out of the 20 rural kebeles in Sodo Zuria Woreda

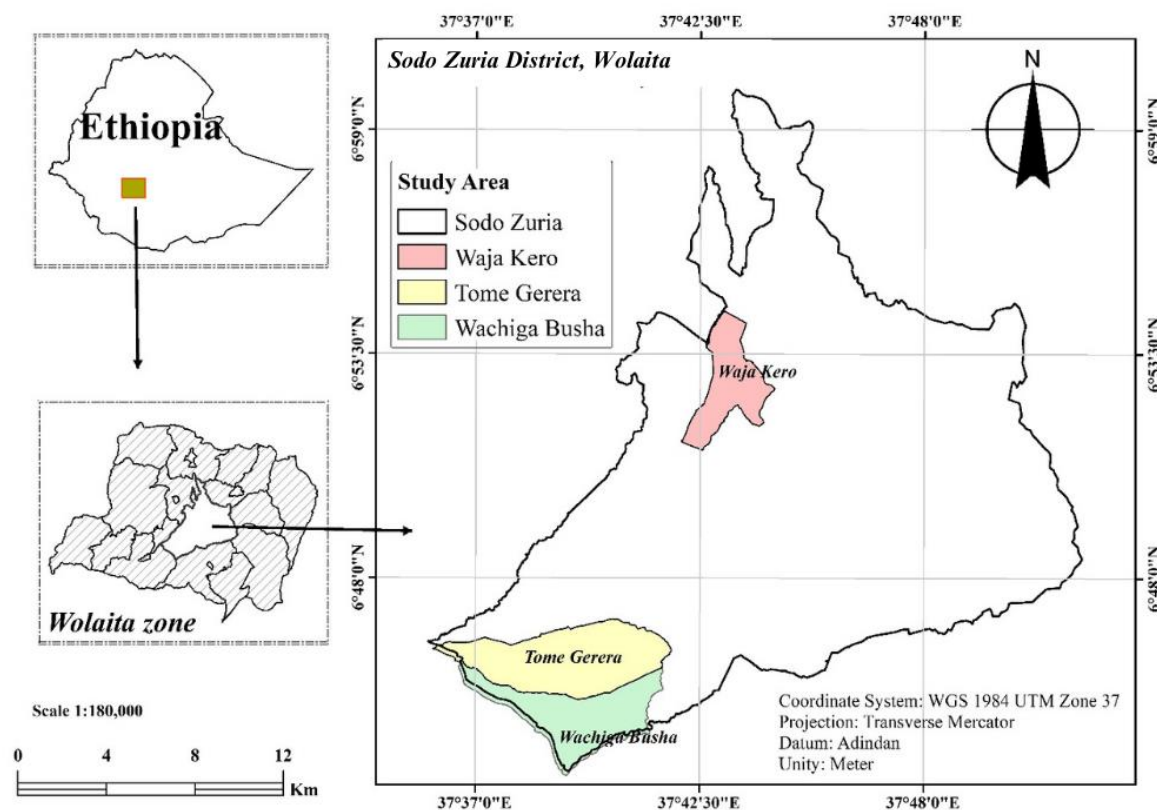


Figure 1. Map of the study location, Sodo Zuria Woreda, south Ethiopia regional state, Ethiopia.

Study design

A community-based cross-sectional study design was applied to document the indigenous knowledge about food preservation techniques and the type of food the community preserved by using the indigenous techniques at the household level among Sodo zuria rural kebeles.

Sample size determination

From 20 rural kebeles in Sodo Zuria Woreda, 3 kebeles were randomly selected. These were Wachigabusha, Wajakero, and Tomegerera. Then the sample size was determined according to Cochran's (1963) single population proportion sampling technique;

$$n = \frac{z^2 pq}{d^2}$$

Where:

n = minimum sample size

z = standard normal deviate 95% (1.96)

q = $1-p$ (probability not included in sample size 50% (0.5))

d = tolerance error of margin set at 0.05.

The calculated samples were 384.

Sampling procedure

In consultation with the Wolaita Zone Administration, Sodo Zuria Woreda (District) was purposively selected due to its reliance on traditional methods for food preservation. From the 20 kebeles in Sodo Zuria Woreda, 3 kebeles were randomly selected for the survey. The calculated sample population of 384 was equally allocated among the three kebeles, with each receiving a sample size of 128. A total of 384 heads of households voluntarily participated in the study.

Each household was selected using a lottery sampling method, where numbers were assigned to each household, corresponding to a subject. Participants were then recruited after obtaining their consent to take part in the study. In addition to the 384 heads of households, 30 key informants (10 from each kebele) were selected with the assistance of district administrative offices, peasant association leaders, district culture and tourism offices, and local elders. For each traditional preservation method, the informants were asked to list and explain the types of food they prepare at home, the preservation methods they use, the procedures they follow, and the ingredients they add.

Data collection and analysis

Data were collected from 384 households using closed-ended or structured questionnaires, along with open-ended questions for key informants to document the detailed processes of the indigenous food preservation techniques. The close ended questionnaire contained two sections; socio-demographic characteristics (Sex,

educational level, occupation, monthly income and age) data was largely presented using descriptive statistics in tables displaying summary values, frequency, and percentages. All data were analyzed using SPSS version 21 software to determine the association of the demographic characteristics and practice of traditional food preservative techniques and statistical significance was determined by considering cut of value $p < 0.005$.

RESULTS

Socio-demographic backgrounds of the study subjects

A total of 384 heads of households were included in the study. Of these, 262 (68.23%) were female and 122 (31.77%) were male (Table 1). The majority of the respondents (111 or 28.9%) were in the age group of 36-45 years old, followed by 26-35 years old (91 or 23.7%) and 15-25 years old (73 or 19%). The number of respondents above 45 years old was 109 (28.4%). With regard to educational status, the majority of the respondents (213 or 55.47%) were illiterate, 106 (27.6) of them were at primary school levels, 52 (13.5%) at secondary school levels and only 13 (3.4%) of the respondents had higher education levels.

Occupationally, the predominant proportion of the respondents were farmers (185 or 48.2%) and merchants (116 or 30.2%), followed by daily laborers (72 or 18.8%) with only 11(2.3%) civil servants. Most of the respondents (243 or 63.3%) said their monthly income didn't exceed ETB 500 and only 30 (7.8%) of the respondents said their monthly income exceeded ETB 700.

Table 1. Socio-demographic backgrounds of the heads of the households in Sodo Zuria.

Socio-demographic variable		Frequency	Percentage
Sex	Male	122	31.77
	Female	262	68.23
Age group	15 -25	73	19.01
	26 - 35	91	23.69
	36 - 45	111	28.91
	46 - 55	62	16.14
	>55	47	12.24
Educational levels	Illiterate	213	55.47
	Primary school	106	27.60
	Secondary school	52	13.54
	Certificate	2	0.52
	Diploma	7	1.82
	Degree	4	1.04
Occupation	Daily labor	72	18.75
	Farmer	185	48.18
	Merchant	116	30.21
	Government employee	11	2.86
Monthly income (birr)*	200 - 500	243	63.28
	500 - 700	111	28.90
	>700	30	7.81

1 USD = 28.45 Birr (2018 exchange rate)

Practice of indigenous food preservation methods among the study subjects

Out of the 384 participants, 61.46% reported always preserving raw food items in their homes, while 20.57% always preserved cooked food items, and 16.67% always preserved perishable foods (Table 2).

Table 2. Practice of traditional food preservative methods in Sodo Zuria woreda, Southern Ethiopia

Variable	Response	Frequency	%
Do you preserve cooked food items in your home?	Yes	79	20.57
	No	305	79.43
Do you preserve raw food items in your home?	Yes.	236	61.46
	No	148	38.54
Do you preserve easily spoiled foods in your home?	Yes	64	16.67
	No	320	81.25

To examine the relationships between indigenous food preservation methods and various demographic characteristics, a chi-square test of association was conducted. This statistical test assesses whether

significant relationships exist between two categorical variables. The results demonstrated significant associations across multiple dimensions. Specifically, the chi-square tests revealed significant relationships between the preservation of cooked foods and demographic factors such as sex, age, education, occupation, and monthly income ($p < .005$). Similar associations were identified for raw and spoiled food items, indicating the influence of demographic characteristics on preservation practices (Table 3).

Table 3. Chi-Square test results for associations between demographic characteristics and indigenous food preservation practices.

Variable	Chi-Square (X^2)	Degrees of Freedom (df)	p-value
Cooked Food Items			
Sex	213.5	1	< .005
Age	384.1	4	< .005
Educational Level	79.850	5	< .005
Occupation	342.7	3	< .005
Monthly Income	57.7	2	< .005
Raw Food Items			
Sex	112.1	1	< .005
Age	277.2	4	< .005
Educational Level	307.9	5	< .005
Occupation	305.4	3	< .005
Monthly Income	355.2	2	< .005
Spoiled Food Items			
Sex	166.1	1	< .005
Age	384.1	4	< .005
Educational Level	359.8	5	< .005
Occupation	609.1	3	< .005
Monthly Income	138.2	2	< .005

Traditional food processing and preservation methods used in the study community

The heads of the households were asked about the types of foods that they often found highly perishable and the preservation techniques they used. The responses they gave to the question regarding the methods and the preserved food items are summarized in Figure 2 and 3, respectively. The most commonly used preservation method was sun drying (126 or 33%) followed by salting (87 or 23%), heating (69 or 18%),

packing or storing in covered containers (34 or 9%), cooling or low temperature storage (28 or 7%), fermentation (24 or 6%) and smoking (16 or 4%) (Figure 2).

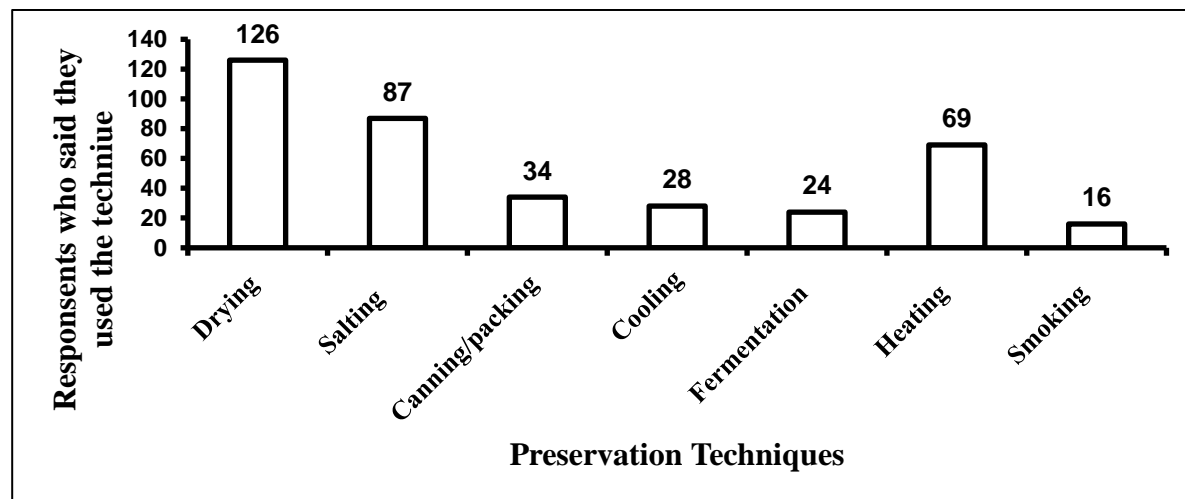


Figure 2. Preservation techniques and number of the respondents that used the preservation method in Sodo Zuria woreda, Southern Ethiopia.

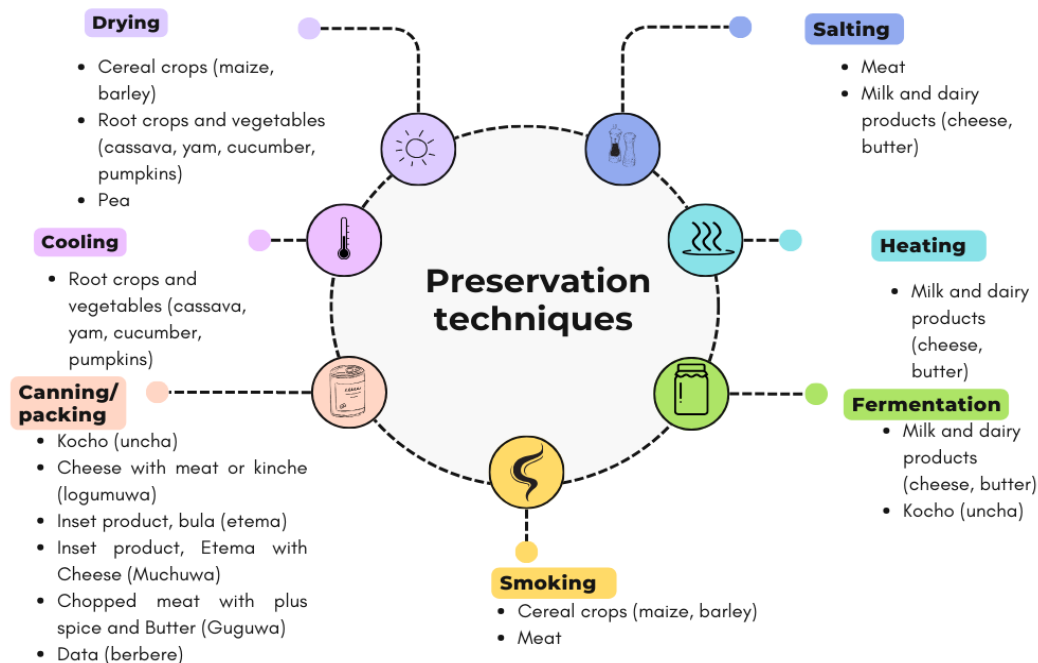


Figure 3. Types of traditional food items and corresponding indigenous preservation methods used among residents of Sodo Zuria woreda, Southern Ethiopia.

The detailed account of the methods and their respective applications was narrated by key informants, who were elder members of the study subjects included in the research. From the recorded seven indigenous food preservation methods, the detailed application of the most widely used methods, such as sun drying, packing/canning, salting, and fermentation, was narrated by the key informants. Some of the methods are not used alone but rather play a role in other preservation methods. For example, salting was reported to be used in combination with smoking, and heating and cooling can be applied in various preservation methods as part of the preservation process. Thus, the methods described below only include some of the standalone indigenous food preservation methods.

Sun drying

Drying by sunlight was said to be applied to a wide range of food items like cereals (maize, barely), root crops, and vegetables (cassava, yam, and pumpkin cucumber) (Figure 3). Maize often is dried in the sun and stored in a woody or bamboo container fumigated with some chemical pesticides (Figure 4D). Similarly, barely is also stored in tight bamboo baskets or local big jars after harvesting (Figure 4D). Among the most common staple root crops preserved by drying in the study community, cassava and yam were the principal ones mentioned. Cassava is preserved after first removing the bark and chopping it into small pieces with knives. Subsequently, the comminuted pieces are dried in the sun and then packed into local containers and stored inside the home (Figure 4, C1 to C4). Yam, cucumber, and pumpkins are also preserved likewise after ripening; they are dried, packed in a woody box, and stored under cool shades outside the home.

Packaging/Canning

According to the respondents, packing or canning is used as a means of preserving various local foods, such as Kocho (uncha), cheese with meat or kinche (logumuwa), bulla (etema), etema with cheese (Muchuwa), chopped meat with plus spice and butter (guguwa), and dat'a (berbere) (Figure 3). Packaging raw or cooked food items with locally made baskets, clay pots, jars, and plastic cans was practiced widely in the study community. For example, one popular dish in the community called 'logumuwa' is prepared from dehulled,

coarsely ground barley, which is cooked by boiling with water and seasoned with mixtures of cheese, chopped beef, and spiced butter. The prepared logomuwa as such is then packed in a clay pot or jar (Figure 5A). Similarly, another local food item, ‘etema’ is prepared from the flour of enset (*Ensete ventricosum*) called bula which is cooked by boiling and seasoned with butter and various spices. The prepared etema is then packed in clay pots or jars similar to logomuwa (Figure 4 B1 to B3). Another popular cooked food prepared and stored between meals is ‘Guguwa’ made from any meat (beef, mutton, or goat meat) that is chopped, cooked by roasting or boiling and seasoned by butter, spice and stored in clay pots (Figure 5C). ‘Muchuwa’ is another popular dish made from cottage cheese (Ayib), cooked ‘etema’ seasoned with butter and salt. It is also prepared and stored between meals in clay pots or jars (Figure 5B).



Figure 4. Plant-based foods produced and preserved using various traditional methods in Sodo Zuria Woreda, Wolaita zone, Ethiopia. **A)** Kocho packed in dry enset leaves. **B1-B3)** Bula (or Etema) packed in enset leaves and plastic containers. **C1-C4)** Cassava pulp with intact bark, peeled, pulverized, and dried, stored in bamboo baskets. **D)** Outdoor bamboo storage bin for dry maize. **E)** Clay pots used for storing barley seeds. **F)** Multipurpose plastic storage bin for dried seeds, flour, and Etema. etc.

Fermentation

Fermentation is another popular food preparation and preservation method identified by the respondents. It is applied mainly to the preparation of fermented dairy products and the principal staple food 'kocho' (Figure 3) made from the pulp of the enset plant. The production of fermented dairy products and 'kocho' fermentation is the same as is done elsewhere in Ethiopia.

For milk preservation, fresh milk is often collected in well-smoked clay pots and left at ambient conditions to undergo natural fermentation by indigenous microorganisms. After one day of fermentation, it forms the traditional sour milk called 'ergo' also locally known as 'meomata'. A considerable amount of milk produced by the household is consumed in the form of 'ergo' or ergo may be used for the production of other dairy products. For example, ergo is churned for the production of traditional butter called 'qibe' and the remaining buttermilk from which most of the butter is separated is further processed by moderate heating of 50 – 70 °C to prepare 'Ayib'. According to key informants, fresh butter separated from the buttermilk is kneaded and washed with cold, salted water that has been boiled earlier. The treated butter is then stored in clay jars (Figure 5F). Ayib is made by heating the buttermilk moderately for about 15 to 20 minutes. Finally, the curd is separated from the whey, and wrapped with enset leaves, on top of it are placed some heavy objects to express the remaining whey from the curd.

Kocho is another important food item other than milk products produced and preserved by fermentation in the study community. It is produced by fermentation of the pulp of pseudostem and corm of enset plant. To make kocho, a pit is dug in the backyard home garden where enset makes the principal component. The inside of the pit is lined with enset leaves to avoid contact with soil and dirt. After the pit is prepared as such, the admixture of pulverized scraps from the fleshy part of the pseudostem and the corm (root part) is filled into the pit. The pulp is overlaid with more enset leaves and a heavy cover is put on top of it to ensure airtight condition. The fermentation may take from months to years and at the end of the fermentation portions are removed from the pit and pressed to remove the liquid part resulting in fibrous moist kocho. To

remove the fiber, the kocho is kneaded and shredded to make it into fine powder which is then wrapped in clean enset leaves and stored until needed for preparation of kocho bread (Figure 4A).

Like kocho, bula (Etema) is also produced from the fermented pulp of enset, only that pulp is derived from the pseudostem rather than admixture from the corm. It is whiter and less fibrous than kocho, often prized nutritious food in the form of gruel and porridge for newly delivered mothers in the study community.

Accompanying meat dishes is a fermented condiment made from chili pepper called data (Figure 3). It is prepared by grinding the green or ripened red chili pepper with a local stone mill manually along with an admixture of garlic and ginger. The mixture is often packed into small jars and allowed to undergo fermentation at ambient conditions (Figure 5D).

Salting and smoking

The preservation of meat, whenever it is available in plenty during the holidays, is of minor importance in the study community. It is cut into thin elongated pieces (Zilzil), salted, and hung on a rope over the fireplace where there is plenty of smoke (Figure 5G).

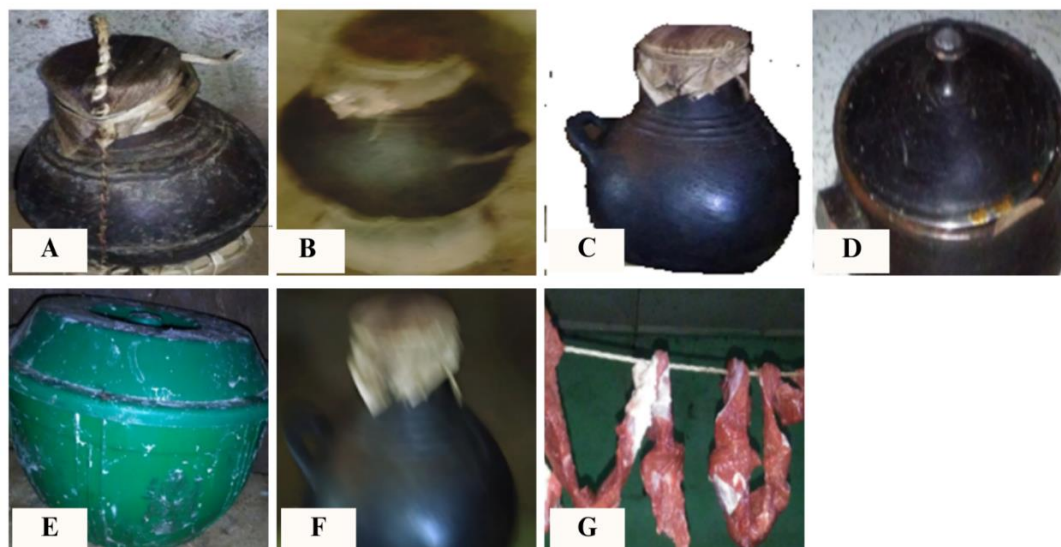


Figure 5. Partially prepared and ready-to-consume local foods produced and consumed by the community in Sodo Zuria Woreda, Wolaita Zone, Ethiopia. **A)** Logomuwa **B)** Mucho **C)** Guguwa **D)** Data (fermented pepper condiment) **E)** Raw kneaded butter **F)** Refined and spiced butter (ghee) **G)** Salted meat cut into strips for preservation by smoking and drying.

DISCUSSION

This study assessed the indigenous food preservation practices and techniques among residents of rural kebeles of Sodo zuria woreda, Wolaita zone, southern Ethiopia. In the present study, 68.2% of the respondents were female, consistent with the general cultural fact that females are responsible for the preparation of food (Nahusnay and Tessfaye, 2015). With regard to the indigenous food preservation practice among the study participants, 61.46%, 20.57% and 16.67% of the participants preserve raw, cooked, and easily spoiled foods in their homes respectively. Majority of the participants reported some level of practice in indigenous food preservation for raw food items, suggesting a cultural inclination towards preserving raw ingredients. However, the practice of preserving cooked and easily spoiled foods (dairy products, meat, and fermented foods) appears to be less common. This could be due to various factors such as convenience, availability of refrigeration, or cultural preferences for freshly cooked meals. These findings contradicted the reports from Nigeria (Olusanya et al., 2005).

The chi-square test of association revealed that demographic factors such as sex, age, educational level, occupation, and monthly income significantly influenced the likelihood of participants engaging in food preservation practices for cooked, raw, and spoiled food items. Similar patterns emerged for raw and spoiled food items, where significant associations were again found with sex, age, educational level, occupation, and monthly income. These findings indicate the importance of understanding how demographic factors shape food preservation practices among the Wolaita people. By identifying these associations, we can better inform future interventions aimed at promoting traditional food preservation methods, ultimately contributing to improved food security and cultural preservation in the region.

The percentage of respondents who used sun drying, the most commonly used preservation method in the study area, was much lower than the 95% reported from Uganda (Agea et al., 2008) and 80% from Nigeria (Nnadi et al., 2013). Since most disease-causing organisms require a moist environment to survive and multiply, drying is a natural technique for preventing spoilage (Sperber, 2009). Indeed, the act of simply

leaving foods out in the sun and wind to dry out is probably one of the earliest forms of food preservation (Adeyeye, 2017). The sun drying method practiced in the study community included spreading the food item on flat surfaces covered by old linen, plastic sheets, and even on the bare wiped earth. Under such circumstances there is little control of the drying process and the food item would be subject to spoilage from wind-borne dirt, vermin, insects, worms, and the food handlers themselves. Microbial toxins may develop under an uncontrolled drying set up leading to poor quality and reduced edibility. Loss of normal color, flavor and loss of vitamins are some of the most important disadvantages of drying food which can be mitigated by controlled drying (Asogwa et al., 2017).

Next to sun drying the study participants also mentioned various methods of storage of food items in covered containers. This is in agreement with the practice of indigenous people in many parts of Africa (Asogwa et al., 2017). Proper crop storage plays an integral part in ensuring domestic food supply (Thamaga-Chitja et al., 2004) and that seed quality and vigor are maintained (Abba and Lovato, 1999). In the present study packaging raw or cooked food items with locally made baskets, clay pots, jars, and plastic cans was also practiced widely in the study community as mentioned by 34 (9%) of the respondents. Storage facilities not only offer the opportunity to provide a supply of food between staple crop harvests but farmers can improve farm incomes by storing crops and selling at premium prices when demand outstrips supply later in the post-harvest period (Olakojo and Akinlosotu, 2004). Proper storage of cooked food items between meals also plays an important role in preventing food-borne disease outbreaks.

Fermentation (24 or 6%) was also recorded in the present study as one of the means to produce and preserve a wide range of foods like milk, milk products, and kocho. According to Asogwa et al. (2017), Fermented foods are defined as those foods which have been subjected to the action of microorganisms and enzymes for the production of foods with distinct quality attributes that are quite different from the original agricultural raw material.

Fermentation is an important food processing technology usually developed by women in most of Africa and some Asian countries (Asogwa et al., 2017). This fact was demonstrated in the present study where the study community described the production of important fermented foods like fermented dairy products and Kocho which are produced mostly by women and staple food for the majority of people in southern Ethiopia. Fermented vegetable foods are also popular in other parts of Africa. For example, 'Gari'– a fermented cassava and ogi in Nigeria (Sanni et al., 2008).

Milk is a highly perishable food product that is susceptible to adulteration, and its quality is greatly influenced by farm management (Bekele et al., 2015). The community in this study, like many in Ethiopia, preserves milk by processing it into various dairy products through fermentation (Gonfa et al., 2001). They produce sour milk known as 'ergo', which is consumed directly or used to make traditional butter and other products. This highlights the importance of indigenous dairy processing methods in the community (Berhe et al., 2017). Various dairy products, including fresh whole milk, whole sour milk (Ergo), butter, Arera (defatted sour milk), Ayib (a traditional cottage cheese), and nitirkibe (ghee), are majorly produced and consumed in many parts of the country (Kuyu and Bereka, 2020). An extensive review and a detailed description of the production of various dairy products in Ethiopia can be found in Ashenafi (2006). Fermented milk is known to contain high concentrations of probiotics, which offer several health benefits. These include improving intestinal tract health, enhancing the immune system, synthesizing and enhancing nutrient bioavailability, reducing symptoms of lactose intolerance, decreasing allergy prevalence in susceptible individuals, and reducing the risk of certain cancers (Parvez et al., 2006).

Kocho, a food item produced and preserved by fermentation, is an important staple in the southern regions of Ethiopia, including the study area. According to the respondents in the present study, Kocho is made by fermenting the pulp of the pseudostem and corm of the enset plant. The detailed process of making kocho in areas where it is consumed in Ethiopia is similar to the findings of this study. According to Birmeta et al (2019), and Kuyu and Bereka (2020), Kocho is made through the fermentation of enset plant pulp, which

is placed in a pit lined with enset leaves to prevent contact with soil. The mixture of pseudostem and corm scraps is added, covered tightly, and left to ferment for months or years. After fermentation, portions are pressed to remove liquid, resulting in moist kocho. The fiber is then removed, and the kocho is kneaded and shredded into a fine powder, wrapped in enset leaves, and stored for later use in making kocho bread (Tedla and Abebe, 1994). After fermentation, the kocho is often stored in pits lined with enset leaves for a minimum of one month, but it can be stored for several months or even years. This food provides a highly carbohydrate-rich staple food for 35% of Ethiopians living in the southern and southwestern parts of the country (Forsido et al., 2013; Yirmaga, 2013). In addition, a study on antioxidant capacity, total phenolics, and nutritional content in selected Ethiopian staple food ingredients revealed that enset and its products have the potential to develop value-added food products with nutritional and health benefits (Forsido et al., 2013).

Generally, fermentation enhances food security in that it provides a cost-effective method of preserving food, thus making it available during periods of scarcity (Asogwa et al., 2017). It could also contribute to food safety by controlling the growth and multiplication of several pathogens in foods, especially in developing countries where economic problems pose a challenge to food safety.

Smoking and salting were used together to preserve perishable food, such as meat, in the present study community. From the total of 384, 87 and only 16 of the respondents used salting and smoking as the means of food preservation, respectively. These methods are widely used for preserving meat, especially during holidays when it is abundantly available. Traditionally, in Africa, meat is consumed unprocessed. However, in general, meat is preserved by drying, smoking, or salting (Addis, 2015). Similar to the findings of the present study, in many parts of Ethiopia and northern Kenya, meat is cut into long pieces (quanta), smeared with powdered pepper, salted, and dried by hanging it above the fireplace for 5-7 days (Oniang'o et al., 2004). According to Rahman et al. (2023), the compounds present in wood smoke have antimicrobial actions that prevent the growth of spoilage-causing organisms. It is also known that salt binds with water molecules

and acts as a dehydrating agent in foods (Okos et al., 2018). A high level of salinity may also impair the conditions under which pathogens can survive (Durack et al., 2008).

CONCLUSION

This study aimed to assess indigenous food preservation techniques among residents of rural areas in the suburbs of Sodo town, Wolaita, southern Ethiopia. The study identified that a significant portion of participants did not practice food preservation methods, highlighting the need for education and awareness. Sun drying and salting were the most commonly utilized preservation methods. There was also a significant association between the practice of indigenous food preservation and various demographic characteristics. Understanding and valuing these indigenous food preservation practices can contribute to promoting sustainable food preservation and contribute to food security in the region. By recognizing the significance of indigenous preservation methods and their cultural context, efforts can be made to preserve and promote traditional practices that contribute to both food preservation and cultural heritage, while enhancing food security.

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**SOIL AND LITTER CARBON SEQUISTRATION POTENTIAL OF COFFEE
AGROFORESTRY IN BERBERE DISTRICT, SOUTHEAST ETHIOPIA:
IMPLICATIONS FOR CLIMATE CHANGE MITIGATION**

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ABSTRACT: The impact of climate change on coffee sector and adaptation response is well documented. However, by large literature ignored the contribution of coffee agroforestry practices to carbon sequestration and improvement of production and ecological service. This study estimates the litter and soil organic carbon (SOC) stock contribution of coffee agroforestry and its implication to climate change mitigation. The coffee agroforestry of the study area which covered 261 hectares was divided into three shade cover types: monoculture, intermediate and dense. The carbon sequestration in litter and soil samples collected from each plot's centers were analyzed using titration method based on Walkley and Black methods. Regression equations were used to estimate litter and SOC stock. The result revealed that the carbon stored varies significantly across the shades. The litter pool monoculture shade stored $4.94 \pm 1.00 \text{ MgCha}^{-1}$, the intermediate shade cover stored $6.83 \pm 0.73 \text{ MgCha}^{-1}$ and the dense shade cover stored $7.71 \pm 0.45 \text{ MgCha}^{-1}$. Likewise, the soil pool carbon stored in monoculture, intermediate and dense shade covers was $29.07 \pm 8.48 \text{ Mg ha}^{-1}$, $48.20 \pm 4.10 \text{ MgCha}^{-1}$ and $61.86 \pm 7.14 \text{ MgCha}^{-1}$ respectively. The SOC value was larger than the litter carbon in all shade categories. In both cases the highest carbon store was witnessed in the densely shade covers. Coffee agroforestry system is amongst climate change mitigation options with high potential to sequester carbon in the agricultural sector and play a crucial role to enhance the co-existence of ecosystem elements, increase production and services; hence, it should be promoted.

Keywords: Climate change mitigation, Coffee agroforestry, Litter, Soil organic carbon.

INTRODUCTION

Human induced climate change is one of the critical global agenda due to its widespread current and residual impact on the wellbeing of mankind (Samalca et al., 2009; IPCC, 2007). Due to the advancement of technology and population pressure the greenhouse gases particularly CO₂ concentration in the atmosphere drastically increased in the 21st century (Hannah and Max, 2020; IPCC, 2014). Every sector contributed to greenhouse gas emission though fossil fuel burning, agriculture, forestry, and other land uses are main sources of CO₂ emission (IPCC, 2014; FAO, 2014). Net greenhouse gas emission from agriculture, forestry and other land use conversion generated over 8 billion metric tons of CO₂ equivalents (FAO, 2014). CO₂ is contributing most to the current global warming than the rest of the greenhouse gases (IPCC, 2014). The CO₂ concentration in the atmosphere which was 417 ppm CO₂ reached at the level of 454 ppm CO₂ concentration in 2017. Global warming is causing the rise of temperature (Samalca et al., 2009), distorting the rainfall distribution behavior. For instance, the global surface temperature is predicted to increase from 1.4 °C to 5.8 °C at the end of 21st century (IPCC, 2001). Humanity has already faced the impact of climate change and extremes such as drought, flood, storms and torrential rainfall (IPCC, 2014; 2007). Agriculture which is the mainstay of farmers is challenged by climate change and population pressure (Krausmanna et al., 2013; World Bank, 2012). Thus, the wellbeing of subsistence farmers' is at risk due to reduction of production and food insecurity (IPCC, 2014). The impact of climate change is expected to be severe in the future (Gomesa et al., 2020). The application of agricultural inputs like fertilizer, pesticides, insecticides etc. to boost yield volume polluted the environment to the extent of disturbing the natural soil formation and nutrient cycle processes (Krausmann et al., 2013). All of these challenges have necessitated the use of climate change adaptation to reduce vulnerability to the adverse impact of climate change. In the same vein, climate change mitigation efforts are necessary to reduce emissions of greenhouse gases (Chunli et al., 2018; IPCC, 2007).

Agro-forestry system integrates agricultural activities and forest systems to enhance the co-existence of ecosystem elements and increase agricultural production and ecosystem services (Tschora and Cherubini, 2020; Mihert, 2019). Hence, agroforestry helps to meet the objectives of reducing land degradation, improve production and food insecurity particularly in developing countries (Waldron et al., 2017; IPCC, 2014; Mbow et al., 2014; Kumar and Nair, 2012; IPCC, 2001)

Although much research exists on the impact of climate change on coffee production and adaptation responses (Jha et al., 2011; Muleta et al., 2007) the contribution of coffee agroforestry to carbon sequestration and improvements in agricultural production and ecosystem services is a neglected issue (Betemariyam et al., 2020; Rice, 2018). UNFCCC, 1997; Understanding the potential of micro level coffee agroforestry to sequester carbon and CO₂ emissions from the agricultural sector has enormous economic and environmental benefits (Dhillon and Van Rees, 2017). Therefore, this study determines the litter and soil carbon sequestration contributions of the coffee agroforestry and infers its implication to climate change mitigation in Berbere District of southeastern Ethiopia.

MATERIALS AND METHODS

Description of the study site

This study was carried out in Berbere District located in the southern highland of Ethiopia. The district is located between 6°25'0" to 6°55'0" N and 40° 00'00" to 40°22'0" E. Haro-dumal, the administrative center of the district, is located 99 km far from Robe, the zonal capital and 530 km far from southeast of Addis Ababa. The district covers 15650.711 km². The study site has distinct topographic features and the altitude ranges from 1170 to 1300 m a.s.l. About 45% of this district is plain; 37% is rugged and gorge while 18 % of the district is mountainous. It has 9^o C annual average minimum temperatures and 23^o C annual average maximum temperatures. It receives bimodal rainfall with an average annual rainfall 1060-1150 mm. The dominant soil categories in the district are Eurtric, combisols and Lithosols soil types (BZAO, 2015).

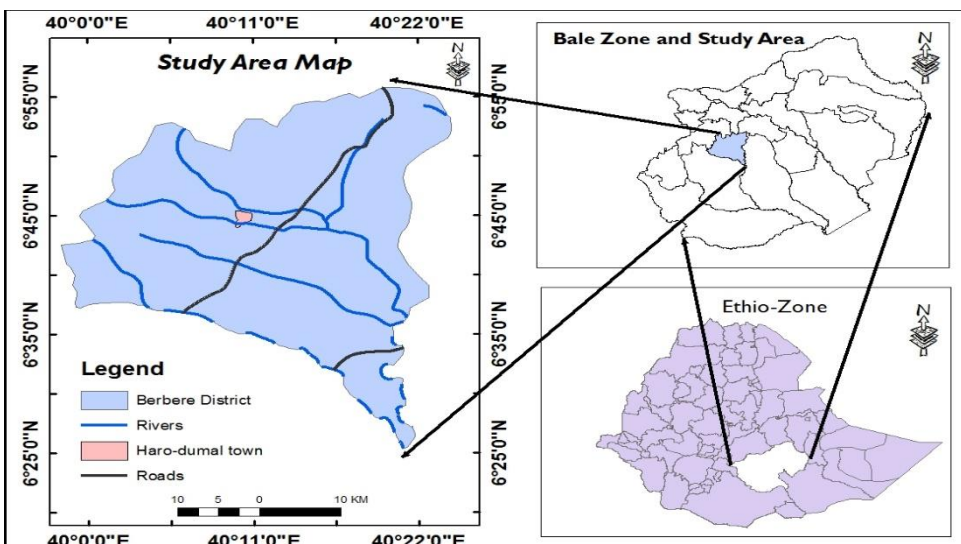


Figure 1. Map of the study area. Source: - Ethio-GIS 2015

Study design and sampling techniques

Preliminary study

Reconnaissance survey was conducted to get familiarity with and in-depth understanding about the biophysical features and livelihood systems within the coffee agroforestry systems (Nortclif, 1978). It was carried out in consultation with the district and zonal finance and economic development office and agricultural development experts. Accordingly, three coffee growing kebeles were selected using the lottery sampling technique out of fifteen Kebeles in the district. The lottery sampling method was used because it is a simple random sampling technique that ensures each kebele had an equal chance of being selected, eliminating bias in the process. This method is scientifically valid as it provides equal probability for all kebeles, ensuring fairness and randomness in selection. By minimizing subjective bias, the lottery method increases the likelihood that the three selected kebeles are representative of the entire population of the fifteen Kebeles. The tree shade types of coffee agroforestry were identified and delineated.

Study design

Descriptive research design was applied in this research. Following the preliminary field survey three representative coffee growing kebeles (Deresa, Gebe and Harewa), were selected using the

lottery method to represent 15 coffee-producing Kebele in the district. The sample sites cover a total of 261 hectares and encompass monoculture, intermediate and dense coffee agroforestry shade cover systems. The gradient of the structural complexity of the coffee agroforestry shade: monoculture, intermediate and dense shade cover was created and classified into 54 plots. Samples were ranked based on shade layer and species abundance.

Rank 1: Monoculture shade cover (MSC): - This system incorporates only one shade layer primarily composed of legumes. It is a deciduous broad-leaved legume that is usually vegetative propagated with stakes. Moreover, it is subject to intensive management including pruning for shade regulation.

Rank 2: Intermediate shade covers (ISC): - This system incorporates two layers, one with leguminous species and a second species that provide significant shade due to minimal pruning and abundant foliage.

Rank 3: Dense shade covers (DSC): - This system features a variety of shade species incorporated into three layers, including legumes, fruit trees, and species used for timber production. This system may represent the highest structural diversity in the study area. Systematic transect sampling techniques were conducted to layout transects along with the shade farm in coffee agroforestry. Sampling plot sized 20m x 20m (400 m²) was systematically assigned on each transect along with the shade farm based on the model of Betemariyam et al. (2020) so that 10 transects were laid accordingly. The distance between the plots was 200 m which is adjusted using GPS and compass. A total of 54 plots were surveyed; 18 plots in each of the three Kebeles. The decision to survey an equal number of plots (18) in each of the three kebeles, despite their differences in size, ensures comparability and balance in the data collected. Scientifically, this approach standardizes the sample size across kebeles, reducing variability due to unequal sampling and allowing for more straightforward statistical analysis. By maintaining an equal number of plots per kebele, researchers can more accurately compare the characteristics or outcomes across the kebeles without the results

being skewed by differences in sample size. The GPS location of each plot was also recorded. The sample size determination also considered capturing available resources and time framework (Picard et al. 2012). These plots were used to collect litter and soil sampling.

Data collection methods

Litter sampling

Litter samples were collected in a 1m x 1m square sub-plot within a 20 x 20 m² plot of land. Litter was collected manually on five sub-plots; four at the corners and one in the center. The five litter samples within the same plot were mixed. The fresh weight of each sample was measured and the result is 100 gm. Fresh sample was taken to laboratory for analysis from each subplot.

Laboratory analysis: litter sample (100 gm) was oven-dried at 65⁰ C. The homogeneously mixed sample collected from each quadrant was oven-dried and its carbon fraction was determined in the laboratory by titration method based on the method developed by Walkley and Black (1934). Finally, for each site, the carbon in dried litter in MgCha⁻¹ was determined.

Soil sampling

Like the litter sample, standard procedures were applied to collect sample soils from the five sub-plots. In each sub-quadrant, the soil samples were taken at a depth of 15 cm using auger. This was followed by mixing soil homogenous samples, labeling, and keeping in a plastic bag. Another soil sample was also collected for determining a bulk density using a standardized 100 cm³ metal soil sampling corer. All soil samples were labeled and taken to the Sinana Agricultural Research Center's soil laboratory for chemical analysis.

Laboratory analysis

The homogeneously mixed soil samples collected from each sub-quadrant were air-dried and the dry weight of each sample was determined. The 100gm homogeneously mixed sample from each quadrant was taken to the laboratory while the carbon fraction of each homogenous sample was

determined in the laboratory by titration method based on the method developed by Walkley and Black (1934). Finally, the bulk density, soil organic carbon and soil organic matter contents were calculated.

Estimation of parameters

Estimation of carbon in litter biomass (LC)

Carbon stocks in the litter were calculated by multiplying litter dry weight per area with the relative carbon concentration of the samples using the formula (Pearson et al., 2005) as shown below.

$$LB = \frac{W_{\text{field}}}{A} \times \frac{W_{\text{sub-sample (dry)}}}{W_{\text{sub-sample (fresh)}}} \times \frac{1}{10000} \quad (\text{equ.1})$$

Where: LB = Litter Biomass (Mgha^{-1}), W_{field} = weight of wet field sample of litter sampled within an area of size 1 m^2 (g); A = size of the area in which litter were collected (ha); $W_{\text{sub-sample, dry}}$ = weight of the oven-dry sub-sample of litter taken to the laboratory to determine moisture content (g), and $W_{\text{sub-sample, fresh}}$ = weight of the fresh sub-sample of litter taken to the laboratory to determine moisture content (gm).

Carbon stocks in litter biomass

$$CL = LB \times \% C \quad (\text{Equ.2})$$

Where, CL is total carbon stocks in the dead litter in mega tone of carbon per ha (MGC ha^{-1}) and % C is carbon fraction determined in the laboratory (Pearson et al., 2005).

Estimation of soil organic carbon

Soil bulk density was determined using the core sampling method of known volume. Then the labeled soil sample was taken to the laboratory for bulk density analysis. It was then oven-dried at 105°c for 24 hours. Then the bulk density of the soil was computed by dividing the weight of the oven-dried soil sample to its volume as shown below.

$$BD = \frac{W_{\text{oven-dried}}}{v} \quad (\text{Equ.3})$$

Where, BD is the bulk density of the soil sample per cm^3 ; W oven-dried, is the weight of oven-dried soil; and V is the volume of core sampler in cm^3 (Pearson et al., 2005).

Finally, the soil organic carbon stock was calculated by using the following formula

$$SOC = BD \times d \times \%C \quad (\text{Equ.4})$$

Where, SOC= soil organic carbon stock per unit area (t ha^{-1}), BD = soil bulk density (g cm^{-3}), D = the total depth at which the sample was taken (15 cm); and % C = Carbon fraction determined in the laboratory (%).

Data analysis

The collected data were organized and run on Microsoft excel datasheet. The measurement of the fresh weight and the dry weight of litter and soil samples were analyzed using Microsoft excel of 2007 and Origin software version 6.1. Descriptive statistics, parameter estimates and regression coefficients were determined. Analysis of variance (one-way ANOVA), was used to determine statistically significant differences of carbon stocks along with shade tree categories for litter and soil carbon pools. Differences at the 0.05 level were reported as statistically significant.

RESULTS

Litter biomass and carbon stock of coffee agroforestry

The coffee agroforestry litter biomass and carbon stock of the study sites is illustrated in Table 1. Both the biomass value and carbon stored in the litter vary remarkably across coffee agroforestry shade covers. The laboratory analysis result showed that average litter biomass of the study area was $0.140 \pm 0.026 \text{ Mgha}^{-1}$. The litter biomass value of coffee agroforestry system was $0.111 \pm 0.023 \text{ Mg ha}^{-1}$ for monoculture shade cover, $0.152 \pm 0.011 \text{ Mgha}^{-1}$ for intermediate shade cover and $0.158 \pm 0.0086 \text{ Mg ha}^{-1}$ densely shade cover.

The average stored carbon in the litter biomass of coffee agroforestry is $6.49 \pm 1.38 \text{ Mg C ha}^{-1}$. The stored carbon in litter biomass was $4.94 \pm 1.00 \text{ Mg C ha}^{-1}$ in monoculture shade cover, $6.83 \pm 0.73 \text{ Mg C ha}^{-1}$ in the intermediate shade cover and $7.71 \pm 0.45 \text{ Mg C ha}^{-1}$ in densely shade cover.

The litter carbon dioxide equivalent (CO_2e) sequestration of coffee agroforestry in monoculture was about $18.13 \pm 3.57 \text{ Mg C ha}^{-1}$ while, the CO_2e of litter carbon stock in intermediate and dense shaded covers were $25.08 \pm 2.59 \text{ Mg C ha}^{-1}$ and $28.33 \pm 1.59 \text{ Mg C ha}^{-1}$ respectively. The mean litter biomass carbon stock of coffee agroforestry carbon dioxide (CO_2e) sequestration in the study area was ($23.85 \pm 5.03 \text{ Mg C ha}^{-1}$). The dense shade tree category displayed the highest litter carbon-stocks compared to shaded monoculture due to the presence of large amounts of decomposing plant residue of legumes, fruit trees and other species in a coffee agroforestry system. The monoculture shade tree category farms have the lowest litter carbon stocks as their trees minimally contribute to the litter layer. The result implies that the litter biomass carbon sequestration potential is encouraging and could contribute to mitigate climate change by reducing atmospheric CO_2 . The variation in the carbon sequestration capacity of coffee agroforestry shade categories suggests that increasing the density biomass of coffee agroforestry is crucial.

Table 1. Litter biomass and carbon stock of coffee agroforestry.

Shade type	LB (Mg ha^{-1})	CL (Mg Cha^{-1})	CO_2 Equivalent (Mg C ha^{-1})
DSC	0.158 ± 0.0086	7.71 ± 0.45	28.33 ± 1.59
ISC	0.152 ± 0.011	6.83 ± 0.73	25.08 ± 2.59
MSC	0.111 ± 0.023	4.94 ± 1.00	18.13 ± 3.57
Total	0.421 ± 0.0426	19.52 ± 2.18	71.54 ± 7.66
Mean	0.140 ± 0.026	6.49 ± 1.38	23.85 ± 5.03

MSC-Monoculture shade cover, ISC - Intermediate shade covers and DSC-Dense shade covers.

Carbon stock in Soil

The bulk density of soil in monoculture, intermediate and dense shaded coffee agroforestry categories is $0.60 \pm 0.032 \text{ gcm}^{-3}$, $0.62 \pm 0.029 \text{ gcm}^{-3}$ and $0.66 \pm 0.029 \text{ gcm}^{-3}$ respectively (Table 2).

The three shade cover systems had bulk density values averaging less than 1.0 gcm^{-3} .

Like the litter carbon stock, the soil pool carbon stock varies among coffee agroforestry shade categories. As depicted in Table 2, the amount of carbon stock in monoculture and intermediate shade covers was estimated to be $29.07 \pm 8.48 \text{ Mg C ha}^{-1}$ and $48.20 \pm 4.10 \text{ Mg C ha}^{-1}$ respectively while the densely shaded part exhibited $61.86 \pm 7.14 \text{ Mg C ha}^{-1}$. The mean soil carbon stock of the study area was $46.37 \pm 15.14 \text{ Mg C ha}^{-1}$. Thus, the soil carbon stock amount in different coffee agroforestry shade categories showed a statistically significant difference ($p < 0.05$). The highest and the lowest amount of carbon were found in the soil of densely and sparsely grown coffee tree categories respectively.

The densely forested coffee trees have the highest ($227.03 \pm 26.20 \text{ Mg C ha}^{-1}$) carbon dioxide sequestration potential. With a calculated value of $106.69 \pm 31.13 \text{ Mg C ha}^{-1}$ the monoculture coffee agroforestry had the lowest carbon dioxide sequestration capacity. The average carbon dioxide (CO_2e) sequestered in the soil of the study area was $170.20 \pm 55.57 \text{ Mg C ha}^{-1}$. The highest and the lowest carbon stock of the soil under dense and monoculture shaded cover implies that intensifying coffee agroforestry could have significant contribution to reduce atmospheric CO_2 and to improve agricultural production and ecological services. Mohammed and Bekele (2014) also highlighted the potential of coffee to sequester carbon.

Table 2. Soil Organic Carbon stocks in Coffee Agroforestry

Shade type	Soil Bulk Density (g cm ⁻³)	SOC (Mg Cha ⁻¹)	CO ₂ Equivalent (Mg C ha ⁻¹)
SC	0.66 ± 0.029	61.86 ± 7.14	227.03 ± 26.20
ISC	0.62 ± 0.029	48.20 ± 4.10	176.90 ± 15.04
MSC	0.60 ± 0.032	29.07 ± 8.48	106.69 ± 31.13
Total	1.9 ± 0.09	139.13 ± 19.72	510.62 ± 72.37
Mean	0.63 ± 0.041	46.37 ± 15.14	170.20 ± 55.57

MSC-Monoculture shade cover, ISC - Intermediate shade covers and DSC-Dense shade covers

Table 3. Summary of values of significance for one-way ANOVA between each shade cover categories of coffee agroforestry for litter carbon and soil carbon pool).

Shade Types	Carbon pools	F-value	<i>p</i> -value
(MSC, ISC, DSC)	LC	1.121	0.335
(MSC, ISC, DSC)	SOC	3.523	0.038

MSC-Monoculture shade cover, ISC - Intermediate shade covers and DSC-Dense shade covers

Table 3 illustrates the significance value of shade cover categories of coffee agroforestry of litter and soil carbon pool. The difference in carbon stock of the litter pool was not significantly different ($p > 0.05$) along the coffee agroforestry shade categories. If we look at the value of each shade categories (monoculture shade stored 4.94 ± 1.00 Mg C ha⁻¹, the intermediate shade cover stored 6.83 ± 0.73 Mg C ha⁻¹ and the dense shade cover stored 7.71 ± 0.45 Mg C ha⁻¹) of coffee agroforestry in the litter carbon pool, little difference was observed among them. Whereas, the soil organic carbon pool showed statistically significant ($p < 0.05$) variation in carbon stock along coffee agroforestry shade categories. In the soil carbon pool, significant difference among shade categories (the monoculture shade stored 29.07 ± 8.48 Mg C ha⁻¹, the intermediate shade cover stored 48.20 ± 4.10 Mg C ha⁻¹ and the densely shade cover 61.86 ± 7.14 Mg Cha⁻¹) was observed which implicates great contribution for climate change mitigation strategies.

DISCUSSION

The concentration of carbon dioxide has drastically increased particularly over the last four decades (Noponen et al., 2013). Agriculture is responsible for about 55% of the carbon dioxide emission from the agricultural greenhouse gas (Baumert et al., 2005). In Ethiopia remarkable amount of carbon is emitted from soil due to improper agricultural activity and deforestation (Demessie et al., 2017). Most literatures focus either on the altitudinal gradient biomass and soil carbon analysis or major land use categories soil carbon estimation (Toru and Kibret, 2019). An Agroforestry system option is preferred to sequester carbon and mitigate climate change (Mohammed and Bekele 2014; Hergoualc'h 2011). This study attempted to estimate the litter and soil carbon stock amount in different shade categories of coffee agroforestry and synthesizes its implication to climate change mitigation in southeastern Ethiopia.

The highest ($7.71 \pm 0.45 \text{ Mg C ha}^{-1}$) litter carbon stored in the coffee agroforestry was calculated in densely shade cover followed by intermediate ($7.71 \pm 0.45 \text{ Mg C ha}^{-1}$) shade cover category. The smallest ($4.94 \pm 1.00 \text{ Mg C ha}^{-1}$) litter carbon was stored in the monoculture shade cover in the study site. The result was cognate with pervious findings (Suárez, 2002), who reported a litter carbon stock range between 3.0 to 9.6 Mg C ha^{-1} in shaded coffee plantations. Alpizar et al. (1985) estimated a litter carbon stock range from 2.0 to 4.0 Mg C ha^{-1} in coffee agroforestry; whereas, Polzot, (2004) found litter carbon stock that ranged from 0.7 to 4.5 Mg C ha^{-1} . The result is also consistent with scholars' assertion that coffee agroforestry having significant contribution to the reduction of atmospheric CO_2 (Mohammed and Bekele 2014; Hergoualc'h et al., 2012; Hergoualc'h, 2011). As suggested by Nair and Nair (2014) the variation of carbon stock in different study sites could be due to biophysical, temporal, and management factors. This reaffirms the potential of coffee agroforestry to sequester carbon is site specific.

The soil is among the largest reservoir in the global carbon cycle (Schmitt-Harsh, 2012). Basically, the carbon is trapped from the atmosphere and fixed by green plants in the soil as soil organic matter (Liski et al., 2002) stayed in the soil pool (Berg et al., 2003). In this study, the carbon stored in the soil pool of the coffee agroforestry examined ranges from $29.07 \pm 8.48 \text{ Mg C ha}^{-1}$ (in monoculture shaded cover) to $61.86 \pm 7.14 \text{ Mg C ha}^{-1}$ (in densely shade cover). The SOC stocks in this coffee agroforestry system was noticeably lower compared to the SOC stocks reported for two coffee agroforestry systems; Enset-coffee ($119.7 \text{ Mg C ha}^{-1}$) and Fruit-coffee ($114.8 \text{ Mg C ha}^{-1}$) in southeastern rift valley of Ethiopia (Mesele, 2013) at depth of 0-30 cm, coffee-based agroforestry in southwestern Ethiopia ($94.30 \text{ Mg C ha}^{-1}$) at depth of 0-30 cm, shade coffee agroforestry system in Indonesia (82 Mg C ha^{-1}) at depth of 0-40 cm (van Noordwijk et al., 2002) coffee Agroforestry in southwestern Togo ($97.3 \text{ Mg C ha}^{-1}$) at depth of 0-40cm (Dossa et al., 2008) and coffee Agroforestry in central valley of Costa Rica ($63.1 \text{ Mg C ha}^{-1}$) at depth of 0-25cm (Häger, 2012). However, the mean SOC stocks in this coffee agroforestry system are noticeably high compared to the SOC stocks of other ecosystems and soils. Lemenih et al. (2004) reported SOC stocks for semi-arid *Acacia etbaica* woodland in southern Ethiopia to be 43 Mg C ha^{-1} for the 0-60 cm soil layer and Swamy et al. (2005) reported SOC stocks for agroforestry systems in Central India to be 27 Mg C ha^{-1} , for the 0-60 cm soil layer. Besides, the mean SOC stock in the current study area was higher than reported for coffee agro-forests in Guatemala ($38.2 \text{ Mg C ha}^{-1}$) at depth of 0-10 cm (Schmitt-Harsh, 2012). Moreover, the mean SOC stock in this study area was almost comparable to the SOC stocks reported for two coffee systems (poly-culture shade organic coffee system $45.1 \text{ Mg C ha}^{-1}$ and Inga-shade organic coffee system $50.5 \text{ Mg C ha}^{-1}$) in Chiapas Mexico (Soto-Pinto et al., 2010) at depth of 0-10 cm. Soil organic carbon of coffee agroforestry depends on the moisture, decomposition of litter carbon, climatic zone, temperature, slope, altitude, management practices and the nature of the soil as well (Dossa et al., 2008). Carbon enters the soil as roots, litter, harvest residues, and animal

manures. It is stored primarily as soil organic matter (SOM). The density of carbon is highest near the surface, but SOM decomposes rapidly, releasing carbon dioxide into the atmosphere.

The bulk density of soil is affected by biophysical and economic factors. Its amount could be determined by consolidation, compaction and the amount of soil organic matter (FAO, 2010; Leiffield et al., 2004; Morisada et al., 2004). For instance, the reinforcing factors such as land use conversion, deforestation, and land degradation increase the bulk density of the soil (Nangware et al., 2019). These factors could alter the soil property through increasing compactness and reducing organic content and soil moisture. The average bulk density of soil for the three shade cover systems was $< 1.0 \text{ gcm}^{-3}$. Thus, to improve the organic matter and moisture content of the soil it is necessary to increase biomass through proper utilization of the forest resources.

Synthesis of coffee agroforestry system implications to climate change mitigation

The issue of climate change mitigation is not an option rather mandatory. Therefore, research reports highlighted the importance of greenhouses gas reduction through environmentally friendly and economically viable options (IPCC, 2014). In this regard, though the carbon sequestration potential is site specific, coffee agroforestry has got the scholars and various stakeholders' attention (Chunli et al., 2018; Kichline et al 2017; World Bank, 2012). Apart from its role to sequester carbon; the importance of the system to reduce erosion, land degradation and improve the ecosystem service; make it best development option to build the resilience of the livelihood of the community. The micro level study results suggest that Ethiopia could have remarkable climate change mitigation through promoting and strengthening coffee agroforestry system. Coffee agroforestry is among the main agroforestry systems in Ethiopia due to its area coverage and economic contribution. Thus, proper and sustainable management of high canopy traditional coffee production system (FDRE, 2011) carbon sequestration requires conservation of the system (Tessema and Kibebew, 2019), the provision of incentives and carbon payment for the smallholder farmers (Kichline et al., 2017).

Otherwise, coffee agroforestry system will suffer from expansion of cultivated and reduction of land suitability due to climate change (Gomesa et al., 2020). We argue coffee agroforestry is among few environmentally friendly and economically valuable agriculture-based carbon sequestration options in Ethiopia and elsewhere in the world.

CONCLUSION

Mitigating the emission of greenhouse gases entails the consolidation of multi-disciplines and collaboration at local and global scale. Berbere district's coffee agroforestry carbon stock showed significant variation and a clear pattern at soil carbon pools along different shade trees categories. However, litter carbon pool density did not show distinct patterns along with shade trees categories. The result revealed an important role in knowing the possible change in carbon stock and thus carbon sequestration capacity of the coffee agroforestry. Carbon stock in litter and soil carbon pools has the potential to decrease the rate of enrichment of atmospheric concentration of Carbon dioxide. Coffee Agroforestry can be one among a range of strategies for mitigating climate change. In this regard, the results of the study imply that the ecological services of coffee agroforestry can be increased by increasing the density of trees so that more carbon dioxide can be sequestered in the soils and litters. This in turn would enhance soil moisture and organic matter content. Therefore, fostering coffee agroforestry can be a viable means of mitigating the impacts of climate change.

RECOMMENDATIONS

The amount of carbon sequestered by litter and soil carbon pool in this study area was significant. Litter and soil carbon sequestrations on the coffee agroforestry have considerable potential to generate carbon trade in the study area in addition to climate change mitigation. Therefore, the government, NGOs, and other concerned institutions should facilitate carbon trades, especially the patch coffee agroforestry offers other benefits to the local people and environmental services.

Propagating coffee agroforestry is vital to decrease the accumulation of greenhouse gases in the atmosphere thereby combating global warming and its negative consequences. Besides, fostering coffee agroforestry considerably contributes to environmental wellbeing by harnessing soil moisture and organic content. Coffee agroforestry can be achieved by increasing the density of coffee trees. However, the optimal density of coffee trees for the utmost outcome of ecological services and farm productivity need to be studied further.

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WOODY SPECIES DIVERSITY AND STRUCTURE IN THE MAJOR LAND USES OF THE GARA MULETA WATERSHED IN EAST ETHIOPIA

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ABSTRACT: Land-use changes cause unique threats to biodiversity. Ensuring sustainable land use planning has a vital role in the successful implementation of biodiversity conservation. Hence, this study aimed to assess the change of woody species diversity and structure associated with land-use change in Gara Muleta, Eastern Ethiopia. For this study, four adjacent land uses, i.e., protected natural forest (PNF), disturbed forest (DF), plantation (PF), and cropland (CL), were considered. A total of 56 square plots having 35m x 35m size with nested plots of 25m x 25m, 7m x 7m, and 1m x 1m were laid systematically for trees with DBH > 50cm, for trees and shrubs for DBH ranges 20-50 cm, for shrubs and for herbs respectively. Shannon index, Simpson's diversity index, Jaccard's similarity, and Importance value Index were analyzed among land use types. One-way ANOVA was used to estimate the mean difference among the land use at $p < 0.05$ using R software version 4.1.0. The result of this study revealed that $H' = 3.5$, $H' = 2.5$, $H' = 1.6$, and $H' = 1.4$ were recorded in the PNF, DF, CL, and PF respectively. This implies that converting natural forests into plantations and cropland and disturbing them leads to a significant loss of woody species diversity and disturbs normal forest structures. Hence, the synergy approach to the landscape, which could be the maintenance of biodiversity requires conservation activities that ensure sustainable uses of the forest and its products. Thus, halting land-use change is important to achieve effective conservation activity.

Keywords: Basal Area, Disturbed forest, Important Value Index, Species richness

INTRODUCTION

The tropical forest represents 44% of the world's forest area which harbors massive terrestrial plant and animal species (Elliot et al., 2013) and it provides numerous goods and services for people who dwell in and around forests (Mukhopadhyay et al., 2007). In particular, Afromontane areas of eastern Africa, including the Ethiopian highlands, also constitute forests with exceptional species richness including endemic elements (Schmitt et al., 2010).

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However, global forest resources are diminishing at an alarming rate due to the conversion of natural forests into other land uses (Gessesse and Johan, 2007). This has threatened the world's biodiversity which serves human well-being (Lehman and Tilman, 2000) and is a significant cause of 15% of the global greenhouse gases (Moges and Tenkir, 2014). In Africa, indigenous forests are being deforested at a rate of four million hectares per year, which is twice the global average rate of deforestation (FAO, 2016). In Ethiopia, between 2000 and 2013, per year, 92,000 ha of forest genetic resource was lost (MEFCC, 2017). The remaining natural forests, which harbor high biodiversity are located on steep slopes at high altitudes and in the remote parts of the country, and they are threatened by anthropogenic activities like agricultural expansion, overgrazing, and illegal use (EBI, 2015). Consequently, this has led to climate change and dwindling ecosystem services, which could affect the livelihood of millions of people relying on forests (Lemenih and Kassa, 2014). It has also resulted in widespread land degradation (Moges et al., 2010), and losses of biodiversity (Mekuria and Yami, 2013).

The Gara Muleta forest is one of the remnant patches of Dry Afromontane forest found in the remote and inaccessible area of eastern Ethiopia. This forest is diminishing at an alarming rate due to the expansion of agricultural land, settlement, and unsustainable use of the forest for firewood collection, construction, and overgrazing according to Gurawa and Kurfa Chale Environment, Forest and Climate Change Office (Teketay, 1996). To mitigate this, some part of the deforested area is planted by exotic species and the remaining natural forest is under the management of the East Hararge Forest and Wildlife Protection Enterprise. To our knowledge, no study was conducted to document the effect of forest disturbance on plant species diversity and structure due to the change of natural forest to other land uses in Gara Muleta watershed. To reduce this gap, assessing the impact of natural forest conversion on woody species diversity and structure enables us to understand the effect of natural forest disturbance and provide information contributing to the implementation of sustainable forest management. Hence, the current study anticipated

to assess the change of wood species diversity and structure associated with the conversion of natural forest to other land use in Gara Muleta to develop a knowledge-based sustainable forest management plan.

MATERIAL AND METHODS

Description of the study area

This study was conducted in the Gara Muleta Dry Evergreen Afromontane forest and its adjacent land uses which is found in the East Hararge zone, Oromiya National Regional State. Geographically, the study site is located between $9^{\circ}13'03.14''$ to $9^{\circ}17'08.72''$ N and $41^{\circ}42'10.11''$ to $41^{\circ}48'52.03''$ E, with the elevation range of 2400-3400 m a.s.l. (Figure 1).

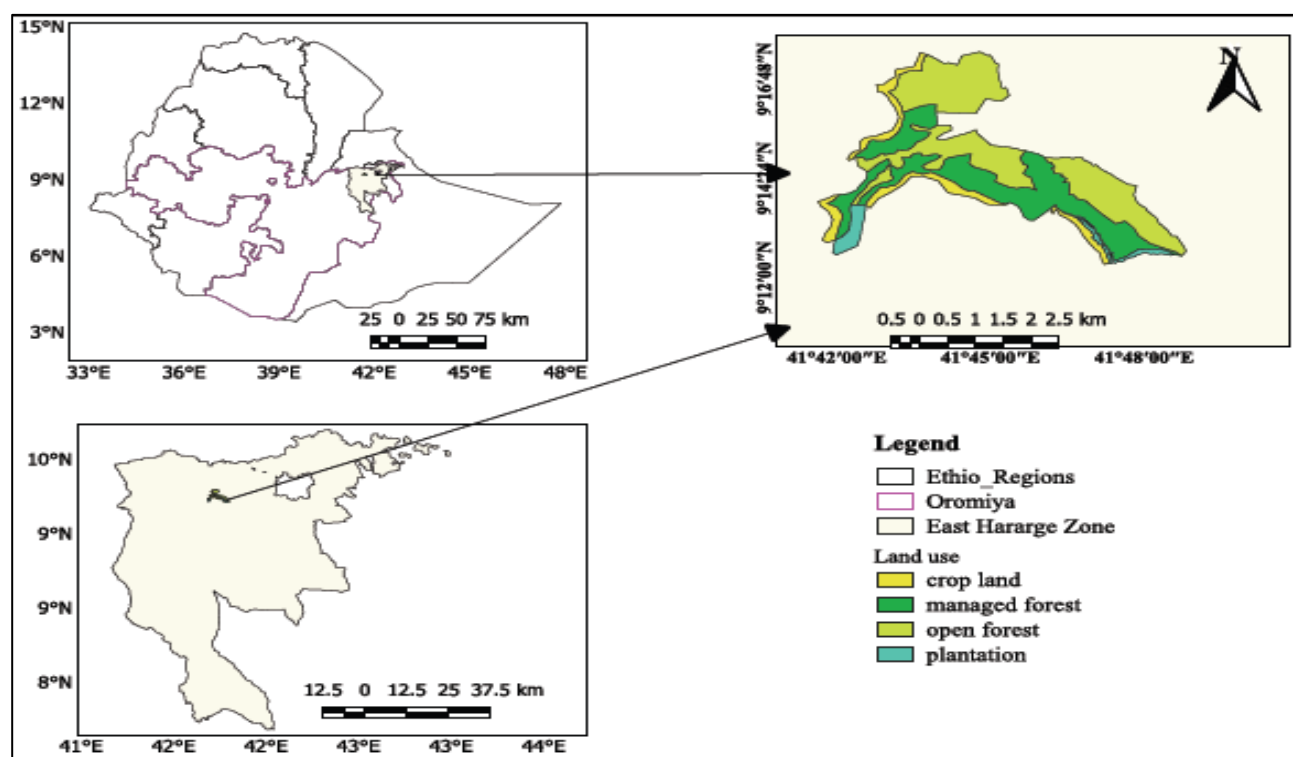


Figure 1. Map of study area produced by QGIS and Google Earth.

Because of the lack of specific long-term climatic data, the New LocClim software was used to produce the long-term monthly rainfall and temperature data (FAO, 2005) and generated a Climadiagram of the study site by R-software version 4.1.0. The mean annual temperature (MAT) and mean annual precipitation (MAP) at the study site were estimated to be 16.7°C and 921mm/year respectively. The precipitation of the

study site has a bimodal distribution pattern with a long rainy season lasting from July to September and a short rainy season from April to June (Figure 2). According to Friis et al. (2010), Dry Evergreen Montane forest is a complex vegetation type occurring from 1800 m a.s.l to 3200 m a.s.l. Gara Muleta forest has an altitudinal range from 2400-3400 m a.s.l. It has a complex mixture of vegetation like *Juniperus procera* and *Podocarpus falcatus*. Plants such as *Juniperus procera*, *Cupressus lusitanica*, and *Eucalyptus camaldulensis* were introduced through plantation activities to enrich the vegetation. This indicates that the Gara Muleta forest vegetation type belongs to dry evergreen Afromontane forest.

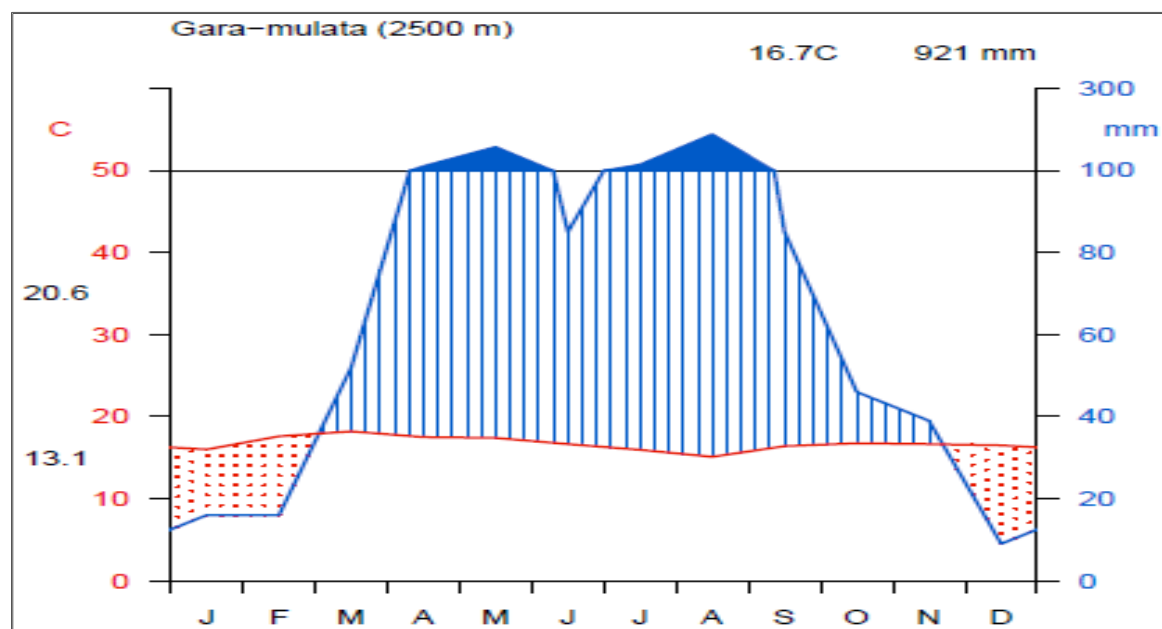


Figure 2. Climadiagram of Gara Muleta forest (produced by new LocClim software).

Coffee, chat, and eucalyptus are perennial plants in the study area. Annual food crops growing in the area include cereals (maize, sorghum, barley, wheat, tef), pulses (beans, soybeans), and root crops (potatoes).

Site selection

The study area was selected following a preliminary survey. Subsequently, the entire forest area was stratified into four land-use types following the level of degradation, species types, and management as described below (Table 1).

Table 1. Description of land use in the study area.

Land use types	Description
Protected natural forest (PNF)	is a remnant natural forest which protected from human and livestock disturbance
Disturbed forest (DF)	is the forest which is dominated by <i>Juniperus procera</i> planted 30 years ago and observed fragment by overgrazing, illegal use, and settlement
Plantation forest (PF)	is the plantation of <i>Grevillea robusta</i> and <i>Cupressus lusitanica</i> species before 10 years following the deforestation of the native forest?
Cropland (CL)	is farmland after conversion from a natural forest 25 years

Sampling and plot establishment

A systematical sampling method was preferred to collect the vegetation and soil samples. The first plot was established by simple random sampling and avoiding the border effect (50 m into the forest). Accordingly, transects were systematically laid along with the altitudinal gradient crossing cropland and plantation to address the whole forest by 1000 m intervals. Later, considering cost-efficiency and scientifically robust approach for most vegetation assessment, the nested square plots were established with the size of 35m × 35m (1225 m²) at 850 m interval distance between plots on predetermined transect line (Walker et al., 2012). Accordingly, 35m x 3 5m plot size was designed for trees with DBH > 50 cm, 25 m x 25 m sub-quadrats for trees and shrubs for DBH ranges 20 -50 cm, 7 m x 7 m for shrubs (Chave et al., 2014) and 1m x 1 m sub-quadrats for herbs. On cropland, 50 m x 100 m plot size was randomly used to compromise the scattered tree in cropland because of the low density of trees in cropland (UNFCCC, 2015). A large sample plot area was used to get woody species from small plots in this land use (Tolera et al., 2008).

The numbers of plots were estimated following the preliminary survey to reach the desired precision and statistical rigor to come up with good results, whereby eight plots were randomly established in the Gara Muleta forest and adjacent land use to obtain the coefficient of variation (CV). As a result, a total of 56 main plots were calculated attending (Eq1) (Pearson et al., 2005). Later, representative sample plots were allocated proportionally 26, 18, 8, and 4 for DF, PNF, CL, and PF respectively.

$$n = \frac{(\sum_{h=1}^L Nh*sh)^2}{\frac{N^2 * E^2}{t^2} + (\sum_{h=1}^L Nh*sh^2)} \dots\dots\dots (Eq 1)$$

Where n = the required number of plots, E = allowed error (mean carbon stock x 0.1, for 10% precision), and t = statistical sample of the t distribution for a 95% level of confidence; t is usually set at 2 as the sample size is unknown at this stage, Nh = the number of sampling units for land use type h = area of the stratum, in ha/area of the quadrat, N = number of sampling units in the population i.e. (N = $\sum Ni$), Sh = standard deviation of land-use 'h'.

Data collection

In each main plot for each land use, all plant species DBH > 5 cm and height \geq 2 m were measured by diameter tape and hypsometer respectively at standard DBH (1.37 m) with recording local and scientific names. Those species \leq 5 cm DBH and < 2 m height were collected by counting as seedlings when diameter < 2.5 cm and height < 1 m; saplings and shrubs have a diameter of 2.5–5 cm, height > 1 m < 2m (Lai et al., 2009).

The identification of woody species was done in the field using key informants, and experts, and each vernacular name was translated to their botanical names using flora of Ethiopia and Eritrea (Edwards et al., 1997; 2000; Hedberg et al., 1997; 2009; Mesfin, 2004).

Data analysis

Woody species diversity

The woody species measured in each land use was analyzed by the Shannon diversity index (Eq2)

$$H' = -\sum p_i \ln p_i \dots\dots\dots (Eq 2)$$

The richness of woody species in each land use was summed up by a total number of different woody species recorded in each of the sampled plots (Magurran, 2004).

Where: Pi is the proportion of individuals in the ith species, n = Total number of individuals.

Where H' = is the Shannon diversity index, S = is the number of species, P_i = is the proportion of total individuals in the i th species, and $H_{max} = \ln(s)$ is species diversity under max equitability conditions.

While Simpson's diversity was calculated by Simpson's diversity index (D) (Eq3)

$$D = \sum_{i=1}^S \frac{n_i(n_i-1)}{N(N-1)} \dots \dots \dots \text{(Eq 3)}$$

Where n_i = the number of individuals in the i th species; and N is the total number of individuals.

The species composition among land-use types was compared by Jaccard's similarity (Eq4) (Kent and Coker, 1992).

$$JS = \frac{c}{S_1 + S_2 - c} \dots \dots \dots \text{(Eq 4)}$$

Where S_1 is the number of species in land use type 1,

S_2 is the number of species in land use type 2, and

C is the number of species common to both land-use types.

Wood species structure

The structural analysis of the wood species was also described by using the following components: IVI, basal area, density, and DBH class distribution. Six DBH classes (i.e., 1 = 5 \geq 10 cm, 2 = 10 –20 cm, 3 = 20 –30cm, 4 = 30 -40 cm, 5 = 40 -50 cm, 6 = >50 cm) were established (Hundera and Gadissa, 2007).

The Importance Value Index (IVI) of woody species in the ecosystem was estimated from the sum of relative density, relative dominance, and relative frequency (Eq 5) (Kent and Coker, 1992).

$$\text{IVI for each species} = \text{RD} + \text{RDOM} + \text{RF} \dots \dots \dots \text{(Eq5)}$$

Where:

$$\text{Relative density} = \frac{\text{No. of individual species}}{\text{Total number of individuals}} \times 100 \dots \dots \dots \text{(Eq6)}$$

$$\text{Relative dominance} = \frac{\text{Basal area for a species}}{\text{Total basal area}} \times 100. \dots \dots \dots \text{(Eq7)}$$

$$\text{Basal area (m}^2\text{)} = (\text{DBH}/200)^2\pi \text{ or } \text{BA} = \pi \text{DBH}^2/4. \dots \dots \dots \text{(Eq 8)}$$

$$\text{Relative frequency} = \frac{\text{Frequency of a species}}{\text{Sum of all frequencies}} \times 100 \dots \dots \dots (\text{Eq 9})$$

Statistical Data Analysis

R software version 4.1.0 and Excel were used for analysis. First data was checked by using the Shapiro–Wilk normality test. Statistical differences among land-use types were tested using a one-way analysis of variance (ANOVA) (Chia et al., 2017). Tukey’s HSD test was used for mean separation if the analysis of variance showed a statistically significant difference ($P < 0.05$). Kruskal Wallis non-parametric analysis was used alternatively if normality tests were violated (Kruskal and Wallis,1952).

RESULTS

Woody species composition

The present study revealed that a total of 77 woody species representing 42 families and 70 genera and 26 species, representing 17 families and 23 genera were recorded from PNF and DF respectively. In the cropland, 20 species from 13 families and 19 genera and in the plantation forest 9 species from 8 families and 9 genera were recorded. Fabaceae, Asteraceae, and Lamiaceae were the most dominant families contributing 16%, 16%, and 13% respectively (Figure 3).

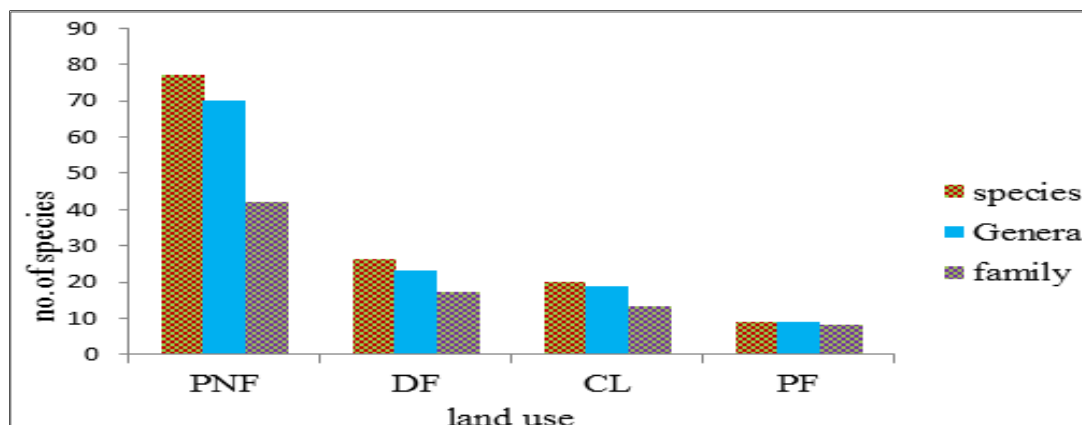


Figure 3. Woody species composition across land uses.

Richness, diversity, and evenness of woody species

The estimated species richness (77), Shannon diversity (3.5), and Simpson index (0.97) in the protected natural forest was higher than what has been recorded in other land uses in the study area. The least species diversity was recorded in crop land and plantations which showed Shannon diversity of 1.6 and 1.4 respectively (Table 2).

Table 2. Species richness, Simpson index, Shannon diversity (H'), and Evenness (J).

Land use	Richness	Simpson	H'	J
PNF	77	0.97	3.5±0.6 ^a	0.84±0.05
PF	9	0.82	1.4±0.2 ^b	0.49±0.1
DF	26	0.41	2.5±0.1 ^c	0.82±0.04
CL	20	0.04	1.6±0.10 ^b	0.48±0.2
F			12.87	17.7
p-value			.000	.006

PNF-natural forest, DF-disturbed forest, PF-plantation, CL-crop land; Different letters indicate significant differences across columns at $p < 0.05$.

Jaccard's similarity Index (%) among land use

The Jaccard similarity coefficient showed the highest similarity in woody species composition between disturbed and natural forests as compared with the other combinations (Table 3). The lowest similarity index was observed between PNF and PF (5%).

Table 3. Jaccard similarity coefficient among studied land use

	PNF	DF	CL	PF
PNF	1	0.48	0.17	0.05
DF	0.48	1	0.12	0.12
CL	0.17	0.12	1	0.17
PF	0.05	0.12	0.17	1

PNF-natural forest, DF-disturbed forest, PF-plantation, CL-crop land

Woody species structure

DBH class distribution of woody species

The diameter class distribution of all woody species in the PNF was reflected in an inverted J-shape. This shows the highest frequency of individual species found in the lower DBH class and declined toward the upper class. Hence, 50.9% of individual species were found in the lower DBH class (class 1-2) and declined toward the higher diameter class. In contrary, in PF, 63.1% of individual species were found in DBH class two and three whereas class one had 1.4% and the rest of the classes were relatively similar. These indicated bell shape. Similarly, in DF 21.9% of individual species were found in classes one and two, and the highest individual species were found in the middle. This implies an irregular pattern. Similarly, in cropland, the distribution of individual species found in the lower class was relatively low whereas their trends showed an irregular pattern. This indicated that some species such as *Catha edulis* (Celastraceae), *Coffea arabica* (Rubiaceae), other fruit, and some economically important shrub species were frequently planted by farmers. Contrary to this, during deforestation, large trees were removed to prevent competition and economically important species e.g., *Podocarpus falcatus* (Podocarpaceae), *Ficus mucuso* (Moraceae), and *Olea europaea* subspecies *cuspidate* (Oleaceae) were retained (Figure 4).

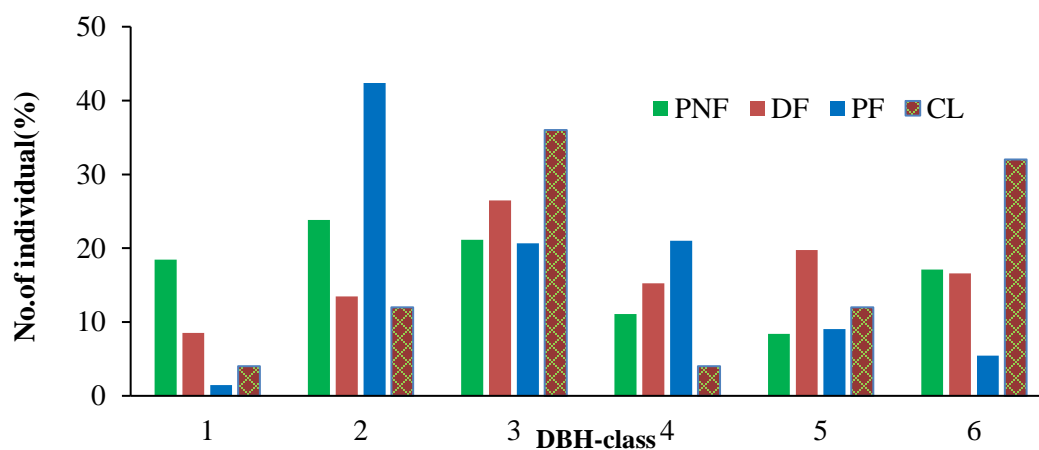


Figure 4. Diameter size class distribution of plant species across land-use types (Where, 1= 5 ≥- 10 cm, 2= 10 –20 cm, 3= 20 –30cm, 4=30 -40 cm, 5= 40 -50 cm, 6= >50cm).

Density and basal area

In the present study the highest stem density was recorded in protected natural forests followed by plantation forests and disturbed forest. The least stand density was found in cropland. This difference was statically significant among the land uses ($F = 5.06$, $P = 0.004$) (Table 4). In the same way, the 35.31 ± 2.5 ($\text{m}^2 \text{ha}^{-1}$) value of basal area recorded in PNF was three times higher than DF and 10 times higher than PF. This indicated a significant difference across the land uses at $p < 0.05$.

Table 4. Stems density and BA under different land-use types

land use	Density ha^{-1}	Basal ($\text{m}^2 \text{ha}^{-1}$)
Protected natural forest	556±89 ^a	35.31±2.5 ^a
Disturbed forest	240±173 ^b	8.56±1.8 ^b
Plantation forest	484±130 ^c	3.41±1.2 ^c
Cropland	69±128 ^d	1.33±0.4 ^{cd}
F-value	5.06	17.51
p-value	0.004	0.000

BA-basal area, SE-standard error, similar letter across column indicates no significant difference at ($p < 0.05$)

Importance value index of woody species (IVI)

The present study showed that *Schefflera abyssinica*, *Trichilia dregeana*, *Nuxia congesta*, *Fagaropsis angolensis*, and *Podocarpus falcatus* contributed 24.4% of IVI in protected natural forests. While *Juniperus procera*, *Fagaropsis angolensis*, *Schefflera abyssinica* (10.4, 3.5%), *Trichilia dregeana* (12, 4%), and *Nuxia congesta* (14.2, 4.8%) were significant native species in the disturbed forest. *Cupressus lusitanica*, *Grevillea robusta*, *Eucalyptus globulus*, *Becium grandiflorim*, and *Galiniara Saxifraga* contributed 89.8% in PF. In cropland, *Podocarpus falcatus*, *Catha edulis*, *Ficus mucuso*, *Cordia africana*, and *Eucalyptus globulus* aggregately contributed 44.1% (Table 5).

Table 5. IVI of some selected tree species across land use.

No.	Species name	IVI across land use							
		PNF	%	DF	%	PF	%	CL	%
1.	<i>Schefflera abyssinica</i> (Hochst ex.Arich.) Harms	19.83	6.6	10.4	3.5				
2.	<i>Becium grandiflorim</i> (Lam.) Pic. Serm.					14.1	4.7		
3.	<i>Fagaropsis angolensis</i> (Engl.) Dale	10	3.3	18.8	6.3				
4.	<i>Trichilia dregeana</i> Sond.	21.53	7.2	12.0	4				
5.	<i>Nuxia congesta</i> R. Br. ex Fresen	15.70	5.2	14.2	4.8				
6.	<i>Podocarpus falcatus</i> (Thunb.) R.Br. ex Mirb.	9.21	3.1					29.7	10.1
7.	<i>Juniperus procera</i> Hochst. ex Endl			84.8	28.4				
8.	<i>Cupressus lusitanica</i> Mill.					80.2	26.		
9.	<i>Grevillea robusta</i> A.Cunn. ex R.Br.					97.9	32.		
10.	<i>Eucalyptus globulus</i> Labill.					59.9	20	12.9	4.4
11.	<i>Galiniera saxifraga</i> (Hochst.) Bridson					19.5	6.5		
12.	<i>Catha edulis</i> (Vahl) Endl							38.2	13
13.	<i>Cordia africana</i> Lam.							18.3	6.2
14.	<i>Ficus mucuso</i> Welw. ex Ficalho							29.8	10.1

PNF=protected natural forest, DF=disturb forest, PF=plantation, CL=crop land.

DISCUSSION

Wood species diversity

The result of the present study indicated that the Shannon diversity of protected natural forest (PNF) ($H' = 3.5$) is substantially higher than cropland (CL) and other land use. This might be due to the high species richness and evenness value in the PNF. The study by Teketay (1996), also indicated the disturbance of natural forests due to overgrazing and edge conversion to cropland. This is also in line with a study by Kefalew et al. (2021) which stated that 33 species were lost due to the conversion of natural forests into farmland. The possible reason for the lower woody species diversity (in the DF) may also be due to the repeated habitat disturbances for firewood collection, settlement, and overgrazing leading to clearance of understory herbs and shrubs. Prior studies have suggested that diversity of woody species in the less disturbed area was higher than highly disturbed area (Teketay et al., 2018; Manaye et al., 2019).

Similarly, in plantation forests, the observed minimum value of species diversity is due to planting selective exotic species, which are fast-growing and preferred for timber. For instance, *Cupressus lusitanica*,

Eucalyptus globulus, and *Grevillea robusta* were planted in areas previously occupied by natural forest to get economic benefit as reported by local community elders. The conversion of natural forests into monoculture plantation forests decreases plant species diversity and richness. This is consistent with the study reported by Denu (2016). This also implies that the conversion of natural forest or modification seriously threatened wood species diversity and leads to loss of plant genetic resources. A study by Tadesse et al. (2014) also indicated the impact of land-use change on woody species distribution.

Compared with other dry Afromontane forests studied in Ethiopia, H' value obtained for the protected natural forest in this study area ($H' = 3.5$) was higher than $H' = 2.57$ for the Menagesha Suba forest reported by Dinkissa (2011), $H' = 2.82$ for the Ades Forest (Reshad et al., 2019), and $H' = 3.04$ of Gemechis forest (Dawud et al., 2018). This variation could be due to dissimilarities of the sites in terms of location, altitude, human impact, rainfall and other biotic and abiotic factors (Chen et al., 2005), and differences in forest management.

Woody species structure

The ecological importance of species in a given ecosystem can be described by their important value index (Worku et al., 2012). High IVI values of a species imply more ecological importance than low IVI values of the species (Haileab et al., 2011). As a result, *Schefflera abyssinica*, *Ekebergia capensis*, *Trichilia dregeana*, *Nuxia congesta*, and *Erythrina abyssinica* contributed 24.4% of PNF. The possible reason for the contribution of this in PNF was related to the presence of higher basal area, abundance, and even frequency of native plant species. This is a line with Manaye et al. (2019) who reported higher IVI in ex-closure than in degraded land. In our study area, there was a high human influence in DF, PF, and CL to favor certain selected species while disfavoring the rest of the native woody species. *Cupressus lusitanica*, *Grevillea robusta*, and *Eucalyptus globulus* were the most favored and dominant exotic species in plantations. This agrees with the finding reported by (Denu, 2016).

Similarly, *Podocarpus falcatus*, *ficus mucoso*, and *Cordia africana* were the species retained on cropland that had ample basal area. These species were retained during clearance of natural forest to be used for shading and for their benefit to be used timber, construction, and income generation. A study by Ewuketu et al. (2014) also showed that species with multiple uses showed higher IVI values and were preferred by local communities. *Coffea arabica* and *Catha edulis* were commonly available on cropland after deforestation.

The result of the diameter size class distribution of PNF was shown in an inverted J-shape which indicates a good regeneration potential of the forest. This is comparable to the stable forest structure reported from Dindin forests (Shibru and Balcha, 2004). On the other hand, the possible reason for decreasing number of individual woody species within class one in PF could be due to the regular clearance of saplings and seedlings of native woody species during pruning and replacement by even aged exotic species. Similarly, in DF, overgrazing of herbs and shrubs, and illegal collection of trees and shrubs could have interrupted normal forest structure. A recent study reported by Atsbha et al. (2019) noted the illegal cutting of trees and shrubs for construction and overconsumption of fuelwood could result in the formation of bell-shape and disturb normal forest structures in the communal grazing land. In CL, the absence of seedling and sapling of native wood in the lower diameter class was observed. This happened because of clearance of mother trees from the cropland by farmers. Decreasing trend in the higher diameter class, indicated the selective removal of a large trees. However, some favored species were retained on farmland for timber, fodder, shelter, and other uses. This is a line with the findings of Tolera et al. (2008).

Compared with another dry Afromontane forest the stand density of PNF in the present is lower than those from the Dindin forest (Shibru and Balcha, 2004) and forest in Northern Ethiopia (Negasi et al., 2018), despite being comparable to the tree density reported from other tropical forests (Chauhan et al., 2008). This variation is probably a result of the variation in site conditions, species characteristics, the economic importance of species, and human-induced disturbances (Shibru and Balcha, 2004).

CONCLUSIONS AND RECOMMENDATIONS

Based on the evidence of the present study the land-use conversion from natural forest to disturbed forest, plantation, and cropland could affect species diversity, density, and structure. Conversion of forest land to other land uses (such as NF to DF, PF, and cropland) results in a significant decline in species diversity and structure. This could lead to the loss of goods and services provided by the natural ecosystem. In addition, the land-use change also interrupts the normal distribution of individual species at DBH class. The study area's natural forest is under threat from the conversion of natural forest to other land uses which could result in the loss of local ecosystem benefits that the local community may gain from the forest. Hence, to curb the problems, we recommend: i) the replantation of the deforested area with native plant species and establishing exclosure on disturbed area to facilitate regeneration of soil seed bank and ii) conduct further study that focuses on focus local knowledge and, the impact of environmental factors on structure, regeneration, and soil seed banking of woody species to better understand the scale of the problem and also draw a comprehensive plan for sustainable management of the forest.

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MEDICINAL PLANTS FOR TREATING ANIMAL AILMENTS: AN ETHNOVETERINARY STUDY IN MORETNA JIRU DISTRICT, NORTH SHEWA, ETHIOPIA

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ABSTRACT: In Ethiopia medicinal plants play a significant role in animal health management. This study was conducted to assess and document medicinal plants used to treat animal ailments in the Moretna Jiru district. Ethnobotanical data were collected from 210 informants through semi-structured interviews, group discussions, and field walks. A total of 25 medicinal plants representing 25 genera and 18 families were used to treat 18 animal ailments. The family Solanaceae (17.54%) was the most represented followed by Asteraceae (15.65%), and Polygonaceae (9.04%). Shrubs (63.43%) were the dominant growth forms followed by herbs (28.34%). Most of the medicinal plants were harvested from the wild (55.74%), from both wild and home gardens (24.70%) and home gardens (19.57%). Leaves (48.08%) were frequently used followed by roots (32.93%), and seeds (10.93%). *Allium sativum* L., and *Artemisia abyssinica* Sch. Bip were the preferred plant for treating the evil eye. Major ailments treated included evil eye (18.08%), leech infestation (13.36%), and blackleg (9.72%). Remedies were primarily administered orally (56.95%), followed by dermal (15.65%), neck application (15.38%), and ocular routes (6.48%). Climate change, agricultural land expansion, deforestation, and droughts are the major threats to medicinal plants. Indigenous knowledge was declining due to culture shifts, and lack of interest of the younger generations. Cultivation of some medicinal plants was the only conservation effort observed in the study area. Thus, conservation efforts in the area remain insufficient, and urgent actions are needed to protect medicinal plant biodiversity and associated traditional knowledge systems.

Keywords: Animal, Ethnoveterinary, Indigenous knowledge, Medicinal plants, Moretna Jiru

INTRODUCTION

Human beings relied on plants for animal health care as early as the time of domestication, dating back to 10,000 years ago (Martin, 1995). They have used medicinal plants to manage various types of human and livestock ailments since time immemorial (WHO, 2002). Medicinal plants provide affordable medicine as

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alternatives to modern medications (Giday et al., 2003). Medicinal plants also provide easily, available, affordable, and more acceptable remedies (Phondani et al., 2020), especially in resource-poor communities (Kebebew et al., 2017). Ethiopia possesses unique flora and fauna because of its wide ranges of topography, geography, and altitude (Woldu, 2008), and it is one of the 12 Vavilov centers of crop genetic resources and harbors the fifth-largest floral diversity in tropical Africa (Kelbessa et al., 1992). Of the estimated 6027 species of higher plants including 27 subspecies 14% of them have medicinal values (Kelbessa and Demissew, 2014). These medicinal plants are used to treat 80% of human and 90% of livestock ailments in Ethiopia (Maki, 2008; Yirga, 2010; Mesfin et al., 2014; Kebebew et al., 2017). Medicinal plant diversity and distribution have degraded over time due to habitat destruction, deforestation, forest encroachment for agriculture, and urbanization, which resulted in a decline and loss of medicinal plants in different parts of the country (Berihane et al., 2011; Jima and Megersa, 2018). The loss of medicinal plants results in a loss of culture and knowledge that is acquired over thousands of years of interaction with the existing flora and ecological setup (Prance, 1991; Kindie and Tamiru, 2021). In addition, indigenous knowledge of medicinal plants has reduced due to acculturation (Kadir et al., 2014), lack of documentation and sound transfer of traditional knowledge, lack of interest of the younger generations, and lack of appropriate medicinal plant conservation activities.

In Ethiopia, though 95% of remedies to treat animal ailments are prepared from plants (Damie et al., 2018; Tanto et al., 2003; Abebe and Ayehu, 1993), medicinal plant species and associated traditional knowledge systems are threatened because of a lack of systematic conservation, research, proper utilization, and documentation (Birhane et al., 2011). The people of Moretna Jiru district have used a variety of medicinal plants to treat animal health problems for generations, but the practice has reduced from time to time, and the conservation practices remain poor. This study aimed to assess and documented medicinal plants used to manage animal health problems and associated knowledge in the district.

MATERIAL AND METHODS

Description of the study area

Moretina Jiru district is found in the North Shewa Zone of Amhara regional state, Ethiopia (Figure 1). It is named after the historic districts of Shewa and Moret, which lies in between Jemma river and Shewa Meda (Girma et al., 2011). The area is located about 200 km Northwest of Addis Ababa (Girma 2011; Negatu and Parikh, 1999), and about 65 km far away from Debre Berhan town, the administrative center of the North Shewa Zone. It has a total area cover of 661.16 Km² with an altitude range from 1500 to 2690 m a.s.l. The latitudinal and longitudinal limit of the area ranges from 9° 52' 28" N to 39° 18' 37" E respectively. The district has two agroecological zones namely, the highland plateau and the Nile Gorge area (Negatu and Parikh, 1999; Girma 2011, Desaaegn and Asnake, 2018). The district is also bordered by Seyadebrna Wayu district in the south, Ensaro district in the southwest, Merehabete district in the northwest, Menze key Gabriel district in the northeast, and Basonawerena district in the east. The district also has a total population of 91,900 (47, 597 male and 43,303 female) with annual growth rate of 1.7% (CSA, 2008). Eucalyptus tree, natural shrubs, fodder trees, and acacia are the major flora in the district. The people rear cattle, got, sheep, equine, and poultry (Desaaegn and Asnake, 2018). Crop livestock production system is the dominant livelihood strategy in the district (Girma, 2011).

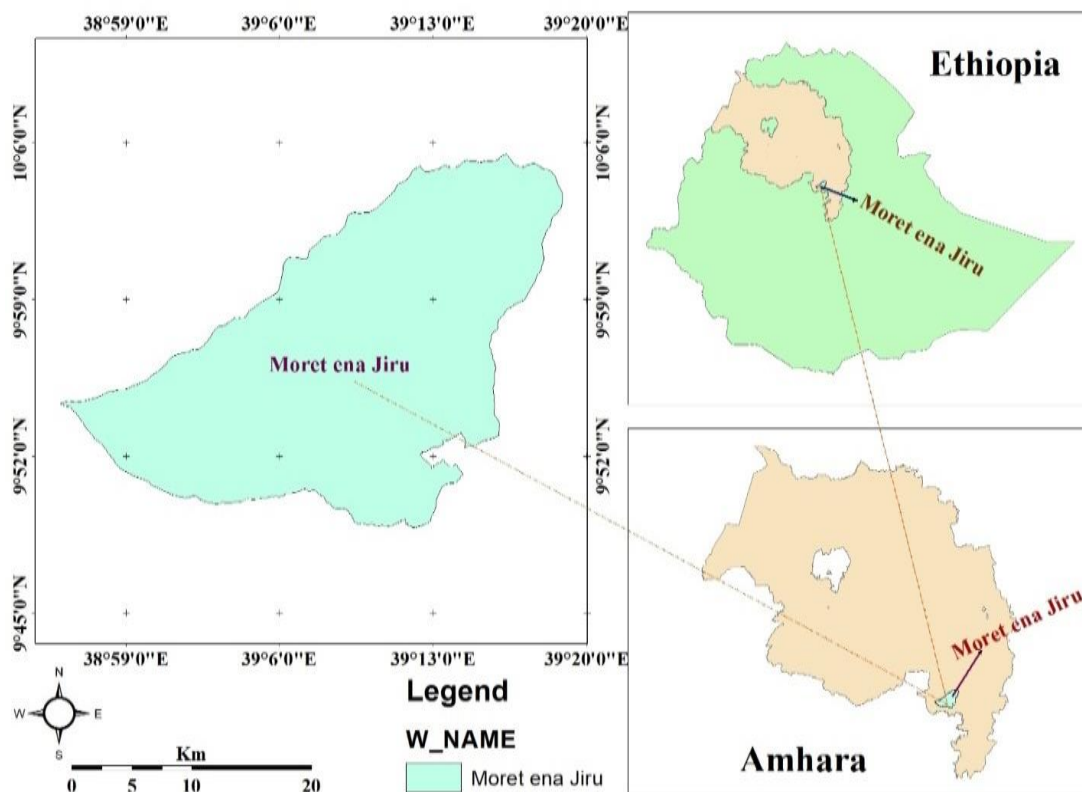


Figure 1. Map showing the study area.

Study site selection

A reconnaissance survey was conducted from August 25, 2020, to September 10, 2020 to get general information on the study area. Information such as agroecological zonation, and availability of potential informants were assessed and recorded during the survey. After the reconnaissance survey, representative kebeles were purposively selected following the approach of Martin (1995). Six kebele were selected based on agroecology (three from Dega and three from Woinadega) to get representative informants. The selected kebeles were Gerba, Woiramba and Kusaye from Dega agroecology and Kayadur, Yimedeb, and Debre from Woinadega agroecology.

Informant selection and data collection

A total of 210 informants which included both general informants (N=180) and key informants (N=30) were selected for this study using systematic random sampling and purposive sampling techniques,

respectively. Ethnobotanical data were collected through semi-structured interviews, guided field walks, and group discussions. Guided field walks and observations helped identify plant sources, growth habits, and distribution. Focus group discussions, involving 10–15 key informants were made to collect information on traditional remedy preparation, threats to, and conservation of medicinal plants.

Specimen collection and identification

Medicinal plant specimens were collected from the study area during guided field walks. The collected medicinal plant specimens were numbered, pressed, dried, and transported to the National Herbarium (Addis Ababa University) for identification. Preliminary identification was done in the field using vernacular/local names, and further identification of the specimen was made using Flora of Ethiopia and Eritrea volumes (Hedberg and Edwards, 1989; Edward et al., 1995; Hedberg et al., 2003; Hedberg et al., 2004; Hedberg et al., 2006), and in comparison with authentic specimens in the national herbarium and verified by the taxonomic experts. The voucher specimens were labeled and deposited in the National Herbarium Addis Ababa, Ethiopia.

Data analysis techniques

Ethnobotanical information of medicinal plants regarding the growth form, habitats, ailments treated, parts used, method and condition of remedy preparations, mode of delivery, and route of administrations were organized and analyzed using Microsoft Excel 2010 and the results were presented in the form of figures and tables.

Preference ranking of medicinal plants

Preference rankings were made for medicinal plants used to treat evil eye disease in animals, which has a high frequency of reports following Martin (1995). Seven key informants were asked to order and rank medicinal plant species based on personal, and community preference by assigning values (5=Best, 4=Very good, 3= Good, 2= Less used, and 1= Less preferred) for each of the medicinal plants presented.

Finally, the total value was added and the rank of each species was done to identify medicinal plants used to treat evil eye.

Informant Consensus Factor (ICF)

Informant Consensus Factor (ICF) was computed to determine people's consensus on the use of medicinal plants for treatments of particular ailment categories. Informant Consensus Factor (ICF) was calculated by using the formula suggested by Heinrich et al. (1998).

$$FIC = Nur - Nt / (Nur - 1)$$

Where "Nur" refers to the total number of use reports for each disease category and "Nt" refers to the total number of species used for that category. It investigates the homogeneity of ethnomedicinal information that was documented by the traditional informants.

A high ICF value is obtained when only one or a few species are reported to be used by a high proportion of informants to treat particular ailments, whereas a low ICF value indicates that the informants disagree over which plants to use.

Identification of threats to veterinary medicinal plants

Direct matrix ranking was done to identify potential threats to medicinal plant species following the methods of Martin (1995) and Cotton (1996). In this method, major threats to medicinal plant species were ranked. For this study, six informants ranked five medicinal plant threats and scored five for the highest value, one for the least value, and zero for no value. Finally, the total score was summed up and ranked.

RESULTS

Demographic characteristics of informants

In this study, a total of 210 informants (180 general and 30 key informants) were involved. The informants were in the age ranges from 20 to 91 and most of them were illiterate 45.7 % (96) and farmers 172 (81.9%) (Table 1).

Knowledge of people on medicinal plants

The average number of medicinal plants reported by male respondents (5.83 ± 2.61) was higher than female respondents (5.30 ± 3.23), the difference was statistically nonsignificant ($P > 0.005$). The medicinal plant knowledge of the community was also non-significant ($P > 0.05$) in the marital status of the community ($P < 0.05$). Elder members of the community (≥ 61 years old) cited more medicinal plants than the adults (41-60 years) (4.98 ± 3.13), and young (20-40 years) (5.48 ± 2.42), and the difference is statistically significant ($P < 0.05$). In the same way, there is a statistically significant ($P < 0.05$) difference between the educational status of the community in terms of medicinal plants reported. Key informants reported more medicinal plants than the general informants but the difference was not statistically significant ($P > 0.05$) (Table 1).

Table 1. Statistical test of significance using one-way ANOVA test on the number of medicinal plants mentioned by the informants (2020-2021).

No	Demographic data of the informant		N (%)	Mean \pm SD	F value	P value
1	Gender	Male	142 (67.61)	5.83 \pm 2.61	1.606007	0.206471
		Female	68 (32.38)	5.30 \pm 3.23		
2	Age	20-40	87 (41.43)	5.48 \pm 2.42	10.58167	0.0000421*
		41-60	66 (31.43)	4.98 \pm 3.139		
		>60	57 (27.14)	7.33 \pm 2.426		
3	Marital status	Single	60 (28.57)	6.01 \pm 3.62	1.010783	0.38893
		Married	130 (61.9)	5.41 \pm 2.42		
		Divorced	15 (7.14)	6.07 \pm 2.81		
		Windowed	5 (2.38)	6.8 \pm 19.2		
4	Educational status	Illiterate	96 (45.7)	5.84 \pm 2.98	3.25769	0.01286906**
		Basic education	11 (5.2)	4.81 \pm 1.25		
		Primary school	54 (25.6)	4.59 \pm 1.83		
		Secondary school	41 (19.52)	4.73 \pm 1.71		
		College and	8 (3.8)	4.5 \pm 0.92		
5	Occupation	Farmer	172 (81.90)	5.88 \pm 2.84	4.456737	0.004668**
		Merchant	19 (9.04)	4.89 \pm 2.33		
		Housewife	13 (6.19)	3.30 \pm 2.52		
		Others	6 (2.85)	7.0 \pm 1.78		
6	Informant category	Regular informants	180 (86)	5.27 \pm 2.69	3.739038	0.054715
		Key informants	30 (14)	6.24 \pm 1.48		

N= Number of respondents; * significant difference ($P < 0.05$).

Medicinal plants used to treat animal diseases

A total of 26 medicinal plant species belonging to 18 families were used to treat 18 animal ailments in Moretna Jiru district. Leech, evil eye, abdominal pain, parasitic diseases, and diarrhea were the most common animal ailments treated by using medicinal plants in the district. From the listed 18 animal ailments only rabies and Lumpy disease has zoonotic behavior and the rest are not. Among the stated animal diseases rabies, diarrhea, leeches, and parasites were the basic public health concerns in the study area (Appendix 1). Solanaceae and Asteraceae have the highest number of species followed by Polygonaceae, Euphorbiaceae, Lamiaceae, and Brassicaceae (Figure 2).

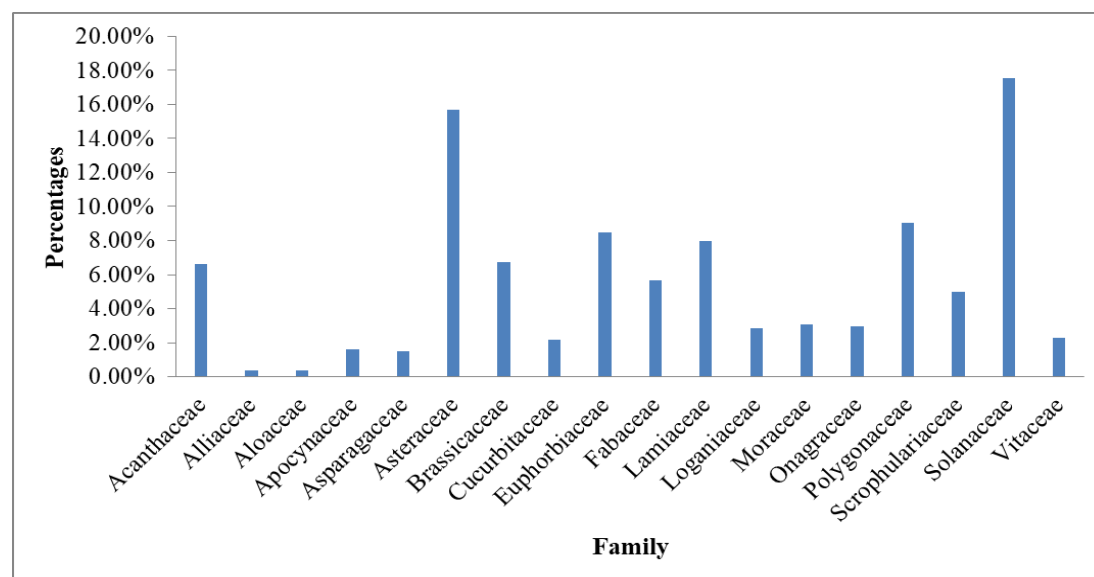


Figure 2. Family distribution of medicinal plants used to treat animal ailments in the district (2020-2021).

Habitats of medicinal plants

In this study, most of the medicinal plants used for remedy preparation were grown in the wild (55.74%) followed by both wild and home gardens (24.70%) and home gardens (19.57%) (Figure 3).

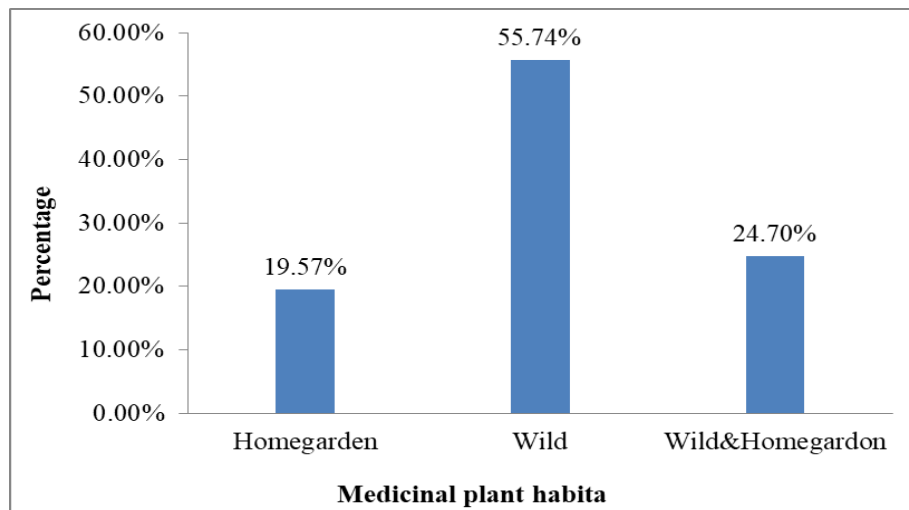


Figure 3. Percentage of medicinal plants used to treat animal ailments based on habitats (2020-2021).

Habits of medicinal plants

Shrubs (64%) were the major medicinal plant habits used for remedy preparation to treat animal ailments in the district followed by herbs, trees, and climbers with 64%, 28 %, 6 %, and 2% respectively.

Plant parts used for the treatment of animal diseases

Leaves were the major plant parts used for remedy preparation of animal ailments in the study area, accounting for 48.04% followed by roots (32.93%) and seeds (10.93%) (Figure 4).

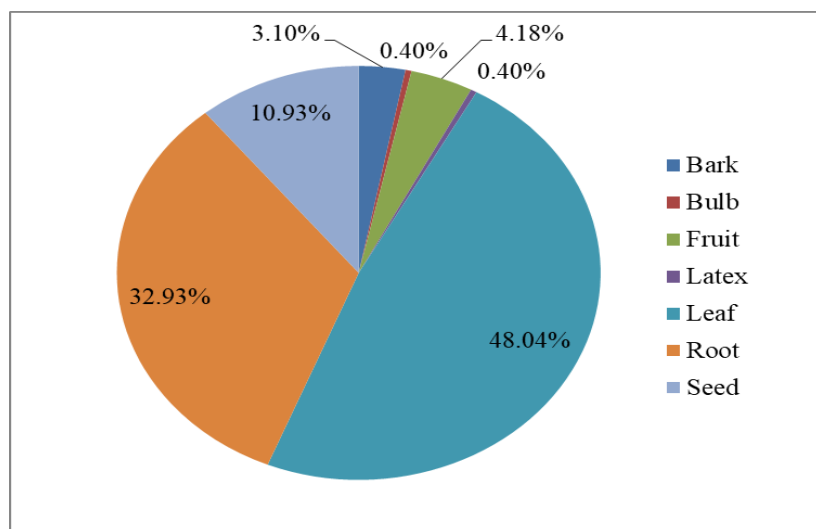


Figure 4. Percentage of plant parts used in the treatment of animal ailments (2020-2021).

Routes of administration

The major routes of administration for animal ailment in the study area were oral, dermal, neck, and ocular routes. Oral routes were the dominant administration routes which accounts for 56.95% followed by dermal routes (15.65%), and neck (15.38%) (Figure 5).

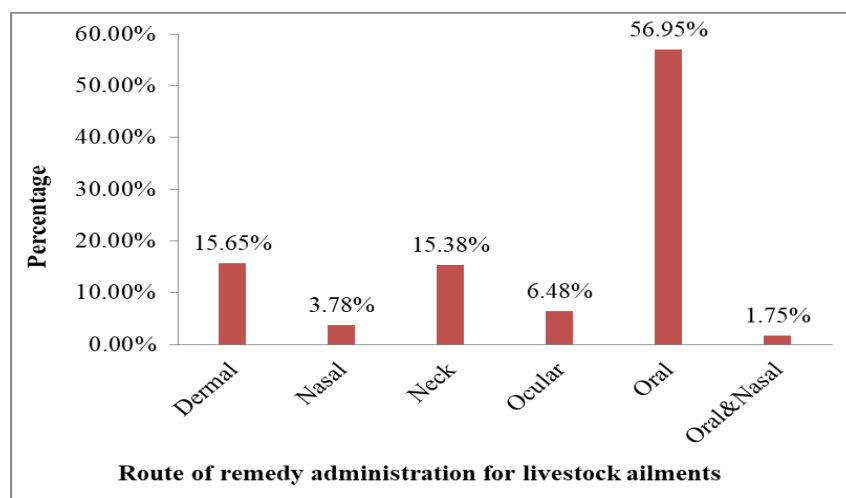


Figure 5. Percentage of the route of administrations for the treatments of animal ailment (2020-2021).

Preference ranking

Preference ranking of medicinal plants was made for evil eye disease in the study area. *Allium sativum* was the best medicinal plant for the treatment of livestock ailments followed by *Artemisia abyssinica* and *Carrisa spinarum* (Table 2).

Table 2. Preference ranking of medicinal plants used to treat evil eye in Moretna Jiru district (2020-2021).

No	Botanical name	Key respondents					Total value	Rank
		R1	R2	R3	R4	R5		
1	<i>Allium sativum</i> L.	5	5	4	5	5	24	1 st
2	<i>Artemisia abyssinica</i> Sch.Bip	4	5	5	4	4	22	2 nd
3	<i>Carissa spinarum</i> L.	5	3	4	5	4	21	3 rd
4	<i>Calpurina aurea</i> (Alt.) Benth	3	4	5	5	2	19	4 th
5	<i>Cucumis ficifolius</i> A.Rich.	3	5	5	3	2	18	5 th
6	<i>Datura stramonium</i> L	1	3	3	4	5	16	6 th
7	<i>Otostegia integrifolia</i> Bent	3	3	4	2	2	14	7 th
8	<i>Withania somnifera</i> (L.) DunalinDC	5	3	2	1	1	12	8 th

NB: The highest score (5) was given for the most effective medicinal plant and the lowest number (1) for the least effective plant

Informant consensus factor

In this study medicinal plants with high ICF value were *Allium sativum* L followed by *Datura stramonium* L. with values of 0.9726 and 0.94.0 respectively and the lowest value was recorded for *Cyphostema cyphopetalum* (Fresen.) (0.8723).

Table 3. ICF of medicinal plants used to treat different animal ailment categories (2020-2021).

Scientific name	Disease categories	Nur	Nt	ICF
<i>Allium sativum</i> L	Gastrointestinal	180	5	0.9722
<i>Datura stramonium</i> L	Dermatological	135	9	0.9403
<i>Solanecio gigas</i> (Vatke)	External parasite	102	10	0.9363
<i>Withania somniferal</i> (L.) DunalinDC	General diseases	99	10	0.9071
<i>Calpurina aurea</i> (Alt.). Benth	Ophthalmological	106	12	0.8936
<i>Cyphostema cyphopetalum</i> (Fresen.)	Neurological disorder	101	14	0.8723

Nur= total number of use reports for each disease category, **Nt**= total number of species used in the category, **ICF**=Informant Consensus Factor.

Threats of medicinal plants

The major threats to veterinary medicinal plants in the study area were agricultural land expansion followed by deforestation and drought (Table 4).

Table 4. Ranking threats to veterinary medicinal plants in the study area (2020-2021).

Respondents (R1-R6)								
Factors	R1	R2	R3	R4	R5	R6	Total	Rank
Agricultural expansion	5	5	5	5	5	4	29	1 st
Deforestation	4	5	5	4	5	4	27	2 nd
Drought	5	4	3	4	5	4	25	3 rd
Overharvesting	3	4	3	4	4	4	22	4 th
Overgrazing	5	2	3	3	4	2	19	5 th

NB: The highest number (5) was given for the most effective medicinal plant and the lowest number (1)

Medicinal plant conservation practices in the study area

The uses of medicinal plants were widespread to treat animal health problems in the study area. However, the medicinal plant conservation practices and awareness of the community were very low. Only 10% of

the respondents were cultivating medicinal plants in their vicinity. The rest 90% of the community was unaware of the conservation practices of medicinal plants and completely relied on wild sources. There was no significant difference between the sex of respondents and medicinal plant conservation practices ($\chi^2 = 0.0097, p = 0.922$) (Table 5). Female informants (10.35%) conserved more medicinal plants than male informants (9.9%), although the difference was not statistically significant. Similarly, there was no significant association between the age of respondents, and conservation of medicinal plants in the study area ($\chi^2 = 1.82, p = 0.402$). However, the awareness was high in young age groups (20-40 years) which was 13.2%. Moreover, the educational status of the respondents had no significant association with medicinal plant conservation practices ($\chi^2 = 0.079, p = 0.999$).

Dependency on medicinal plants found in the wild ecosystem, presence of long dry season in the area, unsustainable harvesting, and climate change poses a significant threat to medicinal plants found in the area. In addition, the knowledge of the community on medicinal plant did not contribute to the conservation efforts.

Table 5. Statistical test of significance using chi square(χ^2) test on the factors influencing medicinal plant conservation practices in the Study Area (2020-2021).

Variable	Categories	χ^2	df	P-value
Sex	Male	0.0097	1	0.9217
	Female			
Age group	20-40	1.8248	2	0.4016
	41-60			
	≥ 61			
Educational status	Illiterate	1.8248	2	0.4016
	Basic			
	Primary			
	Secondary			
	College & University			

DISCUSSIONS

Medicinal plants were widely used to treat livestock ailments in the study area. Similarly, Asfaw et al. (2022) reported that in Ensaro district, North Shewa Zone, Ethiopia, people relied on medicinal plants to treat animal ailments. Moreover, it supports the findings of Abebe and Ayehu (1993) conducted in northern Ethiopia, which reported that more than 90% of the livestock ailments in Ethiopia were treated by herbal remedies rather than modern medications. In the present study, men are more knowledgeable than women in terms of the number of medicinal plants reported even if the difference was not significant. Most of the medicinal plants used to treat animal health problems in the study area belong to the family Solanaceae, Asteraceae, Polygonaceae, Lamiaceae, and Acanthaceae. This is due to their wider distribution in the flora area and the presence of potential bioactive compounds in medicinal plants belonging to these families. Miller and Ruiz-Larrea (2002) showed that the family Asteraceae, Lamiaceae, and Solanaceae were widely distributed and known to have medicinal properties worldwide, due to rich essential oil and secondary metabolites. This is also in line with the works of Hassen et al. (2022) and Asfaw et al. (2022), who reported that Solanaceae, Asteraceae, Euphorbiaceae, and Lamiaceae accounted for the largest share of the reported ethnoveterinary medicinal plant families in Eastern Ethiopia, and Ensaro district, North Shewa zone respectively.

Shrubs were the dominant growth form used in animal remedy formulations which were mostly obtained from wild environments. This may be due to the accessibility of shrubs than herbs, and the presence of curative compounds compared to other growth forms in the study area. The results of this finding in line with the work of Asfaw et al. (2022) who reported that shrubs were the dominant growth form used in remedy preparation to treat animal diseases treatments followed by herbs, trees, and climbers in the Ensaro district. In contrast, Hassen et al. (2022) and Oda et al. (2024) reported that people are heavily reliant on herbs for animal disease treatment in northeastern Ethiopia and the Dugda district of Central Rift Valley, Ethiopia respectively.

Leaves were the dominant plant habits used for remedy formulation followed by roots, and seeds. Crushing and pounding are also commonly used methods of remedy preparation, and water is also used as a solvent to extract the active ingredient from pounded plant materials, and promote the effective delivery of remedy (Gazzaneo et al., 2005). The studies by Asfaw et al.(2022) and Oda et al.(2024) also reported that leaves were the dominant growth form used in remedy preparation and poundings are also the dominant methods of remedy preparation. Leaves are commonly used for remedy preparations due to their easy accessibility, quick processing, and high healing potential. In contrast, roots were the most frequently used plant parts, although their collection poses a threat to the survival of the mother plants (Moges and Moges, 2020).

Most of the medicinal plant remedies were prepared in fresh form. This is due to the high concentration of bioactive compounds essential for effective treatments which are volatile and lost during drying. Lulekal et al.(2014) and Eshetu et al. (2015) also reported that medicinal plant remedies are prepared in fresh form in Ankober District, North Shewa Zone, Amhara region, Ethiopia, and selected districts of Southern Ethiopia respectively. Remedy preparation was done through pounding, crushing, squeezing, and pasting, which is in agreement with the prior findings (Eshetu et al., 2015; Kidane et al., 2018).

Oral routes were the major routes of remedy administration for animal health problems followed by dermal routes and hangs on necks. It is believed that oral administration is easy to deliver and resulted in a speedy recovery of animals. Similar findings were reported by Odat et al. (2024) and Asfaw et al. (2022).

Preference ranking was made for medicinal plants used to treat evil eye diseases which are the most frequently reported disease in the district. This showed people's preference in the selection of medicinal plants to treat livestock ailments. Among those medicinal plants, *Allium sativum* was the most preferred plant used to treat evil eye diseases of animals followed by *Artimisia abyssinica* and *Carissa spinarum*. In contrast, Behailu et al. (2021) reported that *Carrisa spinarum* is the most preferred medicinal plant used

in the treatment of evil eye diseases in the Gura Damolle district, Bale Zone, Oromia region, South East Ethiopia.

The informant consensus factor indicated people's agreement with the use of medicinal plants in the treatment of a particular ailment category. From the medicinal plants *Allium sativum* and *Datura stramonium* showed high informant census factors in the treatment of gastrointestinal and dermatological disorders respectively. Plants having high ICF value are thought to have more biologically active secondary metabolites compared to plants having less ICF. Similar findings were reported by Asfaw et al.(2022) in the Ensaro district, North Shewa zone, Amhara region, Ethiopia.

The results of direct matrix ranking showed that land clearance for agricultural land expansion was the major threat to medicinal plants, followed by deforestation, drought, and unsustainable harvesting practices. This is in line with the works of Temam and Dillo (2016), Odat et al.(2021), and Asfaw et al. (2022) which showed that deforestation and different activities are the major problems faced by medicinal plants. The conservation practices of medicinal plants were poor in the study area. Most of the communities use medicinal plants directly from the wild which affects the sustainability of medicinal plant biodiversity in the long run in the area.

CONCLUSION

The current study disclosed that a total of 25 ethnoveterinary medicinal plants were used to treat 18 animal diseases in 38 preparations. Evil eyes, coccidiosis, diarrhea, leeches, parasitic, stomachache, bloating, black leg, skin disease, and eye diseases were commonly occurring animal health problems treated by using medicinal plant remedies. This indicated the local community's dependence on medicinal plants to manage animal health problems. In the study area, there were significant differences in the knowledge of medicinal plants between age groups and educational status of respondents but not between men and women, and general and key informants, even if there is a difference in the number of medicinal plants reported. The value of preference ranking and informant consensus factor is useful for future antimicrobial

and phytochemical studies whereas direct matrix ranking values call for the conservation attention of ethnoveterinary medicinal plants. Conservation efforts are needed to protect the medicinal plant species and to ensure their sustainable utilization.

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Appendix 1. Medicinal plants used to treat animal health problems in the Moretna Jiru district (2020-2021).

Botanical name	Family Name	Local name	Habitat	Habit	DT	LN	PU	MRP	RA	VN
<i>Allium sativum</i> L.	Alliaceae	Nechishinkurt	Home garden	Herb	Evil eye	Ayneweg	Bulb	The bulb of <i>Allium sativum</i> with roots of <i>Cucumis ficifolius</i> , <i>Datura stramonium</i> , and <i>Capparis tomentosa</i> are pounded, dried, and put on fire and the smoke is inhaled.	Oral & Nasal	MJ21
<i>Allium sativum</i> L.	Alliaceae	Nechishinkurt	Home garden	Herb	Cocicodioides	Yehod kurtet	Bulb	Fresh bulb crushed and mixed with powdered seed of <i>Lepidium sativum</i> and water and given to the animal.	Oral	
<i>Aloe trigonantha</i> Leach.	Aloaceae	Eret	Wild	Herb	Diarrhea	Tekmat	Latex	Eating of the (latex) of the leaf.	Oral	MJ09
<i>Artemisia abyssinica</i> Sch.Bip	Asteraceae	Chigugn	Wild	Herb	Evil eye	Ayneweg	Leaf	Leaf of <i>Artemisia abyssinica</i> with the root of <i>Cucumis ficifolus</i> and <i>Datura stramonium</i> are pounded and tied with a piece of cloth around the neck.	Neck	MJ13
<i>Asparagus africanus</i>	Asparagaceae	Serity	Wild	Shrub	Bleeding	Medmat	Leaf	The leaf is crushed and tied on the bleeding parts of the livestock	Dermal	MJ06
<i>Asparagus africanus</i>	Asparagaceae	Serity	Wild	Shrub	Anthrax	Aba senga	Root	Fresh root is crushed mixed with water and given to livestock to drink.	Oral	
<i>Brassica nigra</i> (L)Koch.	Brassicaceae	Senafich	Home garden	Herb	Stomach ache	Yehod himem	Seed	The leaf of <i>Artemisia abyssinica</i> with the root of <i>Cucumis ficifolus</i> and <i>Datura stramonium</i> are pounded and tied with a piece of cloth around the neck.	Neck	MJ15
<i>Brassica nigra</i> (L)Koch.	Brassicaceae	Senafich	Home garden	Herb	Bloating	Ye hod menefat	Seed	The seeds are pounded, homogenized water to make a drink.	Oral	

<i>Brassica nigra</i> (L.)Koch.	Brassicaceae	Senafich	Home garden	Herb	Parasites		Seed	The seeds are pounded, homogenized with water, and eaten with Injera.	Oral	
<i>Buddleja polystachya</i> Fresen	Loganiaceae	Anfar	Wild	Tree	Leech	Alqt	Leaf	The leaf is pounded and squeezed with water and the juice was given to the animal.	Oral	MJ17
<i>Buddleja polystachya</i> Fresen	Loganiaceae	Anfar	Wild	Tree	Eye disease	Ye ayn hmen	leaf	Fresh leaf is squeezed and the juice added to the diseased eye	Ocular	
<i>Carissa spinarum</i> L.	Apocynaceae	Agam	Wild	Shrub	Evil eye	Ayneweg	Root	Dried root of <i>Carissa spinarum</i> with a leaf of <i>Ruta chalepensis</i> , and <i>Caparris tomentosa</i> are pounded, and put on fire and the animal is made to inhale the smoke.	Oral & Nasal	MJ23
<i>Calpurina aurea</i> (Alt.). Benth	Fabaceae	Digita	Wild	Shrub	Diarrhea	Tekmat	Seed	A drink is prepared from the roasted and pound seeds mixed with water.	Oral	MJ08
<i>Calpurina aurea</i> (Alt.). Benth	Fabaceae	Digita	Wild	Shrub	Evil eye	Ayneweg	Leaf	The leaf is crushed, squeezed, and dropped on the diseased animal's eye	Ocular	MJ10
<i>Calpurina aurea</i> (Alt.). Benth	Fabaceae	Digita	Wild	Shrub	Ectoparasite	Mezhger	Leaf	The affected animal's body part is washed with a mixture of crushed fresh and water	Dermal	
<i>Cucumis ficifolius</i> A.Rich.	Cucurbitaceae	Yemidir embuay	Wild	Herb	Evil eye	Ayneweg	Root	The root of <i>Cucumis ficifolius</i> with the leaf of <i>Artemisia abyssinica</i> is pounded and tied with a piece of cloth on the neck.	Neck	MJ03
<i>Cyphostema cyphopetalum</i> (Fresen.)	Vitaceae	Gindosh	Wild	Climber	Rabies	Yebd wusha beshta	Leaf	A drink is prepared with crushed fresh leaf mixed with water	Oral	MJ12
<i>Datura stramonium</i> L	Solanaceae	Astefaris	Home garden	Herb	Swelling	Ebtet	Seed	The seed of <i>Datura stramonium</i> with the leaf of <i>Clematis simensis</i> is powdered, mixed with goat urea, bolus by cotton, and pasted on the injured part.	Dermal	MJ25

<i>Datura stramonium</i> L	Solanaceae	Astefaris	Home garden	Herb	Evil eye	Ayneweg	Root	The root of <i>Datura stramonium</i> with root of <i>Cucumis ficifolus</i> , and leaf of <i>Artemisia abyssinica</i> are pounded and tied.	Neck	
<i>Echinops longisetus</i> A. Rich.	Asteraceae	Kosheshilae	Wild	Shrub	Skin disease	Yeqoda beshta	Leaf	Fresh leave of is crushed and rubbed on the bodies of animals	Dermal	MJO7
<i>Echinops longisetus</i> A. Rich.	Asteraceae	Kosheshilae	Wild	Shrub	Acute illness	Dingetegna	Root	Crushed the root together with the bulb of <i>Allium sativum</i> , mix with water and given to the animal.	Oral	
<i>Epilobium stereophyllum</i> Fresen	Onagraceae	Wendadm	Wild	Shrub	Lumpy disease	Fentata	Leaf	Ponded the dry leaf, mix with oil and apply it on the wound of livestock.	Dermal	MJ11
<i>Ficus vasta</i> Forssk.	Moraceae	Warka	Wild	Tree	Eye disease	Ye ayn hmen	Bark	The bark is crushed, powdered, and administered to the eye.	Ocular	MJ19
<i>Justicia schimperiana</i> (Hochst.exNees) T. Anders.	Acanthaceae	Sensel	Wild & Home garden	Shrub	Abdominal pain	Yehod hmen	Leaf	Fresh leaf is crushed with the leaf of <i>Rumex nervosus</i> , mixed with water and given to the animal	Oral	MJ24
<i>Justicia schimperiana</i> (Hochst.exNees) T. Anders.	Acanthaceae	Sensel	Wild & Home garden	Shrub	Rabies	Yebd wusha beshta	Leaf	Fresh leaf is squeezed and the juice is given to animals in the morning before food.	Oral	
<i>Lepidium sativum</i> L.	Brassicaceae	Feto	Home garden	Herb	Coccidiosis's	Yehod kurtet	Seed	A drink is prepared from powdered seeds, mixed with a pounded bulb of <i>Allium sativum</i> and water.	Oral	MJ14
<i>Lycopersicon esculentum</i> Mill.	Solanaceae	Timatim	Home garden	Herb	Leech	Alqt	Leaf	Fresh leaves are crushed, mixed with water and given to animals	Oral	MJ05
<i>Nicotiana tabacum</i> L.	Solanaceae	Timbaho	Home garden	Shrub	Leech	Alqt	Leaf	The leaf is pounded, squeezed and the juice is dropped through the left nose of the animals	Nasal	MJ02
<i>Otostegia integrifolia</i> Bent	Lamiaceae	Tinjut	Wild	Shrub	Bloating	Yehod menefat	Leaf	The leaf is squeezed and the juice is given to the diseased animals.	Oral	MJ04

<i>Otostegia integrifolia</i> Bent	Lamiaceae	Tinjut	Wild	Shrub	Evil eye	Yeayn himen	Root	The roots are pounded, tied with a piece of and tied the neck.	Neck	
<i>Ricinus communis</i> L.	Euphorbiaceae	Gulo	Wild & Home garden	Shrub	Anthrax	Aba senga	Fruit	Dried fruit is powdered, mixed with water given to animals	Oral	MJ22
<i>Ricinus communis</i> L.	Euphorbiaceae	Gulo	Wild & Home garden	Shrub	Bloating	Yehod menefst	Root	The root is pounded, mixed with water and salt and given to the animal	Oral	
<i>Rumex nepalensis</i> Spreng.	Polygonaceae	Tult	Wild	Herb	Anthrax	Abasenga	Root	The root is crushed mixed with water and given to diseased animal	Oral	MJ01
<i>Rumex nervosus</i> Vahl.	Polygonaceae	Embuacho	Wild	Shrub	Leech	Alkt	Leaf	The leaf is crushed, squeezed, and the juice is given to animals	Oral	MJ16
<i>Solanecio gigas</i> (Vatke)	Asteraceae	Yeshokokgom en	Wild & Home garden	Shrub	Blackleg	Abagorba	Leaf	The fresh leaf is crushed, mixed with water, and give the drink to diseased animals	Oral	MJ20
<i>Solanecio gigas</i> (Vatke)	Asteraceae	Yeshokokgom en	Wild & Home garden	Shrub	Ectoparasite	Mezhger	Leaf	The leaf is crushed and used to wash the hair of the calf to remove or kill lice	Dermal	
<i>Verbaticum sinaiticum</i> . Benth	Scrophulariaceae	Yahyajoro	Wild	Herb	Blackleg	Abagorba	Root	Crushed leaf is mixed with water and given to animals	Oral	MJ18
<i>Withania somnifera</i> (L.) DunalinDC	Solanaceae	Gizawa	Wild	Shrub	Evil eye	Yeayn himem	Root	The root is tied with a piece of cloth on the neck of diseased animals.	Neck	MJ26

Note: HT= Medicinal plant habit; DT= Disease treated; LN: Local name; PU= Medicinal plant parts used; MRP= medicinal plant remedy preparation; VN= Voucher number.

THE SILENT GLOBAL CRISIS: HOW CLIMATE CHANGE THREATENS WILD VERTEBRATE TAXA

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ABSTRACT: Climate change poses a significant environmental challenge and has widespread impacts on human and natural ecosystems. Vertebrates, especially birds and amphibians, are crucial indicators and components of these ecosystems. However, they are being adversely affected by rapid climate changes, putting them at high risk of extinction. This paper examines the impact of climate change on various vertebrate taxa, focusing on mammals, birds, and herpetofauna. It highlights the specific vulnerabilities of these taxa to climatic stressors and the potential consequences for their survival and distribution. Additionally, it evaluates the implications of these impacts for conservation efforts and offers insights to inform the development of effective management plans and mitigation strategies. By synthesizing the latest research and findings, the paper aims to facilitate a deeper understanding of the complex interplay between climate change and vertebrate species. It emphasizes the urgency of addressing these challenges and underscores the importance of developing proactive, science-based conservation approaches to safeguard vulnerable vertebrate populations and maintain biodiversity in the face of a rapidly changing climate.

Keywords: Climate change, Conservation, Vertebrates, Wildlife

INTRODUCTION

Climate refers to the long-term composition of weather conditions, which are the cumulative effects of an organism's environment in terms of temperature, precipitation, and other factors (Mckelvey and Buotte, 2018). According to Hussein (2011), climate change is defined as any alteration in climate patterns over time, whether caused by natural variability or human activities. The issue of climate change presents a significant environmental challenge that has the potential to hinder sustainable development efforts (IPCC, 2021). It extensively impacts both human and natural systems (Shivanna, 2022). From 1880 to 2012, the average global temperature, combining land and ocean surfaces, has exhibited a warming trend of 0.85°C

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(ranging from 0.65 to 1.06°C) (Xie et al., 2016). The World Meteorological Organization reported that the trend of warming has continued since 1980, with the decade of 2001-2010 being the warmest on record (WMO, 2014). The rate of warming over the past 50 years ($0.13^{\circ}\text{C} \pm 0.03^{\circ}\text{C}$ per decade) is almost double that of the preceding 50 years, and it is projected that by 2100, global temperatures will likely deviate by 5-12 standard deviations from the Holocene mean (Marcot, 2013).

Over the past century, the mean sea level has already increased by approximately 0.19 meters, and projections indicate that the rate of rise will accelerate further in the 21st century (Xie et al., 2016). Different studies have indicated that the emission of greenhouse gases caused by human activities, known as anthropogenic emissions, has reached unprecedented levels and is the primary driver of global warming (Xie et al., 2016; IPCC, 2021; Shivanna, 2022). One of the significant consequences of this warming trend is the rise in mean sea level.

Furthermore, average annual temperatures have been steadily increasing in recent decades, and future predictions suggest an even more substantial temperature rise (IPCC, 2021). This effect is particularly pronounced in Africa due to its geographical location straddling the equator, which generally results in hot climatic conditions (Serdeczny et al., 2017; Dosio et al., 2018; Djalante, 2019). In line with this, Shepard (2019) also stated that temperature rises in Africa near the equator are expected to exceed the global average, resulting in more frequent hot nights and longer heat waves. Climate models currently indicate that the mean temperature across the continent may rise by 3-4 °C by the end of this century, which is about 1.5 times higher than the projected global average increase (Seppälä et al., 2009). These projections highlight the severity of climate change impacts on Africa's climate system and the urgent need for mitigation and adaptation measures to address the associated challenges.

The effects of climate change are evident through various indicators, including rising air and ocean temperatures, shifts in the frequency and intensity of hurricanes, and the occurrence of other extreme climate events (IPCC, 2021). These phenomena have been extensively documented for their impacts on living

organisms (Rosenstock et al., 2015). These changes in temperature and weather patterns, as discussed earlier, contribute to the overall trend of global warming and have significant implications for the environmental protection and biodiversity conservation.

Climate change is causing a global extinction crisis and its impact on wildlife exist at local, regional, and global scales (Cahill et al., 2012). This is an unprecedented incident in the history of our planet, and this crisis is expected to worsen as the climate continues to change. It is anticipated that climate change will become one of the primary drivers of species extinction in the 21st century, mainly due to alterations in breeding times and shifts in species distributions caused by changes in temperature and precipitation patterns (Sonwa et al., 2017; Warren et al., 2018). Due to global warming, approximately 20-30 percent of vascular plant and larger animal species are at risk of extinction (Hussein, 2011).

Furthermore, a significant proportion of endemic species may face extinction by 2050 as a consequence of climate change (Cahill et al., 2012). The analysis by Vié et al. (2008) suggested that certain taxa are more vulnerable than others, with approximately 35 percent of bird species and 52 percent of amphibian species at risk of becoming endangered due to increasing climate change impacts. The same study indicated species that are already at risk of extinction are expected to face more severe consequences. For instance, 70-80 percent of red-listed birds, amphibians, and corals are considered susceptible to the effects of climate change.

Even modest losses in biodiversity are likely to result in significant changes in ecosystem services (Seppälä et al., 2009). It has been projected that a doubling of atmospheric CO₂ levels could potentially destroy or fundamentally alter 35 percent of the existing land habitats worldwide (WWF, 2015). However, the extent to which wild animals in the world can adapt or successfully migrate in response to changing climates remains poorly understood. This information is crucial for current and future conservation planning. In light of the consensus that climate change is occurring, scientists have extensively documented various findings

regarding its impact on biodiversity, as well as its variability and changes. The review provides an overview of the implications of a changing climate on vertebrate taxa.

METHOD

More than 150 documents were systematically collected from various published and unpublished sources, including keyword searches on platforms such as Google Scholar and Web of Science on the impact of climate change on animals. The review focused on different vertebrate taxa, which includes mammals, birds, reptiles, and amphibians. The selection approach included using established inclusion criteria to guarantee that all articles addressed the effects of climate change on these vertebrate taxa. Each point was summarized thoroughly, with a focus on the ecological and physiological responses, and reproduction effects of climate change. During the screening, papers were removed from the review process if they did not specifically address wild animals. Following the collection of manuscripts, a thorough examination of the data was conducted. This entailed compiling data on how climate change affects numerous aspects of vertebrate life, including habitat alterations, reproductive habits, and population dynamics. The synthesized data was then structured to create this thorough review article, which provides a clear and objective assessment of the existing effects of climate change implications on different vertebrate taxa.

1. The effect of climate change on vertebrate taxa

Climate change has discernible and significant effects on various vertebrate taxa, including herpetofauna (amphibians and reptiles), birds, and mammals, both in temperate and tropical regions. One of the most notable impacts of climate change is the alteration of the natural distribution boundaries of plant and animal communities. This shift in distribution is accompanied by changes in the timing of crucial biological events such as flowering, fruiting, and breeding. Additionally, climate change influences community composition, ecological interactions, community dynamics, as well as ecosystem function and services (Kannan and James, 2009).

Many species have evolved over extended periods to adapt to specific climatic conditions and variations (Warren et al., 2018). An experiment by Weyrich et al (2016) which allowed five males to mate with females in an enclosure at a normal temperature of below 5 °C, and then again with other females after spending two months at 30 °C resulted in changes in some genes associated with body temperature. The offspring also exhibited distinct epigenetic modifications, showing that they passed on a different set of changes to their offspring to assist them prepare for their surroundings. But it is not known if every animal can respond in this way as the rapid pace of climate change poses challenges for species to respond and adapt effectively, leading to increased vulnerability and, in some cases, extinction (Weiwei et al., 2012).

1.1 Impacts of climate change on Mammals

Mammals that are particularly vulnerable to the impacts of climate change are those that are not adapted to underground living (fossorial) and have experienced significant temperature changes over the past 60 years (Hetem et al., 2014). Additionally, mammals with low precipitation seasonality within their distribution ranges are at higher risk (Wells et al., 2022). According to the study by Yusefi et al (2021), in areas where there is reduced precipitation and/or temperature fluctuations, plant species may likely have narrower climatic tolerances, resulting in vegetation changes that can lead to habitat loss for the animals inhabiting those areas. This study also found that mammals with a more specialized diet are also associated with a greater probability of experiencing negative responses to climate change suggesting that species with specific dietary requirements may face challenges in finding suitable food sources as climate conditions change. These factors combined contribute to the vulnerability of certain mammal species to the impacts of climate change.

It is important to note that the specific impacts on mammal populations can vary depending on the region, species, and their ecological characteristics. Nonetheless, understanding these patterns and identifying the most vulnerable mammal species can help to design conservation strategies and prioritize efforts to mitigate the effects of climate change on mammalian biodiversity (Yusefi et al., 2021).

1.1.1 Effects in population, body mass and size

The increasing global temperature associated with climate change has been linked to a decrease in body size and/or mass in larger mammals (Martin et al., 2018). This study found a strong inverse correlation between rising global temperatures and the body size of Bison (*Bison bison*) over the past 40,000 years which may be attributed to the impact of increasing temperatures on both metabolic demands and the availability of resources. The study by Yom-Tov (2001) provided evidence that certain mammal and bird species experience reductions in body size and mass due to the influence of climate change-induced temperature increases.

Climate and environmental changes can have an impact on the timing, quality, and quantity of resources available, affecting how rapidly individuals can obtain these resources for growth and energy storage, eventually determining body size (Ozgul et al., 2009; Husby et al., 2011). For example, climate change has been seen to cause body size reductions in giant ungulates (*Mammuthus primigenius*), such as during the Pleistocene, potentially leading to the extinction of some species (Guthrie, 2003). As indicated in WWF (2015), by the year 2080, it is projected that there will be an expansion of arid and semiarid land by 5 to 8 percent, along with increased frequency and intensity of drought periods in certain regions of Africa. These changes in climate can lead to significant shifts in vegetation, favoring deciduous trees and heat-resistant grasses over evergreen trees resulting in loss of habitat to large mammals, particularly the African elephant (*Loxodonta africana*).

A study conducted by Mckelvey and Buotte (2018), found that climate change has already hurt at least one population of 414 threatened mammal species out of a total of 873 (47%). This suggests that these species are highly susceptible to the adverse effects of climate change, and populations in affected areas are likely to experience negative impacts.

These findings highlight the urgent need for conservation efforts to mitigate the impacts of climate change on vulnerable mammal species. Protecting and restoring habitats, implementing adaptive management strategies, and addressing the underlying causes of climate change are crucial steps in ensuring the survival and well-being of these threatened species.

1.2 Impacts on birds

Birds serve as valuable indicators of climate change due to their high sensitivity to shifts in climate and weather patterns (Wormworth and Mallon, 2006). The impacts of global warming on birds are often indirect and can be attributed to factors such as sea-level rise, changes in fire regimes, alterations in vegetation composition, and land use changes (Janice and Mallon, 2010).

Climate change had a negative impact on 298 threatened bird species out of 1,272 (23.4%) (Mckelvey and Buotte, 2018). Species that have experienced significant temperature changes over the past 60 years, they inhabit high-altitude regions, exhibit low-temperature seasonality within their distributions and they tend to show negative responses in both breeding and non-breeding areas (Janice and Mallon, 2010) Negative impacts are also associated with breeding areas that have recorded high maximum temperatures, limited dispersal distances, longer generation lengths, reduced precipitation seasonality, and restricted altitudinal ranges in non-breeding distributions (Janice and Mallon, 2010)

Bird populations residing at high altitudes and colder environments face challenges in adapting to increasing temperatures, as they have limited opportunities to migrate to cooler areas or move upslope (Pounds et al., 1999). Consequently, these populations may be at an elevated risk of extinction. However, modest shifts to higher or lower altitudes can provide some adaptive flexibility, as even slight changes in altitude can lead to significant variations in ambient temperature (IPCC, 2014).

Temperature plays a crucial role in determining the timing of important breeding events in birds, such as laying dates. Higher temperatures can induce earlier laying, which can disrupt the synchronization between the timing of chick-feeding and peak food availability for birds residing in these environments (Reaser et al., 2000). This disruption can have significant consequences for the survival and reproductive success of bird populations.

1.2.1 Effects on bird populations

Numerous studies have established a clear connection between climate change and the decline in bird populations and breeding success worldwide (Markham, 1998; Lemoine et al., 2007; Li et al., 2022; Lakhnarayan et al., 2024). The impacts on certain bird groups can be particularly severe. A notable example is the California arid-land birds, which experienced an alarming 97 percent decline in breeding during an unprecedented drought in 2002, highlighting the disproportionately destructive effect of climate extremes on avian species (Bolger et al., 2005).

Birds inhabiting islands and seabirds are highly susceptible to the consequences of climate change as well. The Galápagos penguin (*Spheniscus mendiculus*), an endangered species, has witnessed a significant population decline, with numbers decreasing by half since the early 1970s. Severe El Niño events lead to adult penguins becoming emaciated and failing to reproduce, resulting in population decline (Boersma, 1998). As climate models project an increase in the frequency of El Niño events in the future (Timmerman et al., 1999), climate change is expected to further diminish these already small and geographically restricted populations of Galápagos penguins, pushing them closer to the brink of extinction (Boersma, 1998).

Climate change poses serious challenges to migrating birds throughout their annual cycles in many places (Silllett et al., 2000) with significant impact on both the number and behavior of migratory species (Jetz et al., 2007). Eighty four percent of migratory bird species face some type of climate-related vulnerability, outweighing all other human-caused threats (DEFRA, 2005). For example, the Arctic-breeding red-breasted goose (*Branta ruficollis*), already classified as globally vulnerable, is projected to lose 99% of its tundra breeding habitat due to climate change (DEFRA, 2005). Similarly, the Baikal teal (*Sibirionetta formosa*), a water bird that breeds in northeast Siberia and winters in South Korea, Japan, and China, has seen its population decline to an estimated 50,000 by 1990, leading to its classification as vulnerable (van Vliet and Leemans, 2006). This species, which nests exclusively in marshes, faces heightened risks from climate change. Another example is the golden bowerbird (*Prionodura newtoniana*), found in northeastern

Australia's Wet Tropics, and it is highly threatened due to climate change (Noble et al., 2005; van Vliet and Leemans, 2006).

These examples underscore the vulnerability of bird populations to the impacts of climate change and highlight the urgent need for conservation measures to mitigate these effects. Safeguarding and restoring habitats, implementing adaptive management strategies, and addressing the root causes of climate change are pivotal in ensuring the survival and well-being of bird species facing these challenges. Continued monitoring, research, and international collaboration are also essential to effectively address the impacts of climate change on bird populations and work towards their conservation and long-term viability.

1.2.2 Effect on bird reproduction

Climate change has had a severe impact on the breeding activity of birds, with warmer temperatures, habitat alterations, and changes in climatic patterns influencing their reproductive strategies (Janice and Mallon, 2010). Tropical bird species, in particular, may shift their breeding periods in response to changes in temperature and rainfall patterns. This can result in earlier breeding initiation or reduced reproductive rates, leading to population declines (Şekercioğlu et al., 2012). Cameroon is among the countries with examples of tropical birds changing their breeding patterns as a result of climatic changes. For example, the little greenbul (*Andropadus virens*) and the African thrush (*Turdus pelios*), have begun nesting in the highlands during the dry season rather than the wet season (Tye, 1992). This demonstrates the types of changes that may occur as a result of climate change. In line with this, the white-throated thrush (*Turdus assimilis*), breed during the wet season when food is abundant (Corlett and LaFrankie, 1998). However, climate change leads to longer and less predictable dry seasons and droughts which can interrupt bird migrations and breeding success, resulting in mistimed life events and potential population declines (Williams and Middleton, 2008; Sekercioğlu, 2010).

The indirect effects of temperature and humidity changes also influence bird behavior and activity. Unfavorable climate conditions can lead to the abandonment of habitats, disrupting crucial activities such

as feeding and breeding displays. Erratic heavy rainfall during the breeding season in mountainous regions can cause a delay in breeding activity (Şekercioğlu et al., 2012).

Specific bird species, such as the Black Bulbul (*Hypsipetes leucocephalus*) and White-collared Blackbird (*Turdus albocinctus*), experience delays in breeding activities such as habitat selection, nest building, and the laying of eggs. These delays are often attributed to unexpected weather events like prolonged dry spells, altered plant phenology, and changes in insect emergence. Conversely, there is evidence of breeding activity advancement in some species due to cues provided by warming temperatures.

Climate change has been observed to cause reductions in clutch size in certain bird species, such as the Lark Bunting (*Calamospiza melanocorys*) (Skagen and Adams, 2012). Studies have found a strong positive relationship between clutch size and annual precipitation, while average maximum temperatures show a strong negative relationship with clutch size (Skagen and Adams, 2012). Environmental variables, including those influenced by climate change, play a significant role in nest-site selection by birds (Acharya and Chettri, 2012).

Changes in breeding seasonality can have detrimental effects on bird breeding success. The mismatch between the timing of breeding and food availability can disrupt the bird's life history strategies (Both and Visser, 2005). Insufficient food resources during the breeding season can lead to breeding failure as the available food might not be enough to support the physiological and metabolic demands of breeding individuals and hatchlings. Furthermore, early breeders may have to compete for resources and nest sites with species breeding at different times, while migratory species may face competition from resident species for limited resources. Climate-induced changes in breeding timing can result in temporal partitioning of the breeding period and intensify interspecific competition, leading to severe consequences (Acharya and Chettri, 2012).

Changes in water temperature during the breeding season in high-altitude freshwater bodies have also impacted the breeding performance of certain bird species. Alterations in surface water temperatures can

reduce prey availability for aquatic birds. Many bird species have specific critical thresholds for water surface temperature, and when the temperature exceeds this threshold, the lack of prey can result in chick mortality (Şekercioğlu et al., 2012).

While the examples provided offer insights into how climate change affects bird breeding activity, it is essential to acknowledge that species and regions may exhibit varying responses. Therefore, continuous research and monitoring are of utmost importance to gain a deeper understanding of these effects and to formulate appropriate conservation strategies.

1.3 Impacts on herpetofauna

Herpetofauna, which includes amphibians and reptiles, are vertebrates that play a crucial role in ecosystems by connecting terrestrial habitats with aquatic ecosystems and higher vertebrates with lower vertebrates (Bickford et al., 2010; Bickford et al., 2018). Despite their ecological diversity and significant position in trophic dynamics, herpetofauna are often insufficiently considered in ecosystem planning and management (Acharya and Chettri, 2012).

Ectothermic organisms, such as amphibians and reptiles, are particularly vulnerable to the effects of environmental temperatures (Huey et al., 2009). Numerous studies have focused on elucidating the mechanisms behind the decline or disappearance of amphibian and reptile populations (Sinervo et al., 2010; Siddiqui and Imran, 2019).

The distribution and ecology of both amphibians and reptiles are closely governed by rainfall and temperature patterns, making them highly susceptible to the impacts of climate change (Federal et al., 2016; Siqueira et al., 2009). Most ectotherms do not perform optimally at the upper end of their thermal tolerance range but exhibit better performance at lower temperatures, known as the thermal optimum. Climate change can exacerbate the effects of biotic and abiotic factors such as diseases and infections, intense UV radiation, predators, and competition, leading to a global decline in species (Federal et al., 2016; Siqueira et al., 2009).

Recent studies have highlighted the alarming decline in herpetofauna populations worldwide. For example, a survey conducted in North America revealed that over 30% of amphibian species and 20% of reptile species are at risk of extinction (Smith et al., 2014). Similarly, in tropical regions, such as the Amazon rainforest, the loss of amphibian and reptile biodiversity has been accelerating, primarily due to habitat destruction and climate change (García-Navas et al., 2021). These findings emphasize the urgent need for conservation efforts and the integration of herpetofauna into ecosystem management strategies.

1.3.1 Impacts on reptiles

Reptiles rely on obtaining heat from their environment to carry out vital biological processes such as feeding, digestion, and reproduction. They achieve this by directly exposing themselves to sunlight or by coming into contact with surrounding objects. Consequently, any changes in environmental temperature can significantly impact their activity patterns, physiological performance, behavior, distribution, and reproductive capabilities (Sinervo, 2010). Moreover, when considering other ongoing environmental issues such as habitat modification, vegetation loss, and the subsequent reduction in shade, refuge availability, perching sites, and nesting sites, reptiles become particularly vulnerable to local population extinctions due to alterations in their thermic environments.

The degree of vulnerability varies among reptile species and depends on their specific life history characteristics. Factors such as the timing of reproduction, reproductive mode (oviparous or viviparous), habits (diurnal, nocturnal, arboreal, terrestrial, etc.), the types of environments they inhabit, and their sensitivity to temperature play crucial roles in determining their susceptibility to environmental changes (Dayananda et al., 2021).

Recent studies have highlighted the impacts of climate change on reptile populations. For instance, research conducted in a Mediterranean region observed that rising temperatures have led to shifts in reproductive phenology in multiple reptile species, with earlier onset of egg-laying and hatching (García-Navas et al., 2021). Similarly, in tropical regions, such as the Caribbean, rising temperatures have been linked to changes

in the sex ratios of reptiles with temperature-dependent sex determination (TDSD), potentially affecting population dynamics and genetic diversity (Miller et al., 2018). These findings underscore the importance of understanding the specific responses of reptiles to temperature changes and implementing conservation strategies to mitigate the potential negative consequences.

1.3.1.1 Effects of climate change on reproduction and development of reptiles

There exist studies which have emphasized that climate change poses a significant threat to reptile populations (Evans, 2019; Kellogg, 2019; Dayananda et al., 2021), particularly due to its impact on the sex determination of embryos during incubation (Clarke and Zani, 2012). Fluctuations in temperature can lead to biases in the sex ratio of offspring, with increases or decreases in temperature skewing the proportion of the clutch towards one sex (Doody et al., 2004; Clarke and Zani, 2012). Research has shown that nests exposed to higher temperatures exhibit dramatic differences in sex ratios compared to those in shaded sites (Doody et al., 2006).

Temperature plays a critical role in determining the sexes of most reptilian species. For example, the Painted Turtle (*Chrysemys picta*) in the southeastern United States is highly sensitive to even slight variations (≤ 1 °C) in their local thermal environment with a minor increase in temperature resulting in a significant bias towards female production (Girondot et al., 2004). Such skewed sex ratios among adults can have profound consequences, including the possibility of unfertilized egg-laying by females, the loss of annual cohorts of offspring, and an increased risk of population extinction (Lopez-Alcaide and Macip-Rios, 2011). Although females may exhibit behavioral adaptations by selecting cooler nesting sites, this alone may not be sufficient to compensate for recent climate change (Bickford et al., 2018). Consequently, deviations from the normal sex ratio due to global warming can disrupt the population dynamics of reptilian communities.

Furthermore, certain species of reptiles are highly dependent on specific environmental conditions, such as humidity, water availability, or extreme habitats like deserts. These species, in addition to experiencing

thermal fluctuations, can be severely affected by prolonged droughts, further exacerbating the challenges they face (Westphal et al., 2016).

Recent research conducted on a population of Green Turtles (*Chelonia mydas*) in a tropical region has shown that rising temperatures can result in a significant imbalance in the sex ratio of hatchlings. Higher average nest temperatures have been associated with an increased production of female offspring, potentially leading to a shortage of males and reduced genetic diversity within the population (Jones et al., 2024). This highlights the vulnerability of reptiles to climate change-induced shifts in sex ratios and the potential long-term consequences for population viability.

1.3.1.2 Effects on migration of species along the elevation gradient

Due to their preference for warmer climate and scaly body, reptiles are less likely to be affected by climate change compared to amphibians. While warmer temperature seems to be beneficial on a short-term basis, its long-term impact is detrimental. As observed in other organisms, one of the significant impacts of climate change on reptiles is the shift in altitudinal and latitudinal limits of species (Bickford et al., 2010). With the increase of temperature, the animals tend to seek refuge towards higher elevation leading to upward migration. There are some examples of such movements. Monocled Cobra (*Naja kaouthia*), shown in Figure 1, is a tropical species and occurs mostly below 1000 meters above sea level (masl); but this species was observed at 1700 masl showing clear evidence of its upward movement. While there are many instances of uphill migration of species due to increased temperature, there are also reports of downhill migration from high to mid-elevation due to various reasons (Bickford et al., 2018). Species sandwiched at mid-elevation from low and high elevation may increase the species richness initially but in long term due to competition, altered community dynamics may result in loss of biodiversity.



Figure 1. *Naja kaouthia*, a species of lower elevation but observed at middle elevation in South Sikkim, India - a case of uphill migration (Source: Acharya and Chettri, 2012).

1.4 Impacts on amphibians

Amphibians are potentially good bio-indicators due to their highly permeable skin and dual mode of life (Beebee, 1995). According to Blaustein et al. (2010), amphibians are likely to be highly sensitive to climate change. They are also very susceptible to environmental variation since they have permeable skin, eggs without shells (not amniotic eggs), and a complex life cycle that exposes them to changes in both the aquatic and terrestrial environment (Tomé, 2011). They are susceptible to changes in temperature and humidity, as well as to exposure to large doses of UV radiation (Blaustein et al., 2010).

Climate change is impacting amphibian populations worldwide (Acharya and Chettri, 2012). Globally, more than 32% of amphibian species are listed as threatened by the International Union for Conservation of Nature (IUCN) and some estimates suggest 122 species have gone extinct since 1980 (Tomé, 2011). The reasons for this global amphibian decline and rise in threatened species are numerous and complex, but for many species climate change cannot be precluded as a main cause (Ficetola et al., 2008). Ryan et al. (2014) showed that climatic warming and resultant wetland desiccation are causing severe declines in amphibian species.

Climate change affects three major physiological functions of amphibians' viz., water balance, thermo-regulation and hormonal regulation of reproduction (Bickford et al., 2018). The permeable nature of the amphibian skin results in high rate of water loss through evaporation thereby disturbing the normal water balance of the body. Moisture availability also influences amphibian behavior. As amphibians are poikilothermic vertebrates, thermo-regulation has manifold effect on amphibian body physiology such as digestion, oxygen uptake, vocalization, emergence from hibernation, development, metamorphosis and growth (Bickford et al., 2018). Most of these processes are complex and they have cascading effect on various other body functions. In addition, most amphibians are able to carry out their activities at suboptimal temperature and unable to survive at near critical maximal temperature (Bickford et al., 2018).

1.4.1 Effects on habitat of Amphibians

Habitat loss and degradation are by far the greatest threat of amphibians, affecting 63% of all species (Pacifci et al., 2017). Climatic warming and resultant wetland desiccation are causing severe declines in amphibian species. Climate monitoring over six decades in Yellow Stone National Park, USA indicated that the landscape and the local biological communities have significantly altered. Due to this reason, amphibians have declined significantly (Blaustein et al., 2010; McMenamin et al., 2008). Precipitation, humidity, and soil moisture can influence water availability for amphibians, and can therefore influence survival and behavior. Changes in temperature and precipitation will influence the physiology, behavior, and ecology of many amphibian species (Blaustein et al., 2010; Xie et al., 2016).

1.4.2 Effects of climate change on amphibian reproduction and development

Jorgensen (1992) showed that the increase of temperature and thermal variation are the basic signal for emergence and reproduction in anurans. Reproductive cycles in amphibians are controlled by gonadotropin releasing hormone released from the hypothalamus which influences the activity of gonads (Beebee, 1995). While reproduction in amphibians is affected by many factors, rainfall seems to be the most significant especially for tropical species (Bickford et al., 2010). Amphibians prepare for breeding after the onset of

rainfall. Onset of rainfall provides environmental cue to the hypothalamus which then prepares for breeding. Due to unusual rainfall event or early summer rain, some amphibians start breeding earlier than their actual breeding time. The short and heavy episode of early rain followed by dry spells leads to drying of many streams before amphibians complete their metamorphosis. Such irregular rainfall pattern poses serious threat to both eggs and larva; either they face the risk of being washed away by heavy rains or face desiccation before the completion of metamorphosis leading to mass mortality. Advancement in breeding season in amphibians has been reported from many other regions (Bickford et al., 2010; Bickford et al., 2018). Breeding of amphibians in temperate zone has also been affected due to climate change (Beebee, 1995).

1.4.3 Effects of climate change on amphibian movement

Raxworthy et al. (2008) found an average of 19-51 m uphill movement of 30 species of herpetofauna in Madagascar over a period of one decade due to climate change. Many amphibians across the globe have shifted their range towards higher elevation due to climate change (McFall et al., 2001). Duan et al. (2016) showed that, under climate change, amphibians move to higher altitudes. Generalist species can easily adapt to climate change by extending their range upwards. However, specialist in terms of diet, micro-habitat and temperature are unable to adapt to climate change. As the animals of lower elevation moves upward, there is no space for species of higher elevation to move up indicating serious ecological consequences leading to extinctions (D'Amen and Bombi, 2009; D'Amen et al., 2010).

Most amphibian species have narrow elevation width (Acharya and Chettri, 2012), and this reflects their sensitivity towards various environmental factors which changes at a faster rate along the elevation gradient. Endemic and restricted range species are the major victims of climate change (Federal et al., 2016). One of the best examples is the golden toad which disappeared from Costa Rica due to narrow distribution limit (Root et al., 2005). However, species with broad elevation range can expand their ranges and hence become

better colonizers. It is apparent that climate change has relatively more effect on biodiversity of low to mid-elevation compared to higher elevation (Pounds et al., 2006).

1.4.4 Climate change and emerging amphibians' diseases

Amphibians are susceptible to fungi, bacteria and viruses. Mokhatla et al. (2015) and Weinsheimer et al. (2009) reported that infectious diseases have been implicated in numerous population declines. Based on the studies conducted in the past decades, a number of investigators have proposed that emerging infectious diseases may be stimulated by climate change and changes in the levels of UV-B radiation reaching the earth's surface (Blaustein et al., 2010).

Most of the reported amphibian mass mortality events have been associated with the emerging fungal pathogen *Batrachochytrium dendrobatidis* (Bd) and viruses of the family Iridoviridae. Chytridiomycosis, an amphibian disease caused by Bd, plays a major role in amphibian population collapses in both protected and disturbed habitats around the world (Hoffman et al., 2010). It may be also responsible for the most spectacular loss of vertebrate biodiversity due to disease in recorded history (Skerratt et al., 2007). According to the study by Olson (2011), Olson and Saenz (2013) and Xie et al. (2016), Bd is found on every continent where amphibians exist. It infected close to 700 amphibian species globally and is implicated in worldwide amphibian populations' decline (Wake and Vredenburg, 2008). For example, the western toad is a montane amphibian broadly distributed across the western United States. But the toads have declined in some locations, particularly at the southern extent of their range (Corn et al., 2005). One of the reasons is the species suffers from Bd, and a warmer climate may allow Bd to spread to higher elevations and become even more widespread (Mckelvey and Buotte, 2018).

In addition, in the study carried out by Pounds et al. (2006), the high-altitude golden toad of Monteverde, Costa Rica, has extirpated because of Chytrid fungus which extensively proliferated due to increasing temperature because of climate change. Since the temperature is optimum in mid elevation for fungal proliferation, the impact of this disease is experienced mainly in mid elevations. The study carried out by

Gower et al. (2012) in Ethiopia also showed that of the 120 frogs sampled, 51 were positive for Bd and at least one specimen of all sampled genera and all but three putative species were positive for Bd, and only one individual each was sampled for the three species that were Bd negative.

SUMMARY

Climate change has been felt worldwide and its impact is clear on different organisms and ecosystems. The contemporary world displays various signs of climate change's impact on water sources, flora, and fauna. While we have ample examples to prove that many species of animals have responded to climate change but precise responses are not known. Vertebrates especially birds and amphibians are important indicators and components of ecosystems worldwide and are already being negatively affected by contemporary rapid changes in climate. Climate strongly affects the distribution, abundance, and ecology of amphibian species due to the presence of moist skin and biphasic life in nature. Climate changes will have impacts on indicator species that are not uniform across the globe. Climate change is already impacting ecosystems and the habitat of fauna, but enhanced conservation and management of biological resources can mitigate these impacts and contribute to solutions to climate change. To understand and address the climatic effect on fauna in Ethiopia we recommend widespread and long-term monitoring across the country.

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Ethiopian Journal of Biodiversity

Guideline for contributors

1. Types of papers

- **Research papers** - Research papers should not exceed 8000 words in length, including Figures, Tables and References. Moreover, they should not contain more than 10 Figures and/or Tables
- **Review papers** - Critical and comprehensive reviews that provide new insights into or interpretations of the subject through a thorough and systematic evaluation of available evidence that should not exceed 10,000 words including Figures, Tables and References
- **Short communications** - Short communications such as opinions and commentaries should not exceed 1500 words and they must be brief definitive reports which need not be divided into Materials and Methods, Results and Discussions
- **Book Reviews** - Book review which is a critical evaluation of published books in any discipline of biological sciences/biodiversity will be published under this column

2. Manuscript preparation

2.1 Article style and structure

Manuscripts should be written in American English, typed double-spaced, on A4 size, with margins of 1.5 cm on top and bottom sides of the paper, 2 cm on left and 1.5 cm on the right. A font size of 12 points (Times New Roman) should be used throughout the manuscript. The major sections of the manuscript include title, abstract, keywords, introduction, materials and methods, results, discussion, conclusion and recommendation, acknowledgements and references. Those sections having headings and sub-headings should not have more than three levels. All pages and lines should be numbered with the title page being page 1

2.2 Title page

- **Title:** The title should be clear, short and precise and it should not exceed 20 words.
- **Author name and affiliations:** Full name(s) of the author(s) and address (es) including institution(s) in which the research was carried out and affiliation(s) of the author(s) if more than one shall be indicated. Where there is more than one affiliation, match authors and their appropriate affiliations with superscript numbers
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2.3 Manuscript format

- **Abstract:** The abstract of the manuscript should not exceed 250 words. It should give the reader the objectives of the study, how the study is conducted, the main findings and major conclusions. There should be no reference citations and abbreviations
- **Keywords:** Four to six words and/or phrases should be listed in alphabetical orders at the bottom of the abstract
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- **Conclusion and recommendation:** presented in a short form and appears after a discussion section. It highlights the implications of the key findings.
- **Acknowledgements:** appear in a separate paragraph before the reference, and should be as brief as possible. All sources of funding should also be declared.

2.4 References style

EthJBD follows referencing style described below. Unpublished results and personal communications are not recommended on the reference list, but maybe mentioned in the text and indicated in footnotes. Citation of a reference as 'in press' implies that the item has been accepted for publication. Moreover, citation in the text should follow the same referencing style. The citation styles described below is also applicable for Ethiopian Authors' work.

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For books with one author includes the following:

Example: One author AND first edition:

Acquaah, G. 2012. Principles of plant genetics and breeding. Oxford: Wiley-Blackwell.

Example: One author AND NOT the first edition

Dahl, R. 2004. Charlie and the chocolate factory. 6th ed. New York: Knopf.

Books with Two or More Authors:

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Desikan, S. and Ramesh, G. 2006. Software testing. Bangalore, India: Dorling Kindersley.

For Chapters in Edited Books:

Harlan, J. R. 1971. On the origin of barley: a second look. In: R. A. Nilan, ed., Barley Genetics vol. II Proc. 2nd Barley Genetics Symposium. Washington State Univ. Press, Pullman, pp. 45 - 50.

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Brown, D. 1998. Digital fortress. New York: St. Martin's Press.

Brown, D. 2003. Deception point. New York: Atria Books.

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Examples:

Engels, J. M. J. 1994. Genetic diversity in Ethiopia in relation to altitude. *Genetic Resources and Crop Evolution*, **41: 61-73.**

Lemessa, D., Hylander, K. and Hambäck, P. 2013. Composition of crops and land use types in relation to crop raiding pattern at different distances from forests. *Agriculture Ecosystems and Environment*, **167:71-78.**

Mewded, B., Negash, M. and Awas, T. 2020. Woody species composition, structure and environmental determinants in a moist evergreen Afromontane forest, southern Ethiopia. *Journal of Forestry Research*, **31(4): 1173-1186**.

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When citing journal articles found on a database or through a website, including all of the components found in a citation of a print journal, but also include the medium ([online]), the website URL, and the date that the article was accessed.

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Last name, First initial. Year published. Article Title. *Journal*, [online] **Volume (Issue number): page(s)**. Available at: URL [Accessed Day Mo. Year].

Example:

Raina, S. 2015. Establishing Correlation Between Genetics and Nonresponse. *Journal of Postgraduate Medicine*, [online] **61(2):148**. Available at: <http://www.proquest.com/products-services/ProQuest-Research-Library.html> [Accessed 8 Apr. 2015].

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Bejiga, G. and van der Maesen, L.J.G. 2006. *Cicer arietinum* L. [online] PROTA. Available at: [https://uses.plantnet-project.org/en/Cicer_arietinum_\(PROTA\)](https://uses.plantnet-project.org/en/Cicer_arietinum_(PROTA)) [Accessed 1 Mar. 2020].

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Avogel.com, 2015. *A. Vogel plant encyclopaedia*. [online] Available at: <https://www.avogel.com/plant-encyclopaedia/> [Accessed 20 Apr. 2015].

6.2.6 Citation in text

One author: The last name of the author followed by year of publication will be cited in the text.

Example:(Brown, 2005).

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2.7 Tables

Tables should be as editable text and be placed on a separate pages at the end of the manuscript. Number tables consecutively (i.e. Table 1, Table 2, etc.) in accordance with their appearance in the text and avoid vertical lines and shading in the table cells. Table captions should be descriptive and appear above the table. Footnotes and sources to tables should be placed under the table. Larger datasets can be uploaded separately as Supplementary Files

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Figure should be prepared in formats like JPEG, TIFF and JPG, with the resolution of 300 dpi or higher. Captions should be numbered consecutively (Figure 1, Figure 2, etc.) and placed below the figure. Figures from other sources should be used with the permission of the publishers of the articles. Figure citations in the text should always be with capital "F" as follows:

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Manuscripts should be submitted to the EthJBD via e-mail or online submission system in word format (.doc, .docx). The submission should be accompanied by a cover letter stating the novelty of the finding and the manuscript was neither submitted nor published elsewhere

The author(s) should ensure that the entire checklist stated in the guide for authors are present; and these include:

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- A reference section containing all sources cited in the text
- Declaration and conflict of interest statement
- Referee suggestions and their contact details (optional)

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