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Research Article

Urban Green Space Development and Management Challenges in Debre Tabor Town, Ethiopia

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Article Info

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Abstract

The development and management of green spaces is challenging in Ethiopia, as in many other developing countries, resulting in the reduction and destruction of green spaces. This study identifies the primary challenges and factors influencing the development and management of urban green spaces in Debre Tabor Town. Data were collected through household surveys, key informant interviews, and focus group discussions, using descriptive and inferential statistical analyses. The household survey revealed that connectivity (92.9%) and the need for continuous follow-up and maintenance activities (88.2%) are critical challenges in the management of urban green spaces. Additionally, the study highlights how inadequate government policies, weak institutional capacities, political instability, inefficient land use and the absence of clear norms significantly hinder effective green space development, often leading to illegal activities. The socioeconomic status of respondents was found to play a significant role in shaping their perceptions of urban green space benefits. The predictive model indicated that six independent variables—age ($p = 0.000$), educational status ($p = 0.010$), family size ($p = 0.044$), income ($p = 0.027$), access to information ($p = 0.004$), and years of residence ($p = 0.000$) collectively accounted for 49.9% of the variance in residents' perceptions of green space benefits. Conversely, household sex, marital status, and occupation were weakly associated with these perceptions. Overall, the findings underscore the urgent need for enhanced public awareness, strategic policymaking, and efficient land use systems to improve the development and management of urban green spaces in Debre Tabor, thereby enriching the community's quality of life.

Keywords: Challenge, Development, Green Space, Management, Perception, Urban, Debre Tabor Town

1 Introduction

Urban green spaces (UGS), defined as urban areas transformed from natural or semi-natural ecosystems into spaces influenced by human activity, are essential for enhancing urban living conditions (Bilgili & Gokyer, 2012). These spaces are integral contributors to urban sustainability, as they fulfil various ecological and social functions. For instance, Shah & Haq (2011) asserted that urban green spaces provide crucial social, economic, cultural, and psychological services that significantly enhance the well-being of urban dwellers. Such multifunctionality highlights the urgency for careful planning and management of urban green spaces in urban settings.

The development and management of urban green spaces necessitate interdisciplinary and integrative approaches that maximize their potential benefits. According to Tuzin et al. (2002), urban green spaces encompass both public and private open spaces that are predominantly covered by vegetation, providing opportunities for active and passive recreational activities. Moreover, they play a pivotal role in improving the urban microclimate. Research has shown that urban areas rich in vegetation can significantly mitigate the urban heat island effect, which is intensified by extensive hard surfaces such as asphalt and concrete that absorb solar radiation and retain heat. Appropriately managed green spaces help reduce the overheating phenomenon characterized by urban heat islands, thereby improving the comfort and health of urban inhabitants (Konijnendijk et al., 2013; Fam et al., 2008).

At a system level, urban green spaces generate benefits that extend

beyond the individual, contributing to cities' overall attractiveness and liveability. Well-managed green spaces can enhance city appeal by drawing in residents and businesses, fostering economic vitality and job creation (Tarrant & Ken, 2002). For instance, studies have demonstrated that neighbourhoods with ample green space often experience higher property values, increased local spending, and lower healthcare costs, all of which are attributable to improved public health outcomes (Feng et al., 2020). Trees also provide vital ecosystem services, including air filtration, noise reduction, and carbon sequestration, which have profound health implications (Azagew & Worku, 2020). However, the degradation of urban green spaces poses significant environmental and socioeconomic challenges. For example, Girma et al. (2019) emphasize that the erosion of urban green spaces can lead to habitat destruction, biodiversity loss, increased urban heat island effects, compromised stormwater management, and disruption to urban ecosystems.

Despite these numerous benefits, many cities are currently grappling with significant challenges in urban green space development and management. Rapid urbanization and infrastructure expansion have increasingly placed urban green spaces at risk, with unplanned urban growth leading to the degradation and loss of these vital ecosystems (Nebel & Wright, 2000). Recent urban management strategies highlight the necessity of developing comprehensive master plans designed to protect such spaces from ongoing threats (Azagew & Worku, 2020). This is crucial as many countries struggle to address a multitude of urban management challenges, including environmental degradation and climate change, which require effective strategies to harness the benefits of urbanization while minimizing its adverse effects (Alemayehu, 2014).

The issue of urban green space degradation is particularly pronounced in developing countries, where uncontrolled urbanization and burgeoning populations have severely impacted the urban environment (Mpofu, 2013; Haq, 2020). The environmental, economic, aesthetic, and social values associated with urban green areas are affected by rapid urban expansion and insufficient green amenities. The United Nations (2020) estimated that urbanization trends will continue to escalate, necessitating urgent measures to maintain urban ecological integrity.

In the context of Ethiopia, rapid urbanization and population growth have significantly contributed to the deterioration of urban green spaces, as seen in towns like Debre Tabor. Urban expansion leads to issues such as inadequate waste management systems, water and air pollution, illegal settlements, and adverse impacts on urban landscapes (Tegenu, 2010). Moreover, the migration from rural areas to urban centers amplifies these challenges, resulting in chaotic development patterns and increased pressure on already limited green resources. As stated by DTUDHCO (2019), Debre Tabor is experiencing an unprecedented rate of urbanization characterized by extensive land demand and fragmentation of natural habitats.

Despite the evident benefits of urban green spaces, their essential role in urban development remains inadequately recognized within Ethiopia's policy framework. The lack of holistic policies addressing green space integration into urban planning continues to hinder progress in urban sustainability (MUDH, 2015). Furthermore, the inadequate provision of high-quality urban green space does not align with the population growth and governance systems of various Ethiopian cities (Tsegaye & Tegenu, 2010). This oversight is particularly concerning given that well-planned and managed urban green spaces are critical for improving urban resilience against climate change and pollution (Alemayehu, 2014; Azagew & Worku, 2020).

While various studies have explored urban green space conditions in different parts of Ethiopia, there remains a notable gap in research that has focused specifically on Debre Tabor Town. Understanding the status, challenges, and management practices surrounding urban green space in this location is vital for identifying gaps and developing effective mitigation strategies. Therefore, this study assesses the challenges and opportunities associated with urban green space development and management in Debre Tabor Town. It is anticipated that the findings will raise awareness among planners, managers, and policymakers, prompting them to adopt measures that effectively address the challenges while maximizing opportunities for enhancing urban green spaces.

2 Research Methods

2.1 Description of the study area

Debre Tabor is one of the oldest cities in Ethiopia; its existence dates as far back as fourteen centuries (SGCTO, 2017). Geographically, the Town is located 97km from Bahir-Dar, the capital city of the Amhara regional state, and 667 km from Addis Ababa, the capital city of the country. It is situated between 11°50'–11°51' N latitude and 38°00' - 38°1'E longitude with an altitude of 2,706 m above sea level (Figure 1). Currently, the town has been serving as a center for the seat of the South Gondar administration Zone and Farta District. The town is divided into six kebeles (the smallest administrative unit in Ethiopia). According to the Debre Tabor Town Administration Mayor office (2018) report, in 2004, the total population was approximately 78,000 (DTAO, 2018); however, based on population projection data, the total population of the town was estimated to be approximately 96,973 (CSA, 2013). The livelihoods of town residents are dominated by small businesses and urban agriculture. The town covers a total of 3515.98 hectares of land. From the total urban land use, approximately 37.61% (469.85 hectares) of the parcels were occupied by social services, residential areas, and road networks covering 23.82% (297.56 hectares) and 18.11% (226.27 hectares, respectively. On the other hand, agricultural land within the town boundary covers 17.52 (397.06 hectares) and urban forest land accounts for 15.74% (356.73 hectares) of the land (DTAO, 2018).

Urban green area has to be delineated within the frameworks of urban plans at the town or kebele level together with a conducive working environment that guarantees sustainable participation of the public. Currently, only a small area of urban land (2.99 ha) is developed as a green area, which shares 0.24%; thus, little attention is given to the development and management of green space in the town.

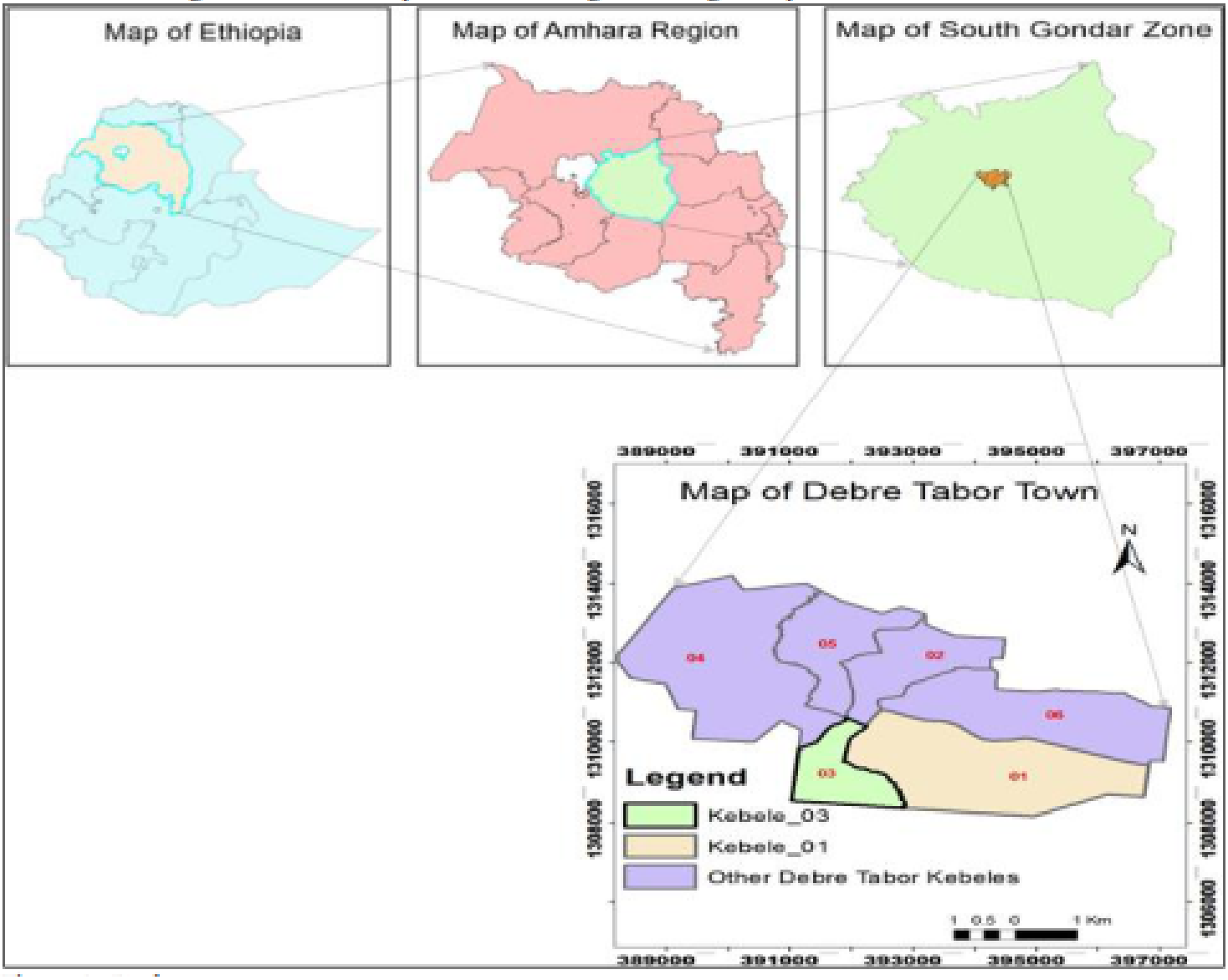

Figure 1: Study area map

2.2 Research design and sampling techniques

The study employed a mixed-methods research approach, incorporating both quantitative and qualitative methods. The quantitative approach involved collecting numerical data through household surveys using questionnaires, whereas the qualitative approach focused on collecting non-numerical information through in-depth interviews, focus group discussions, and field observations. This methodological choice was made to address potential deficiencies associated with the use of a single method.

The sampling frame for the questionnaire survey encompassed all urban areas within the town boundaries. Purposive sampling was then employed to select kebeles and households for the survey, with an initial stratification by kebele population to ensure broad geographical coverage. Out of the six kebeles, two were selected based on residents' green space management practices and attitudes toward urban green space management, encompassing both poor and good practices. Subsequently, mature respondents (age¿18 years) were selected within the selected villages using simple random sampling.

2.2.1 Sample size determination

The target population of this study included heads of household living in sampled kebele administrations. Due to cost, time, and variable measurement procedure limitations, all populations were not included in the study. Hence, in this study, the total sample size was determined based on Cochran's (1977) equation 1 which is described below. These sampling techniques are often regarded as superior due to their systematic approach to sample size estimation

and ensure that the sample accurately reflects the population.

$$n = \frac{Nz^2pq}{d^2(N-1) + z^2pq}$$

Where n is the sample size, N is the Population of the town, $q = 1 - P = 1 - 0.14 = 0.86$, d is the level of precision 0.06 (Cochran, 1977), and Z is the standard normal deviation at a 94% confidence interval equal to 1.

Proportion of the population (P) = Total household sample unit of kebeles = 0.14

Total population of the town .....(2)

For the selected kebeles, the total number of households is 9388 and 3395, and the sum is 12783, respectively. The ±6% precision level of the sample size was computed using the equation above, with a confidence level of 94% and $d = 0.06$ (maximum variability). Therefore, the total number of sample households' sizes is expressed as follows.

$$n = \frac{12783(1.96)^2(0.14)(0.86)}{(0.06)^2(12783–1) + (1.96)^2(0.14)(0.86)}$$

Generally, out of 12783 households in the two villages, 127 sample HH respondents were selected for the questionnaire survey to collect data related to the challenges and opportunities of the development and management of urban green space in the study area.

2.3 Method of data collection and analysis

This study employed several key methods for data collection, including household surveys, key informant interviews, focus group discussions (FGDs), transect walks, and field observations. Each of these methods played a vital role in comprehensively capturing the various dimensions of the subject matter.

2.3.1 Household survey

The household survey gathered factual information, identified challenges, and documented observations and experiences from the sampled households. This method addressed the current public understanding of urban green spaces as well as the challenges associated with the development and management of urban green spaces. A total of 127 respondents were selected for face-to-face interviews from different kebeles, comprising 72 male-headed households and 55 female-headed households. The selection of respondents was conducted using simple random sampling techniques, ensuring a diverse representation of different socioeconomic conditions. Throughout the survey, all social groups were identified and accounted for, which facilitated in-depth discussions later in the research.

2.3.2 Baseline Survey and Pre-testing

Prior to the main survey, a baseline survey and pretest involving 10% of the total sample were conducted. This preliminary phase aims to assess the socioeconomic, environmental, and physical conditions of urban green spaces within the study area. The findings from the baseline survey were instrumental in refining the household questionnaire and developing the semi-structured questionnaires necessary for gathering comprehensive data from the respondents.

2.3.3 Key informant interviews

For this study, 16 key informants were selected and interviewed from sample kebeles. The key informants included urban park leaders, gardeners, beautification and sanitation officers, urban planners, land administration officers, and town administration managers. Their expertise provided in-depth insights into the development and management of urban green spaces in the area and contributed valuable context to the findings.

2.3.4 Focus group discussions (FGDs)

Additionally, 25 individuals were selected for the FGDs, comprising elders, gardeners, youth association members, and businesspeople. These discussions focused on predetermined topics and served to verify and cross-check the data obtained from the household surveys for each sample kebele.

2.3.5 Transect walks and field observations

Transect walks and physical observations were used to conduct subjective and qualitative assessments of the development and management conditions of green spaces within the town. This method facilitates on-the-ground evaluation of the physical environments being studied.

2.3.6 Data analysis

To analyze the socioeconomic characteristics and their awareness of the benefits of urban green spaces, multiple linear regression models were employed (Equation 3). Before linear regression analysis, nominal or categorical variables were transformed into dummy or binary variables using SPSS software. This transformation simplified the regression analysis and ensured that the assumptions of the regression were met. The multiple linear regression equation used in this study is as follows:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \cdots + \beta_n X_n + \epsilon$$

Where:

- Y = dependent variable, i.e., the awareness level of the community regarding the benefits of urban green spaces.
- β_0 = a constant indicating the intercept of the regression equation.
- β_1 to β_n = independent variable coefficients.
- ϵ = error term.
- X_1 to X_n = independent variables, i.e., respondents' socioeconomic characteristics.
  - X_1 = Age of respondent (years)
  - X_2 = Education of the respondent (years)
  - X_3 = Gender of the respondent (M=1, F=2)
  - X_4 = Annual income (the ET Birr)
  - X_5 = Marital Status
  - X_6 = Occupation (types of occur)
  - X_7 = Household Family Size (Numbers)
  - X_8 = HH access to information.
  - X_9 = Household year of stay (years)

3 Results and Discussion

3.1 Challenges in the development and management of urban green space practices

The development of urban green spaces requires the collaborative involvement of all stakeholders to be effectively realized. However, as indicated in Table 1, there is a significant shortfall in urban green space availability within the town. A substantial 92.9% of respondents reported a lack of physical connectivity among green spaces, while 81.1% noted insufficient integration with existing urban infrastructure. This lack of connectivity and integration significantly hampers the effectiveness of green spaces, underscoring a disconnect between their planning and actual functionality (Alberti, 2016).

3.1.1 Maintenance and quality issues

The quality and maintenance of urban green spaces are also pressing concerns. The survey revealed that 76.4% of respondents believed the quality of these areas was very poor. This deterioration is often associated with a lack of expertise, insufficient community awareness, and inadequate commitment from local leadership to manage and develop urban green spaces appropriately (Benedict & McMahon, 2006). Additionally, 66.1% of the respondents indicated inadequate access to urban green space infrastructure, illustrating a systemic issue that limits community engagement and the utilization of these areas (Zhou et al., 2020).

3.1.2 Policy and Land Allocation

Despite Urban Development Policy, which emphasizes the careful planning and integration of green space within urban settings, the current study found that only approximately 2.99 ha (0.24%) of the town's total land area is designated as planned green space. Surprisingly, only 33.9% of respondents reported the availability of green space within their locality. This discrepancy reveals a failure in policy implementation or land management practices, where governmental and nongovernmental entities have not adequately developed or managed urban green spaces (Kearney, 2006).

Unfortunately, these objectives have yet to be realized due to low levels of awareness regarding urban green space benefits among community members. Both the key informants and focus group discussion participants echoed that local communities had not been adequately involved in the planning, development, and ongoing management of urban green spaces in the area (Bhowmik & Hossain, 2021).

Thus, the development and management of urban green spaces in the study area face considerable challenges stemming from inadequate planning, poor policy frameworks, limited community involvement, and insufficient maintenance. Addressing these challenges requires a concerted effort from all stakeholders to enhance the quality and availability of urban green spaces, ultimately benefiting the community and the environment.

3.2 Correlation between challenges in the development and management of urban green space

3.2.1 Rapid Urban Population Growth

Approximately 69.29% of the sample households, as indicated in Table 2, confirmed that such growth leads to the degradation of green areas, as evidenced by illegal settlements, informal markets, and waste dumping. This illustrates that as the population of a town increases, so does the demand for land, inevitably fostering illegal activities that adversely affect urban green spaces. Urban population growth has been identified as a primary driver of change in global land use and land cover (Ferreira et al., 2019). Chi-square test results further revealed a significant association between rapid population growth and urban green space development and management at a 5% significance level ($\chi^2 = 3.327$; $p = 0.048$). This finding indicates that the expansion of urban populations directly impacts the effectiveness of green space management. Specifically, the proliferation of unplanned settlements makes greenspace one of the most threatened ecosystems in urban environments (Teimouri & Yigitcanlar, 2018; Puplanpu & Boafo, 2021).

Table 1: Communities' responses to the existing development and management of green space.

No	Variables	Yes		No		Total
		No	%	No	%	
1	Development, availability, and accessibility of urban green space	43	33.9	84	66.1	127
2	Poor legal, policy, and institutional frameworks on urban green space development and management	72	56.7	55	43.3	127
3	Deteriorated quality and maintenance of green space in the town	97	76.4	30	23.6	127
4	The destruction of green space in urban environments is extremely high	103	81.1	24	18.9	127
5	Limited protection and conservation activities of green infrastructure	84	66.1	43	33.9	127
6	Lack of integration among stakeholders (GS integrate with other infrastructure organizations)	103	81.1	24	18.9	127
7	Lack of community involvement in GS management	99	78.0	28	22.0	127
8	There are no continuous follow-up and maintenance activities (fencing)	112	88.2	15	11.8	127
9	Lack of connectivity (GS interlinking different functionally and physically)	118	92.9	9	7.1	127

Table 2: Challenges in the development and management of urban green space

No.	Challenges	Yes		No		χ^2	P-value
		No.	%	No.	%		
1	Rapid Urban Population Growth	88	69.29	39	30.7	3.327	0.048*
2	Poor implementation of government policies	97	76.4	30	23.6	14.276	0.000**
3	Political Instability	110	86.6	17	13.4	11.198	0.001**
4	Lack of Clear Standards and Standards	100	79	27	21.3	19.328	0.000*
5	Nature of a Town's Topography	48	37.8	79	62.2	0.020	0.887
6	Urbanization complexity	89	70.1	38	29.9	5.646	0.017**
7	Inadequately Skilled and Motivated Employees	77	60.6	50	39.4	6.495	0.011*
8	Information and Knowledge Gaps in UGSI	67	52.8	60	47.2	7.258	0.007**
9	Weak institutional arrangements and capacity	85	66.9	42	33.1	28.417	0.000**
11	Weak accountability and commitment of stakeholders	112	88.2	15	11.8	12.279	0.002**
12	Land Use Planning System	83	65.4	44	34.6	11.775	0.001**

NB: ** and * indicate statistical significance at the 1% and 5% levels, respectively.

3.2.2 Poor implementation of government policies

The development and management of urban green spaces are severely affected by the lack of direct government policies, strategies, and guidelines. Although some indirect regulations exist, as noted in Table 2, 76.4% of respondents reported experiencing poor implementation of government policies related to urban green spaces. This problem stems from a lack of public awareness and inadequate political commitment by local leaders. The data indicate that poor policy implementation leads to a decline in green space development and an increase in illegal activities in these areas. Additionally, chi-square analysis demonstrates a strong statistical association between the implementation of government policy and urban green space management at a 1% significance level ($\chi^2 = 14.276$; $p = 0.000$). Several studies have underscored that the absence of a cohesive policy framework for green space development and the ineffective application of existing policies represent the main challenges in establishing recreational parks and enhancing urban greenery (Gezahegne, 2014; Mersal, 2017). Supporting this view, Girma (2019) stated that the inadequacy of policy and legal frameworks results in insufficient quality green spaces for increasingly urbanized populations. This aligns with Puplanpu and Boafo (2021) findings that urban green space functions and values often receive minimal attention in research and policy discussions, especially in many developing countries.

3.2.3 Political Instability

The findings reveal that political instability significantly impacts the development of urban green spaces, with 86.6% of respondents indicating it as a challenge (Table 2). Stability to political and peace conditions is crucial for any development initiative, including urban green space management. A stable political environment fosters stakeholder engagement and community participation in developing green spaces. As shown in Table 2, a statistically significant association between political instability and urban green space management at a 1% significance level ($\chi^2 = 11.198$; $p = 0.001$). Mensah (2014) attributed these challenges to rapid urbanization, limited resource capacity of green space institutions, lack of prioritization for green spaces, corruption, uncooperative local attitudes, and political unrest (Yeshitela, 2019). Key informant interviews and focus group discussions confirmed that ongoing political instability leads to illegal actions that result in damage to street trees, reduced budget allocations, and decreased stakeholder involvement in urban green space development.

3.2.4 Lack of Clear Standards and Standards

Approximately 79% of respondents indicated that a lack of clear norms and standards for the development and management of urban green spaces adversely affects their overall effectiveness. The chi-square test revealed a statistically significant association between the presence of clear norms and standards and urban green space management at a 1% significance level ($\chi^2 = 19.328$; $p = 0.000$). Breed et al. (2014) argued that the absence of operationalized social norms and values negatively impacts green space development. Similarly, research conducted by Artmann (2014) shows that urban residents' norms and standards significantly influence green space management practices through their choices, which can either facilitate or hinder the greening of urban areas (Chang et al., 2013).

3.2.5 Urbanization Complexities

As indicated in Table 2, approximately 70.1% of respondents confirmed that the complexities of urbanization significantly affect the development and management of urban green spaces. Rapid infrastructure development, population growth, and increased socioeconomic activities exert significant pressure on green space development in developing countries like Ethiopia. The chi-square test shows a strong statistical association between urbanization complexities and urban green space management at a 5% significance level ($\chi^2 = 5.646$; $p = 0.017$). This finding correlates with research highlighting that accelerating urbanization and socioeconomic development present substantial challenges to effective green space management in cities (Raffaele et al., 2009; Shah, 2011; Woldegerima et al., 2016; Teferi & Abraha, 2017), where urban sprawl and densification lead to a decline in available green areas.

3.2.6 Inadequately Skilled and Motivated Employees

Effective management of urban green spaces heavily relies on skilled and motivated workforce. Approximately 60.6% of respondents reported an inadequate number of trained professionals responsible for green space management in their area, which hindered development efforts. The quality and appeal of a town's green spaces are ultimately dependent on the capabilities and dedication of its workforce (Woldegerima et al., 2016). Furthermore, the chi-square test indicates a significant association between access to skilled employees and effective management of green spaces at a 1% significance level ($\chi^2 = 6.495$; $p = 0.011$) (Table 2). Various studies have shown that efficient management of green infrastructure cannot be achieved without qualified and committed professionals, adequate funding, and enhanced public awareness (Kefelew and Lika, 2015).

3.2.7 Information and Knowledge Gaps

The results revealed that 52.8% of respondents identified a lack of information and knowledge regarding urban green space management as a major obstacle (Table 2). Insufficient expertise contributes to poor species selection and inadequate planning for green areas and recreational facilities. The chi-square test demonstrates a significant association between information and knowledge gaps and urban green space management, with a 5% significance level ($\chi^2 = 6.495$; $p = 0.011$) (Table 2). A deficient understanding of urban green space development often results in improper management and destructive development practices. Research by Alberta Community Development (2000) emphasized that a lack of information is a significant barrier to the use of urban green spaces.

3.2.8 Weak Institutional Arrangement and Capacity

According to Table 2, 66.9% of respondents believe that weak institutional arrangements and capacity contribute to ineffective urban green space management. The chi-square test supported this claim, indicating a strong statistical association between institutional weaknesses and urban green space management at a 1% significance level ($\chi^2 = 28.417$; $p = 0.000$). Key informants and focus group discussions revealed substantial deficiencies in human resource capacity, financial resources, and equipment related to green space management. Inadequate staffing, limited funding, and insufficient equipment restrict the ability to implement effective management practices. The existing literature widely recognizes institutional challenges as significant impediments to urban green space planning (Haaland & van den Bosch, 2015).

3.2.9 Poor Stakeholder Accountability and Commitment

Table 2 reveals that 88.2% of the respondents noted poor stakeholder accountability and commitment to urban green space management in the town. This lack of engagement results in a limited community understanding of the benefits associated with urban green spaces, leading to low participation and mobilization efforts. Consequently, many green areas are encroached upon by illegal settlers and temporary markets. The absence of robust stakeholder accountability undermines the overall effectiveness of urban green space initiatives. Julie et al. (2016) highlighted that community participation is often a crucial element in green space planning and management, yet it frequently fails to reach its potential, resulting in missed opportunities to enhance urban livability. Additionally, the chi-square test indicates a significant association between stakeholder accountability and urban green space management at a 1% significance level ($\chi^2 = 12.279$; $p = 0.002$). Observations and field assessments confirm that inadequate leadership commitment results in the neglect of green spaces, culminating in damage to facilities and vegetation. Smith (2009) emphasized that effective stakeholder participation, collaboration, and communication significantly enhance urban green space development and management (Azadi et al., 2011).

3.2.10 Land use planning system

As shown in Table 2, most respondents (65.4%) indicated that the urban land-use planning system plays a crucial role in shaping the

development and management of green spaces. However, the chi-square test revealed an insignificant association between land-use planning practices and urban green space management at a 5% significance level ($\chi^2 = 11.775$; $p = 0.001$). UN-Habitat (2011) and Kefelew and Lika (2015) highlighted the significant loss of urban green areas due to inappropriate land-use policies and illegal settlements in urban environments.

3.3 Resident's perceptions toward the benefit of urban green space

This study employed multiple linear regression analysis with nine predictor variables to assess residents' perceptions of the benefits of urban green spaces. The analysis revealed a moderate association between demographic factors such as age, occupation, marital status, and distance from home, confirming an overall preference for urban green spaces among residents. The predictive model accounted for 49.9% of the variance in residents' perceptions of these benefits ($R^2 = 0.499$, Adjusted $R^2 = 0.489$). Notably, seven out of the nine independent variables demonstrated significant influence on residents' perceptions of urban green space benefits, with differences in variables such as household age, educational status, family size, income, access to information, and years of residence being statistically significant at $p < 0.05$.

3.3.1 Age of households

Demographic variable influencing perceptions of urban green spaces. The regression model indicated a significant association at $p < 0.05$, highlighting the strong correlation between age and perception (Table 3). Specifically, older residents tend to have lower perceptions of the benefits of urban green spaces than their younger counterparts. This trend was supported by field observations and focus group discussions, which revealed that younger individuals often engage more actively in recreational green spaces. Previous studies have suggested that older populations may prefer tranquil nature-based activities, such as walking in parks or forests, reflecting different levels of engagement with urban greenery (Hillsdon et al., 2006; Abdul, 2012; Young-Chang & Keun-Ho, 2015; Mikias et al., 2017a).

3.3.2 Educational status of households

Multiple regression analysis revealed a significant correlation between educational status and perceptions of urban green spaces ($\beta = 0.176$, $t = 2.635$, $p = 0.010$; Table 3). Higher levels of education correspond to improved understanding and appreciation of the benefits provided by urban green spaces, suggesting that educational attainment enhances individuals' skills, abilities, and capacity to recognize the value of these areas (Mikias et al., 2017a). Thus, educational status serves as a crucial predictor of positive perceptions, aligning with the expectation that more educated individuals are likely to be more aware and supportive of urban greenery (Mikias et al., 2017b).

The analysis indicated that family size significantly influenced perceptions of urban green spaces, showing a negative correlation ($\beta = -0.088$, $t = -2.040$, $p = 0.044$; Table 3). This confirms that as the size of a household increases, perceptions of the benefits of urban green space tend to decline. Larger families appear to have less appreciation for green spaces than smaller families, consistent with findings that indicate smaller family units often prioritize and recognize the value of recreational activities in green areas (Young-Chang & Keun-Ho, 2015).

3.3.3 Access to Information

Access to information plays a critical role in shaping residents' perceptions of urban green space benefits. The multiple regression results ($\beta = 0.410$, $t = 2.954$, $p = 0.004$; Table 3) confirmed a strong positive association, indicating that areas with better access to urban greenery significantly enhance residents' understanding and appreciation of these spaces. Residents equipped with adequate information are more likely to recognize and utilize the benefits of urban green spaces effectively (Beyerl et al., 2016).

Income of Households

The influence of household income on urban green space perception is notable. The regression analysis revealed a positive relationship between higher household income and a greater appreciation of urban green spaces ($\beta = 7.998$, $t = 2.246$, $p = 0.027$; Table 3). This indicates that as household income increases, perceptions of urban green space benefit. Households with higher incomes tend to demand more recreational opportunities in green spaces. Research indicates that wealthier households often reside in areas with abundant, well-maintained green spaces and have greater access to public recreational areas (Neynen et al., 2006; Landscape Institute, 2009; Sister et al., 2010). Conversely, lower-income households report limited access and fewer visits to such spaces (Jonathan et al., 2015).

Household Years of Stay

The tenure of residence also contributes to perceptions of urban green spaces. The regression analysis revealed a significant positive association between duration of residence and perception of urban green benefits ($\beta = 0.021$, $t = 4.037$, $p = 0.000$; Table 3). Longer-term residents are more likely to recognize and appreciate the benefits offered by nearby urban green areas, corroborating findings that suggest prolonged exposure leads to increased awareness and valuation of local green spaces (Raffaele et al., 2009; Mikias et al., 2017b).

Table 3: Multiple regression analysis of socioeconomic factors on perceptions of the benefits of urban green spaces

	Unstandardized Coefficients		Standardized Coefficients			Collinearity Statistics	
Model	B	Std. Error	Beta	t	Sig.	Tolerance	VIF
(Constant)	2.789	.448		6.220	.000		
Gender	-.065	.137	-.032	-.476	.635	.932	1.073
Age at the HH	-.037	.009	-.311	-4.258	.000**	.802	1.246
Marital Status	-.033	.085	-.045	-.629	.530	.831	1.203
Educational level	.176	.067	.214	2.635	.010**	.650	1.537
Occupation	-.065	.066	-.081	-.988	.325	.639	1.564
Family size	-.088	.043	-.145	-2.040	.044*	.849	1.178
Annual Income	7.99	.000	.186	2.246	.027*	.626	1.598
Access to Information	.410	.139	.199	2.954	.004**	.943	1.060
Household Years of Stay	.021	.003	.271	4.037	.000**	.954	1.048

Source: Survey Results, 2020

* p ¡ 0.05, ** p ¡ 0.01

Insignificant Predictors

In contrast, the multiple regression analysis identified sex, marital status, and occupation of household members as insignificant predictors of residents' perceptions of urban green space benefits. Each of these variables yielded non-significant results ($\beta = -0.065$, $t = -0.476$, $p = 0.635$; $\beta = -0.033$, $t = -0.629$, $p = 0.530$; and $\beta = -0.065$, $t = -0.998$, $p = 0.325$, respectively; Table 3). These findings reveal that demographic variables have negligible influence on perceptions in the context of the study area compared with the significant predictors discussed. In general, the study highlights the multifaceted influences on residents' perceptions of urban green spaces, demonstrating that factors such as age, educational status, and family size, access to information, household income, and tenure significantly shape how these spaces are valued. These insights contribute to understanding urban green space dynamics and underscore the importance of targeting educational and informational initiatives to enhance community engagement with green infrastructure.

4 Conclusion

Management and development of urban green areas necessitate coordinated efforts involving human, institutional, and financial resources. This study highlights the pressing challenges faced by urban green spaces in Debre Tabor, where the inadequate allocation of green space (0.24% of the total urban area) directly hampers residents' ability to access and enjoy these essential resources. The legal, policy, and institutional frameworks designed to support green space management are notably deficient, characterized by high levels of degradation and neglected infrastructure. Furthermore, the limited conservation efforts and poor maintenance of existing green spaces underline the urgent need for enhanced management practices. The analysis indicates a notable disconnect among stakeholders and a lack of community engagement, further compounded by the insufficient connectivity between the different functional and physical aspects of green areas. Although the town administration has set aside a budget of 20,927,829.40 birr for green space initiatives, there is an absence of financial contributions from local communities and private entities, which are crucial for sustainable development. Political and administrative challenges, including poor policy implementation and instability, have significantly hindered effective green space management. Contributing factors include a shortage of skilled personnel, information gaps, limited institutional capacity, ineffective decision-making processes, inadequate stakeholder accountability, and unclear standards. Of the six predictor variables influencing residents' perceptions of the benefits of urban green spaces, educational status, income, and access to information emerged as positive contributors, while age and family size had negative effects. Despite these substantial challenges, the Debre Tabor situation is not without hope. By strategically addressing the identified issues and leveraging existing opportunities, the town can foster a more sustainable and vibrant environment that promotes healthy and accessible green spaces. Key recommendations include: Actively involve local residents in the planning, development, and maintenance of green spaces to foster a sense of ownership and encourage stewardship. Develop clearer policies that outline norms and standards for green space management and conservation, ensuring they are effectively implemented. Encourage public-private partnerships and seek financial contributions from local businesses and community organizations to supplement government funding. Invest in training programs for local employees to enhance their skills in urban planning, landscape management, and community engagement. Conduct outreach efforts to inform residents of the environmental, social, and health benefits of urban green spaces, thereby increasing demand and support for such initiatives. Develop a long-term strategic plan that integrates various stakeholders, addresses connectivity issues, and prioritizes the development and rehabilitation of green spaces.

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Conflicts of interest/Competing interests

The authors declare no potential conflicts of interest regarding the publication of this work.

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Research Article

Correlations and path coefficient analysis of Grain yield and Grain yield related traits in Small seeded Common bean genotypes (Phaseolus vulgaris L.) at Goro and Gimir, Southeast Ethiopia

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Abstract

Common bean (Phaseolus vulgaris L.) is one of the crops produced by thousands of farmers in Bale. This study was conducted to assess the association of grain yield and grain yield related traits among small seeded common bean genotypes. Sixty-four common bean genotypes were evaluated in 8 X 8 simple lattice design at Goro and Gimir in 2021. Results of analysis showed significant(p_i0.05) and positive strong correlation at phenotypic and genotypic levels for number of primary branches, number of secondary branches, number of pods per plant, number of seeds per pod and number of seeds per plant with grain yield at both sites. These traits except number of seeds per plant had positive direct effects on Grain yield at genotypic level. The present study showed weak association of plant height and hundred seed weight with all the traits. The presence of non-significant correlations of the two variables indicated that the two traits are independent of each other or that genes concerned are located far apart on the same chromosome or they are located on different chromosomes. Days to flowering had negative and significant(p_i0.01) genotypic and phenotypic correlations with grain yield and the trait also exerted negative direct effect on grain yield at genotypic and phenotypic levels at both locations. This suggested that the importance of considering these traits during selection to improve grain yield in subsequent generations. In contrast, the negative direct effects of days to flowering and maturity as well as the negative indirect effects of these traits via other traits on grain yield suggested the need to select genotypes for early flowering and maturity for the study area.

Keywords:common bean, Ethiopia, genotypic correlation, phenotypic correlation.

1 Introduction

Common bean is a major grain legume consumed worldwide; particularly in Sub-Saharan Africa (SSA). It is seed-propagated and diploid (2n=22) with a relatively small genome (650 Mb) (Broughton et al., 2003). It grows best in warm climate at optimum temperature of 18 to 24°C and between 1400 and 2000 m.a.s.l. (Teshale et al., 2006). As a result, it is an important crop for food security and nutrition (Margaret et al., 2014).

Common beans have two geographic centers of domestication, namely the Mesoamerican and Andean centers. The multiple centers of domestication of the crop have endowed it with relatively high diversity that is broadly classified into two gene pools, Mesoamerican and Andean (Gepts and Bliss, 1986); Singh et al., 1991). The Andean lines have larger seeds in which 100 seed weight is above 30 grams while Mesoamerican lines have smaller seed size i.e., their 100 seed weight is less than 30 grams (Gonzales et al., 2009). There are also variations in genotypes of common bean with different bean sizes and color. For instance, the small size genotypes vary from the small black wild type to the large white, brown, red or mottled seeds (Cobley and Steele, 1976).

For effective selection, information on characters' association with yield and among treats themselves, and the extent of environmental influence on the expression of these characters are necessary (Yagdi, 2009; Ejigu et al., 2017). Yield is the principal factor for determining improvement of a crop. Like other crops, seed yield in com-

mon bean is a quantitative character and influenced by a number of yields contributing traits. The selection of desirable types should therefore be based on yield and yield components. Information on mutual association between yield and yield components is necessary for efficient utilization of the genetic stock in the crop improvement program (Nechifor et al., 2011). To achieve significant progress in breeding programs, it is essential to know the relationship between seed yield and its components (Assady et al., 2005).

Correlation and path coefficient analysis could be used as an important tool to bring information about appropriate cause and effects relationship between yield and some yield components (Khan et al., 2003). Although correlation estimates are helpful in determining the components of complex trait such as Grain yield, they do not provide an exact picture of the relative importance of direct and indirect influences of each of the component characteristics of the trait. Path coefficient analysis provides a more effective means of separating direct and indirect factors, permitting a critical examination of the specific forces acting to produce a given correlation and measuring the relative importance of the causal factors. Correlation and pass co-efficient analysis of traits studies have been also conducted by considerable number of researchers on common bean, for instance, Kassaye, (2006), Karasu and Oz (2010), Salehi et al. (2010), Alamayehu, (2010), Daniel et al, (2015), and Barecha (2015), Ejara(2017).

Most of the studies on common bean correlation and path analysis of traits were conducted in other parts of the country. However, there are no reports on common bean under Bale zone (southeast Ethiopia) conditions, in where monocropping practice is a major crop production problem. Moreover, information is lacking on the potential of common bean genotypes in southeast Ethiopia in general and Ginnir, and Goro district of Bale zone. Hence the present study took place with the following objectives.

1. To determine associations among yield and yield related traits in small seeded common bean genotypes.
2. To evaluate the direct and indirect effects of yield related traits on grain yield of small seeded common bean genotypes.

2 Materials and Methods

2.1 Description of the Study Area

The experiment was conducted under field conditions at two potential areas of Bale and east Bale Zones. Both sites receive bimodal rainfall characterized as the main cropping season from July to October and short rain from March to May. The annual total rainfall of the area ranges between 806.9 and 1066.7 ppm and mean temperature ranges from 13.1–22.5°C (Bikila Mengistu et al. 2020).

Goro is located at 524km away from Addis Ababa in southeastern Ethiopia, 60 and 75 km from the near-by towns, Robe and Goba, respectively. The site is situated at 6° 59'20.97" N latitude and 40° 29'45.16" E longitude and elevation of 1771 meters above sea level. The soil is predominantly Vertisol in properties. The major crops grown widely in the area include cereal crops (barley, wheat, maize and teff), pulse crops (common bean, chickpea and lentil), spices (coriander, fenugreek) and vegetable crops (onion, potato, tomato and pepper) under rain fed and irrigation. Cereal crops are predominantly grown in the area (Taye and Abera, 2010; Amanuel et al., 2022).

Ginnir is located 599 km away from Addis Ababa. The site is situated at 7° 10'42.02" N latitude and 40°42'58.64"E longitudes at 1972 m.a.s.l. The Vertisol soil type of Ginner district is suitable to produce cereal, pulse, oil and horticultural crops (Wubishet et al., 2016; Amanuel et al., 2022).

2.2 Plant Materials

A total of 64 small-seeded common bean genotypes, of which 60 genotypes and two released varieties were obtained from the Melkasa Agricultural Research Center (MARC) and two released varieties from Sinana Agricultural Research Center (SARC), which were used as standard checks. The small seeded common bean genotypes and released varieties are listed in Table 2.

2.3 Experimental Design and Management of the Experiment

The field experiment was laid out in 8*8 Simple Lattice Design. The plot size was 4.8 m^2 (4 rows of 3m long) with plant-to-plant and row-to-row distances were maintained at 10 and 40 cm, respectively. The genotypes were assigned to plots randomly within each incomplete block of each replication. All other crop management and protection practices were applied uniformly to all genotypes as recommended for the crop.

2.4 Data Collection

Data on phenology and yield were registered on plot basis while data on growth traits and yield components were collected from 10 randomly taken sample plants as described in descriptors of Phaseolus vulgaris (IBPGR, 1982) and Handbook on evaluation of Phaseolus Germplasm (Cuadrado et al., 2001).

2.4.1 Data collected on plot basis

At individual plot level data on Days to 50% of flowering, Days to maturity, Seed yield per hectare (kg) and 100 seed weight (g) were collected.

Table 1: Description of geographical positions and soil physico-chemical properties of the test locations.

Parameter	Goro	Ginner
Geographical position		
Latitude	6°59'20.97" N	7° 10'42.02" N
Longitude	40° 29'45.16" E	40° 42'58.64"E
Altitude (m.a.s.l.)	1771	1972
Soil Property		
pH (1:2:5)	6.89	6.82
OC (%)	1.19	1.18
P_{avail} (ppm)	8.43	10.23
CEC (cmol.k8 (+) kg soil^{-1})	49.46	47.46
Soil texture		
Clay, %	46	52
Sand, %	20	21
Slit, %	34	27

[1]Source: Sinana Agricultural Research Center, (2017/18) (unpublished data). OC = Organic Carbon, Pav = Phosphorus availability, CEC= Cation exchange capacity.

2.4.2 Basic parameter data collection

Plant height (cm), number of primary branches per plant, number of secondary branches per plant, number of pods per plant, number of seeds per plant (NSPL), number of seeds per pod (NSPP).

2.5 Phenotypic and Genotypic Correlation Coefficients

The phenotypic and genotypic correlation coefficients were computed using the formula suggested by Singh and Chaudhury (1996).

Phenotypic coefficient of correlation (rp)

$$rp = \frac{Pcovxy}{\sqrt{(\sigma^2 px.\sigma^2 py)}}$$

Genotypic Coefficient of Correlation (rg)

$$rg = \frac{Gcovxy}{\sqrt{(\sigma^2 gx.\sigma^2 gy)}}$$

Where
rp = Phenotypic correlation coefficient, rg = Genotypic correlation coefficient
Pcovxy = Phenotypic covariance between variables x and y
Gcovxy = Genotypic covariance between variables x and y
$\sigma^2 gx$=Genotypic variance for trait X, $\sigma^2 gy$=Genotypic variance for trait Y
$\sigma^2 px$=Phenotypic variance for trait X, $\sigma^2 py$=Phenotypic variance for trait Y

2.6 Path Coefficient Analysis

The path coefficient obtained by using the general formula of Wright (1921) by solving the following simultaneous equations, which express the basic relationship between correlation and path coefficient.

$$r_{uj} = p_{uj} + \sum r_{ik}.p_{kj}$$

Where; r_{uj} = mutual association between the independent character (i) and dependent character (j) as measured by the genotypic correlation coefficient, p_{ij} components of direct effects of the independent character (i) on the dependent variable (j) as measured by the genotypic path coefficient; and $\sum r_{ik}.p_{kj}$ =summation of components of indirect effects of a given independent character (i) on a given dependent character (j) via all other independent character (k)

The coefficient of correlations at phenotypic level was tested for their significance by comparing the value of correlation coefficient with tabulated r-value at g-2 degrees of freedom. However, the coefficient of correlations at genotypic level was tested for their significance using the formula described by Robertson (1959) indicated below:

$$t = \frac{rg}{\sqrt{\frac{1-rg^2}{g-2}}}$$

Where: SEgxy= Standard error of genotypic correlation coefficient between character x and y
hx = Heritability value of character x
hy = Heritability value of character y

The calculated absolute t value was tested against the tabulated t-value at g-2 degrees of freedom for both phenotypic and genotypic

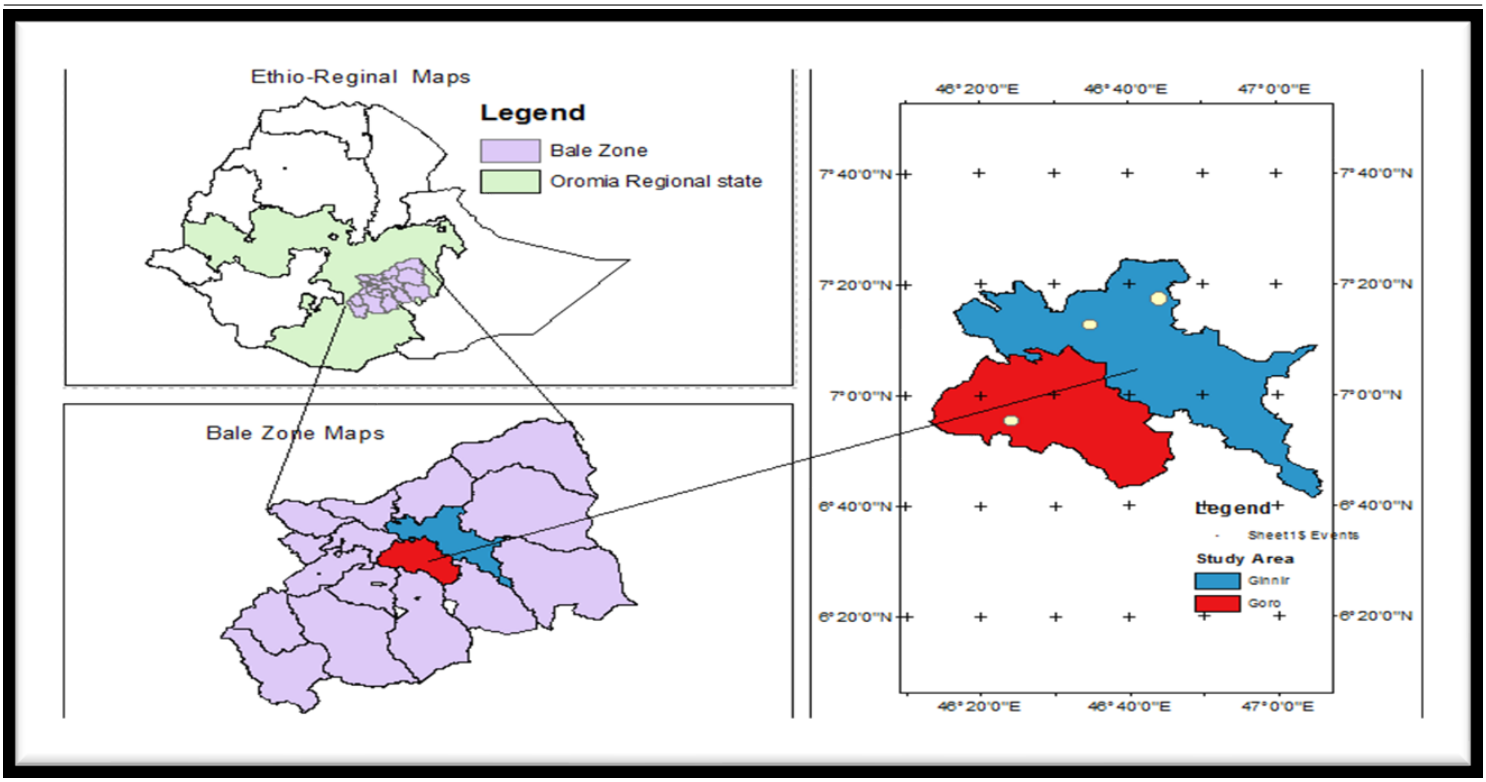

Figure 1: Map of Ethiopia showing the experimental sites.

correlations. Environmental correlation coefficients were tested at [(g-1) (r-1)-1)] degrees of freedom, where g is the number of genotypes.

The contributions of the remaining unknown factors (effects) were measured as the residual effect (RE) is calculated as:

$$\sqrt{1 - R^2}$$

, $R^2 = \sum p_{ij} r_i$

3 Results and Discussion

3.1 Genotypic and Phenotypic Correlation Coefficients of Grain Yield with other Traits

Estimates of genotypic and phenotypic correlation coefficients were computed for different characters at Ginir (Table 3) and at Goro (Table 4). The computed characters include number of secondary branches, pods per plant, seeds per pod and seeds per plant at genotypic and phenotypic levels at two locations Grain yield had positive and highly significant (P¡0.01) correlations with number of primary branches. Reports by (Ejara et al., 2017; Kassa et al., 2019; and Chaudhary et al., 2020) revealed positive and significant relationships of grain yield with number of primary branches, number of secondary branches, Number of pods per plant and total number of seeds per plant.

The presence of highly significant(P¡0.01) and positive correlation of these traits with grain yield at genotypic and phenotypic levels indicate prime importance of these traits in selection program to identify common bean genotypes with high grain yield. The estimate of genotypic correlation is higher than their respective phenotypic correlations for most of the traits except for number of secondary branches indicating strong inherent relationship between the traits. Direct selection only for higher grain yield could be misleading because many factors interact to determine grain yield of crops. Selections for separate grain yield traits which are less influenced by the environment than grain yield itself are useful to acquire genotypes with better grain yield abilities (Gatti et al., 2005). Phenotypic correlation measures the extent to which the two observed traits are linearly related while genotypic correlation measures the degree of the same genes or closely linked genes cause co-variation (simultaneous variations) in two different traits (Singh and Chaudhary, 1977; Falconer and Mackay 1996; Sharma, 1998). The inherent or heritable association between two variables is a genotypic correlation but phenotypic correlation varies at different environments and lessened by the significant interaction of environment (Kumar and Reddy, 2014).

Grain yield had negative and highly significant (P¡0.01) associations with days to flowering at genotypic and phenotypic levels at both Ginir and Goro Vertisol locations (Table 3 and Table 4). The negative and highly significant(p¡0.01) association of this trait with grain yield suggested the importance of giving attention to days to

Table 2: List of Common bean genotypes and varieties test at the study sites.

No	Genotypes	Seed Color	Origin	No	Genotypes	Seed Color	Origin
1	CB170087-39-2	Red	MARC	33	CB170008-6	Red	MARC
2	CB170065-22-1	Red	MARC	34	CB1615-11-72-2	Red	MARC
3	CB170025-3	White	MARC	35	CB170002-10	White	MARC
4	CB170060-8	Red	MARC	36	CB170052-23	Red	MARC
5	CB170038-15	White	MARC	37	CB170064-10-3	White	MARC
6	CB170065-40-1	Red	MARC	38	CB170046-8-2	Red	MARC
7	CB170046-5-2	Red	MARC	39	CB170001-20-2	White	MARC
8	CB170052-30-3	Red	MARC	40	CB170044-57-1	Red	MARC
9	CB170065-59-2	White	MARC	41	CB170003-21	White	MARC
10	CB170044-55-1	White	MARC	42	CB170037-18	Red	MARC
11	CB170001-17	Red	MARC	43	CB170038-36-3	White	MARC
12	CB170044-44-2	White	MARC	44	CB170008-3	White	MARC
13	CB170001-3-2	Red	MARC	45	CB170008-4	White	MARC
14	CB170044-88-3	White	MARC	46	CB170001-5-3	White	MARC
15	CB170024-5-1	Red	MARC	47	CB170038-11-3	White	MARC
16	CB170066-6	White	MARC	48	CB170052-3-2	White	MARC
17	CB170044-46	Red	MARC	49	CB170058-3-1	White	MARC
18	CB170044-31-3	Red	MARC	50	Gen0418	White	MARC
19	CB170003-24-1	Red	MARC	51	CB170003-17	White	MARC
20	CB170046-5-1	White	MARC	52	CB170001-18	Red	MARC
21	CB170044-89-2	Red	MARC	53	CB170065-59-1	White	MARC
22	CB170002-11-1	Red	MARC	54	CB170064-3-2	White	MARC
23	CB170065-56	White	MARC	55	CB170001-9-4	White	MARC
24	CB170044-31-1	White	MARC	56	CB170003-16	White	MARC
25	CB170003-28	Red	MARC	57	CB170046-42	Red	MARC
26	CB170044-41-3	Red	MARC	58	CB170003-20	Red	MARC
27	CB170002-1	White	MARC	59	CB170001-11	White	MARC
28	CB170064-10-2	Red	MARC	60	CB170003-19	White	MARC
29	CB170003-23-1	White	MARC	61	SeR119	Red	MARC
30	CB170051-7	White	MARC	62	Awash-2	White	MARC
31	CB170058-10	White	MARC	63	Gobu	White	SARC
32	CB170051-3-1	Red	MARC	64	Wabero	White	SARC

Table 3: *
The genotype and the variety listed from 1 to 62 were obtained from Melkasa Agricultural Research Center (MARC) and the two varieties listed as No. 63 and 64 were obtained from Sinana Agricultural Research Center (SARC).

flowering in the process of the selection of common bean genotypes for high grain yield. The presence of non-significant correlations of the two variables indicated that the two traits are independent of each other or that genes concerned are located far apart on the same chromosome or they are located on different chromosomes. In plant genetics and breeding studies, correlated traits are of prime importance because of genetic causes of correlations through pleiotropic action or developmental interactions of genes and changes can be brought in correlated traits either by a natural or/and artificial selection (Singh, 1993; Falconer et al., 1990; Sharma, 1998). Ketema and Geleta (2022) reported that days to maturity and plant height had negative and non-significantly correlated with grain yield at genotypic and phenotypic level. Simon et al. (2020) reported that positive and non-significant phenotypic and genotypic correlation coefficients of hundred seeds weight with grain yield of common bean genotypes. Simon et al. (2020) reported that positive and non-significant phenotypic and genotypic correlation coefficients of hundred seeds weight with grain yield of common bean genotypes

The coefficients of genotypic and phenotypic variations were generally low for days to maturity and plant height which could be due to limited variability in the genetic materials studied. Ejara et al. (2017) and Kassa et al. (2019) reported that grain yield had non-significant and negative correlation with days to maturity and plant height. Ketema and Geleta (2022) also reported negative and non-significant association of days to maturity and plant height with grain yield of common bean genotypes. Ejara et al. (2017) reported that early flowering and maturing genotypes produce a higher grain yield than the late ones in most situations. In contrast, Bagheri et al. (2017) reported positive and significant association of days to flowering with grain yield in common bean. Simon et al. (2020) also reported positive and significant association days to flowering and days to maturity with grain yield.

3.2 Genotypic and Phenotypic Correlation Coefficients among Yield Related Traits

Positive and significant (p¡0.05) correlations among phenology parameters (days to flowering and days to maturity) were observed at phenotypic level, while positive and non-significant at genotypic level. Days to maturity with plant height at genotypic and phenotypic levels showed positive and non-significant correlations. Days to flowering with number of primary branches, number of secondary branches, number of pods per plant, number of seeds per pod and number of seeds per plant showed negative and significant (P¡0.05) correlations at genotypic and phenotypic levels. Days to maturity had negative and non-significant genotypic and phenotypic associations with number of primary branches, secondary branches, pods per plant, seeds per pod and hundred seed weight at Ginnir and Goro (Table 3 and Table 4). The presence of non-significant correlations of these traits with days to maturity indicated that they are independent of each other.

Number of primary branches showed positive and highly significant (p¡0.01) association with number of secondary branches, number of pods per plant, number of seeds per pod and number of seeds per plant. The number of secondary branches showed positive and significant (p¡0.05) correlation at genotypic and phenotypic level with number of pods per plant, number of seeds per pod and number of seeds per plant. The number of pods per plant also showed positive and significant (p¡0.05) correlation with the number of seeds per pod and number of seeds per plant at Goro (Table3 and Ginnir (Table 4).

At both genotypic and phenotypic levels, the number of seeds per pod also showed positive and highly significant(p¡0.01) association with number of primary branches, number of secondary branches, number of pods per plant and number of seeds per plant at both Goro and Ginnir aite. The number of seeds per plant also showed positive and highly significant (p¡0.01) genotypic and phenotypic association with number of primary branches, number of secondary branches and number of pods per plant. On the other hand. The hundred seed weight had negative and non-significant genotypic and phenotypic association with days to flowering, days to maturity and plant height. This negative association of hundred seed weight with those traits indicates a compensatory relationship between them. More late flowering and maturing could result in the reduction of the seed size because of competition among seeds for limited food reserves (Dewey and Lu, 1959). The correlation results of the present study had showed that the genotypic correlation coefficient in most cases was higher than their corresponding phenotypic correlation coefficient. This suggests that there was an inherent relationship between these traits and the possibility of effective phenotypic selection (Choyal et al., 2018).

Correlation coefficient is a statistical measure commonly used to find out the degree of relationship between two or more variables and changes brought about by a natural or artificial selection among correlated traits. The genotypic correlation coefficients having similar sign and nature to the corresponding phenotypic correlation coefficient bring similar changes among correlated traits either by a natural or artificial selection (Falconer et al., 1990); Sharma, 1998). Therefore, any pairs of traits that had positive correlation of the present common bean genotypes indicated the possibility of correlated response to selection. Unlike positive correlation, negative correlation between two desirable traits may make it impossible to achieve the simultaneous improvement of those traits along with each other.

Ejara et al. (2017) reported that number of branches showed positive correlation with number of Seeds per pod, number of seeds per plant and grain yield at genotypic and phenotypic levels. Razvi et al. (2018) also reported number of pods per plant showed significant (P¡0.05) and positive correlation with number of branches, number of seeds per pod and grain yield in common bean. However, the present study showed weak association of plant height and hundred seed weight with all the traits. Such disagreement can be explained as reported by Falconer and Mackay (1996) indicating that the genetic and environmental variations influenced those traits through different physiological mechanisms. The occurrence of positive or negative genetic correlation is due to pleiotropy or genetic links among the genes responsible for these characteristics (Ghobary and Abd Allah, 2010).

3.3 Genotypic and Phenotypic Path Analyses of Yield and other Traits

The correlation coefficient indicates the association of variables' total effect that does not show the direct effect and indirect effects of variables. The path analysis is the portioning of the total correlation into direct and indirect effects of independent variable(s) on dependent variable (Singh and Chaudhary, 1977; Dabholkar, 1992). According to Wright (1921), path coefficient analysis provides a better knowledge of direct and indirect causes of associations, and it permits a critical examination of the specific forces acting to produce a given correlation and measures the relative importance of each causal factor.

The results of genotypic path coefficient analysis of grain yield with other traits are presented in Table 5 and Table 6 at Goro and Ginnir. respectively. While, phenotypic path coefficient analysis of grain yield with other traits are presented in Table 7 at Goro and Table 8 at Ginnir,. Number of primary and secondary branches, number of pods per plant, number of seeds per pod and number of seeds per plant had positive and highly significant (P¡0.01) correlation. Days to flowering had showed negative and highly significant (P¡0.01) genotypic and phenotypic correlation at Goro (Table 3) and Ginnir Table 4).

In the present study, only characters that had significant relationship with grain yield were included in the path analysis (Dewy and Lu, 1959). Number of primary branches, number of pods per plant and number of seeds per pod had high positive direct effects of grain yield at genotypic and phenotypic levels, at both Goro and Ginnir. The results of this study revealed that the number of secondary branches had a small positive direct effect on grain yield, which can be counter balanced by high direct effect through number of primary branches, number of pods per plant and number of seeds per pod. Number of primary branches, number of pods per plant and

number of seeds per pod had significant (P¡0.05) and positive association with grain yield. Therefore, important consideration should be given while practicing selection aimed at the improvement of grain yield.

The trait that has positive correlation with grain yield and has large and positive direct effect is considered as an important component of grain yield (Dabholkar, 1992). In this study, the observed positive and significant correlations of number of primary branches, number of secondary branches and number of pods per plant with grain yield were the true relationship suggesting that the direct selection of genotypes for yield through these traits will be effective.

Days taken to flowering and number of seeds per plant had negative direct effects at genotypic and phenotypic level, and indirect effects via number of primary branches, number of secondary branches, number of pods per plant and number of seeds per pod, whereas other traits had positive indirect effects at Goro and Ginnir. The indirect effects via most other traits were negligible. Therefore, the phenotypic correlation with grain yield was eagerly due to the direct effect. The number of primary branches had a positive direct effect at genotypic and phenotypic level on grain yield at both Goro and Ginnir, likewise, the significant and positive correlation between number of primary branches and grain yield might be due to considerable indirect effect of number of primary branches via number of secondary branches, number of seeds per pod and number of pods per plant. Daniel et al. (2015) had reported that path coefficient at genotypic level showed that number of pods per plant had positive direct influence on grain yield while days to flowering and number of seeds per plant had showed negative direct effect on grain yield. Mukerem et al. (2019) also reported similar results for days to flowering had exerted negative direct effect on grain yield of common bean.

Residual effect in genotypic path analyses at Goro and Ginnir was 0.261 and 0.401 Table 5 and Table 6, respectively, showing that 97.39% and 95.99% of the variability in grain yield was explained by the component factors at genotypic levels. The remaining 2.63 and 4.01 % could be explained by other traits, not considered in this study. While at phenotypic level residual effect was 0.1024 and 0.816, at Goro and Ginnir, respectively, indicating that 89.76% and 91.84% of variability was explained by component factors (Table 7 and Table 8).

4 CONCLUSION

Grain yield showed positive and highly significant ($p < 0.01$) correlation with numbers of primary branches, number of secondary branches, number of pods per plant, number of seeds per pod and number of seeds per plant at genotypic and phenotypic level. On the other hand, grain yield had showed negative and highly significant ($p < 0.01$) correlation with days to flowering at genotypic and phenotypic level at both Goro and Ginnir. Number of primary branches, number of secondary branches, number of pods per plant and number of seeds per pod had positive direct effect on grain yield at genotypic and phenotypic levels at Goro and Ginnir suggesting that the direct selection of genotypes for these traits will be effective to identify genotypes for high grain yield. Days to flowering and number of seeds per plant exerted negative direct effect on grain yield at genotypic and phenotypic levels. Therefore, much attention should be given to these traits as they are helpful for indirect selection to improve grain yield in small seeded common beans.

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Table 4: Genotypic path analysis of the direct (bold) and indirect effect of yield related traits on grain yield of 64 common bean Genotypes at Goro, 2021

Traits	DF	NPB	NSB	NPPP	NSPP	NSPL	GY
DF	**-1.0183**	0.3278	-0.2123	-0.6675	-2.6655	3.2558	-0.98**
NPB	0.9470	**-0.3525**	0.1940	0.6898	2.6013	-3.1395	0.94**
NSB	0.8248	-0.2608	**0.2621**	0.3783	2.1838	-2.5582	0.83**
NPPP	0.3055	-0.1093	0.0446	**2.2251**	0.4496	-2.0155	0.9**
NSPP	0.8452	-0.2855	0.1783	0.3115	**3.2114**	-3.4109	0.85**
NSPL	0.8553	-0.2855	0.1730	1.1571	2.8261	**-3.8760**	0.85**

Residual = 0.026

Table 5: Genotypic path analysis of the direct (bold) and indirect effect of yield related traits on grain yield of 64 common bean Genotypes at Ginnir, 2021

Trait	DF	NPB	NSB	NPPP	NSPP	NSPL	Rg
DF	**-0.27**	-0.41	-0.06	-0.36	-0.45	0.61	-0.95
NPB	0.26	**0.45**	0.07	0.36	0.43	-0.60	0.96**
NSB	0.21	0.38	**0.08**	0.31	0.39	-0.52	0.85**
NPPP	0.25	0.41	0.06	**0.39**	0.44	-0.63	0.92**
NSPP	0.25	0.40	0.06	0.35	**0.49**	-0.62	0.93**
NSPL	0.26	0.41	0.06	0.38	0.47	**-0.65**	0.94**

Residual = 0.040

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Table 6: Phenotypic path analysis of the direct (bold) and indirect effect of yield related traits on grain yield of 64 Common bean Genotypes at Goro, 2021

Trait	DF	NPB	NSB	NPPP	NSPP	NSPL	rg
DF	**-0.5480**	-0.2662	-0.1310	-0.5117	-1.9882	2.3970	-0.96**
NPB	0.4767	**0.3060**	0.1181	0.4913	1.8591	-2.2741	0.9**
NSB	0.3890	0.1959	**0.1845**	0.2661	1.5234	-1.7517	0.75**
NPPP	0.1370	0.0734	0.0240	**2.0470**	0.1549	-1.5058	0.86**
NSPP	0.4219	0.2203	0.1089	0.1228	**2.5821**	-2.6122	0.78**
NSPL	0.4274	0.2265	0.1052	1.0030	2.1948	**-3.0731**	0.8**

^{2}Residual = 0.102

Table 7: Phenotypic path analysis of the direct (bold) and indirect effect of yield related traits on grain yield of 64 Common bean Genotypes at Ginnir, 2021

Trait	DF	NPB	NSB	NPPP	NSPP	NSPL	rg
DF	-0.35	-0.27	-0.04	-0.02	-0.10	-0.15	-0.93**
NPB	0.31	0.30	0.04	0.02	0.09	0.15	0.92**
NSB	0.25	0.25	0.05	0.02	0.08	0.13	0.77**
NPPP	0.31	0.27	0.04	0.03	0.10	0.16	0.90**
NSPP	0.29	0.25	0.04	0.02	0.12	0.16	0.87**
NSPL	0.31	0.27	0.04	0.02	0.11	0.17	0.92**

Residual=0.082

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Research Article

Abundance and distribution of mona monkey (Cercopithecus mona Schreber, 1775) in Osun Osogbo World Heritage Site, Nigeria

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Abstract

The objective of the present study was to evaluate the abundance and distribution of mona monkey (Cercopithecus mona Schreber, 1775) in Osun Osogbo World Heritage Site, Nigeria. This study used the line transect method to estimate population densities and map the spatial distribution of Mona monkeys (Cercopithecus mona) in Osun Osogbo World Heritage Site (OOWHS). Transects were marked at intervals of 0.05 km to facilitate data collection. Data were analyzed using Microsoft Excel 2016 and SPSS version 2023 to generate frequency tables. The mean density of mona monkeys was found to be high (220.75) in OOWHS. The morning and evening censuses revealed a significant statistical difference between the morning and evening censuses (P = value +0.353 at 0.05). The spatial distribution of mona monkeys was observed to be more in Transect A (near the gate of OOWHS) than in any other range within the selected ranges due to the fact that (Cercopithecus mona) is semi-habituated as a result of high tourism activities at this site and the presence of the tour guides offices that offered protection to the animals and their proximity to the flora composition of palm trees (Elaes guinensis) that serve as food sources and are mostly frequently utilized by the mona monkeys. It is suggested that sustainable management should be in place in monitoring the species in low relative abundance areas of the site.

Key words: Abundance, conservation, distribution, mona monkey, Nigeria

1 Introduction

The mona monkey (Cercopithecus mona) and other non-human primates occupy important ecological niches in their habitats; they are primarily fruit- and shoot-eating primates that consume a variety of plant components (Smith & Johnson 2019). Primates play a vital role in tropical forests, serving as pollinators, seed dispersers, seed predators, and even sequestering carbon, all of which are essential to the resilience and health of the forests.

Therefore, interactions between human groups and the mona monkey (Cercopithecus mona) remain complex and warrant additional study (Johnson et al. 2018). Lemurs, lorises, tarsiers, monkeys, apes, and humans are categorized as primates, a varied order of mammals (Rylands et al. 2017). Primates are classified into two main groups: Prosimians, which include tarsiers, lorises, and lemurs; and anthropoids, which comprise humans, monkeys, and apes (Sussman & Raven 2017). This is the method used in conventional classification.

There are more divides within the anthropoid group, such as new world monkeys and old-world monkeys (Rylands et al. 2017). Another significant group of primates are apes, which include gibbons,

orangutans, gorillas, chimpanzees, and bonobos (Napier & Napier 2017). The predominant habitat of the mona monkey (Cercopithecus mona) is tropical rainforest and dense secondary forests found in West African nations like Nigeria, Ghana, Cameroon, and the Ivory Coast (Haffer et al. 2017).

Due to the dangers caused by human activity to the species' protection, the population of this species in the forest is declining. Activities such as logging, deforestation, and agricultural development have disrupted the mona monkey's native range and fragmented its habitat (Hernández-Lambraño et al. 2019). This has led to the species' designation as "Vulnerable" on the International Union for Conservation of Nature's (IUCN) Red List, highlighting the pressing need to ascertain its distribution and population status (IUCN 2021).

However, because of their ecological significance and susceptibility to various threats, researchers and conservationists have been interested in the abundance and distribution of mona monkeys (Cercopithecus mona). The monkeys are primarily found in West African tropical rainforests and gallery forests, mainly in Nigeria, Ghana, the Ivory Coast, and parts of Cameroon (Rödel, 2017). These tropical regions offer suitable habitats that provide the resources needed for the survival and reproduction of this primate species. Additionally, one factor influencing the distribution of mona monkeys (Cercopithecus mona) is the availability of suitable habitat.

According to Dunn and Chapman (2018), they have a predilection for dense, old forests with lots of tree canopies because they offer them plenty of food sources and defense against predators. The distribution range of these species has been greatly affected by habitat fragmentation and destruction brought about by human activity (Kamgang et al. 2019). Mona monkeys run a significant risk of isolation and restricted access to essential resources as a result of ongoing forest clearing brought on by human activity and the growing human population. This will have an impact on the diversity of the species. Studies have evaluated the number of mona monkeys in several habitats using a variety of techniques.

Utilizing line transect surveys is one popular strategy that entails walking along pre-established transect lines and documenting any signs or sightings of primates (Mbebi et al. 2018). Additionally, the food preferences of the mona monkey have been connected to its abundance. Although they are primarily fruit-eating primates, they also eat leaves, flowers, and insects (Ziegler et al. 2017). Their population size and general health are significantly influenced by the presence of these food sources in their habitat. Variations in fruit population dynamics are caused by changes in fruit availability brought on by anthropogenic or seasonal factors.

To secure the survival of the species by providing bigger and more connected habitats, conservation initiatives have been launched to safeguard the mona monkey and its habitat in protected areas and wildlife corridors (Gadsby et al. 2020). Furthermore, educating people about the value of protecting the Mona monkey and its natural habitat is crucial to ensuring the survival of the species for future generations.

2 Materials and Method

2.1 Study area

The grove, one of the few remaining examples of a rainforest in Nigeria, has a core area of 75 hectares and is a prime example of a real primary rainforest, which is rapidly disappearing in the West African Sub-region. The Osun Osogbo World Heritage Site is situated in Osun State, southwestern Nigeria, along the banks of the Osun River in the Osogbo Local Government Area. The coordinates of its location are 7° 45' 02" N and 4° 33' 08" E. The holy grove is located on a high area that is roughly 350 meters above sea level on the edge of Nigeria's southern woods (NCMM 2019). The primary vegetation types in the OOWHS rain forest ecosystem are savanna trees, thicket islands, and grasslands (Wahab 2014).

In 1965, The Grove was initially designated as a National Monument. To safeguard the entire 75 hectares, this original designation was expanded and changed in 1992. The Federal Government of Nigeria granted the Government of Osun State trusteeship for the Grove under the Land Use Act of 1990. Traditional practices, such as prohibitions against fishing, hunting, poaching, tree cutting, and farming, as well as myths and taboos, have been employed to safeguard the site against potential dangers. Osun Oshogbo Scare Grove is included in the National Tourism Development Master Plan, which was created in collaboration with the United Nations Development Program (UNDP) and World Tourism. It is also a significant hub for the conventional IFA oracle divination knowledge system.

The Osun Osogbo Sacred Grove was named a UNESCO World Heritage Site in 2005 in honor of its cultural and natural value. The UNESCO inscription has contributed to increasing public awareness of the grove's conservation and preservation efforts, guaranteeing the grove's survival for upcoming generations (NCMM 2019).

2.2 Sampling technique

For the population census, the total count approach was applied online transects (Olaleru et al. 2020; Spaan et al. 2017). Using the line transect approach to survey mona monkeys, the following assumptions were made. 1) The transect clearly shows the presence of every mona monkey. 2) Before being noticed, mona monkeys stay on the transect. 3) There is precise distance measuring and the Mona monkeys' placement is not affected by transects.

For this investigation, distance measurements were gathered using line transects. Due to its relative simplicity, accuracy, speed, cost-effectiveness, and precision, it is the primary approach used to survey diurnal primates.

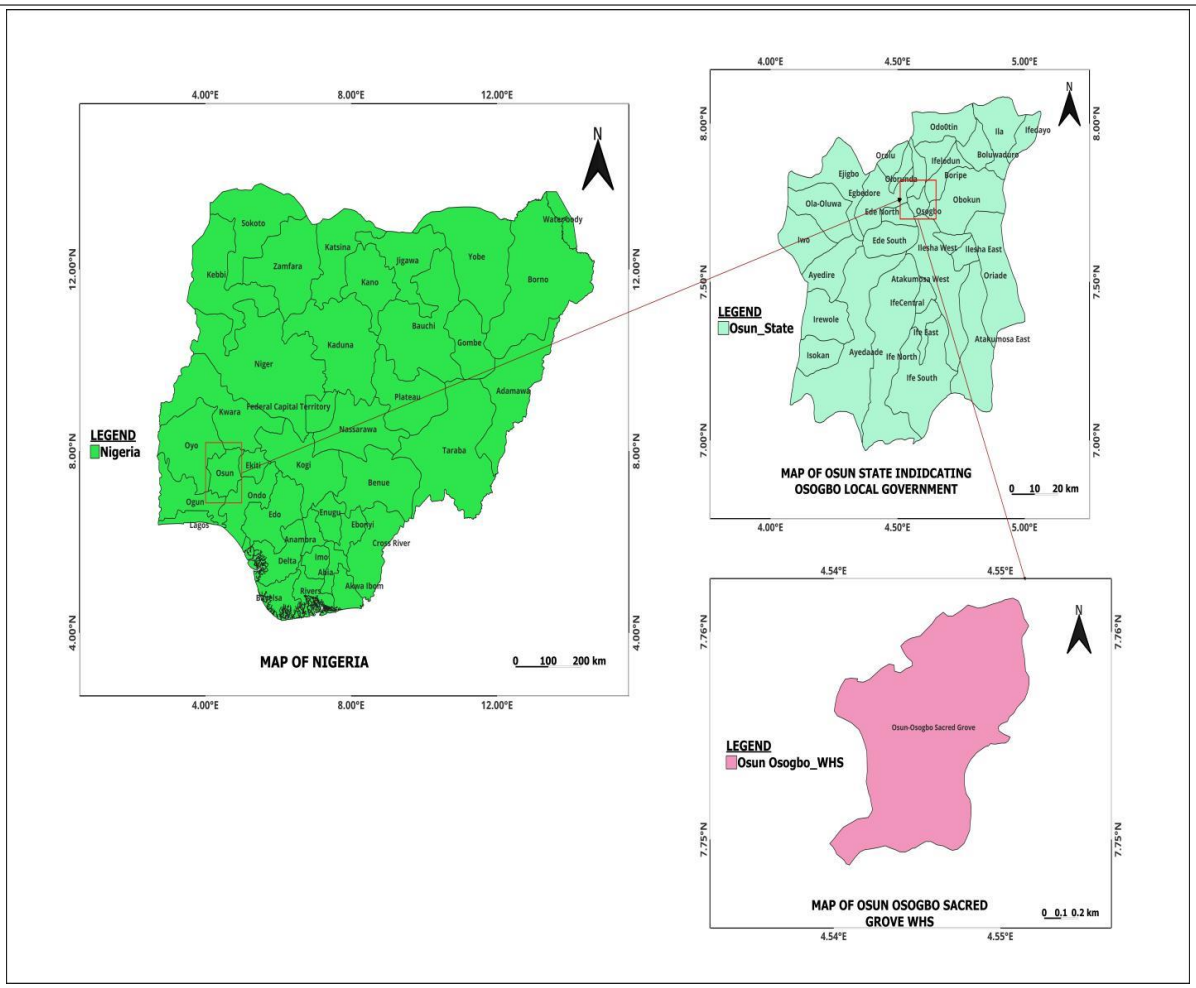

Figure 1: Map Showing the location of Osun Osogbo World Heritage Site

2.3 Field Procedure for Ecological Data Collection

Five transects were randomly and systematically selected from the study area using preexisting or established trails, tracks, and roads as transect lines. Each transect measured approximately over 0.15km and had a width of 0.02km. The transects were divided into two groups: one from the grove's first market and second palace side, one from its other side known as the first palace, and two from the main road between the two sides. To facilitate the identification of animal locations on transects, distances were indicated with flagging tapes at intervals of 0.05 km.

The survey was carried out for a total of four months from March to June 2023. In four days over the course of a month, enumerations were done between the hours of 8:00 am and 3:30 pm. At least two observers counted the monkeys they saw inside each transect interval as the transects were walked at the 1.5 km/h advised by White and Edwards. The transects began at the main entrance gate and went through the grove. Witnesses counted the monkeys from both sides of the transect for ten to fifteen minutes after spotting a group. Every fifty meters, there was a ten-minute rest period. When a single Mona monkey (Cercopithecus mona) was sighted within 20 meters of a troop, it was regarded as a member of the group, increasing the likelihood of finding other Mona monkeys that might hide or run away when approached. Other primate species that were sighted within 20 meters of Mona monkey sightings were also recorded.

The parameters were recorded using a Garmin eTrex 30X GPS, which was used to monitor the species name, time of observation, estimated population size, sighting distance, names of the trees the species was spotted on, and sighting positions (coordinates). Signs of illegal grazing, noise pollution, animal disturbance, and the gathering of non-timber forest products (NTFP) were also seen on transects. The entire hike was 5.2 km. The troop size and composition were analyzed based on the gender and body size of everyone. They were separated into alpha males, adult males, adult females, and juveniles. The alpha males were the biggest guys in the group. Males were larger than females in adulthood due to sexual dimorphism. All adult males were identified by well-developed testicles. Adult females were noticed by protruded of the nipples of nursing females.

Those who were not reliant on their mothers and were larger than infants but smaller than adult men or females were considered juveniles. Maternal clinging has been observed in infants (Olaleru et al., 2020). The diet and feeding patterns of the mona monkeys were studied using the direct observation approach during the transect walk. It was noted which plant species the animal consumed as

well as the sections of them.

2.4 Method of data analysis

The data were analyzed using both descriptive and inferential statistics, with the results shown in tables. The population of the troops was examined for significant differences (P ¡ 0.05) using the Duncan test. The study was performed using the Duncan test in the Statistical Package for the Social Sciences (SPSS) version 23 (IBM Corp., 2015).

By methodically inspecting several transects marked inside the grove and recording and gathering data (such as animal observations and GPS locations), it was possible to examine the geographical distribution of Mona monkeys and pinpoint areas of high and low abundance. The method as described by Akinsorotan (2017) was used to determine the encounter rate and species relative abundance for the species (Equations 1 and 2).

$$\text{Mean Encounter Rate} = \frac{\text{Number of sightings}}{\text{Total distance walked}} \quad (1)$$

$$\text{Species relative abundance} = \frac{\text{Species abundance}}{\text{total abundance}} \times 100 \quad (2)$$

3 Results

3.1 Mean Encountered Rate

The species' encounter rate, according to the survey was 6.9 troops/km. It demonstrates that 6.9 troops of the species were seen for every kilometer travelled along the transects.

3.2 Population Size and Relative Abundance

According to the findings, there were 220.75 mona monkeys on average in the Osun Osogbo World Heritage Site. Table 1 also displays the relative abundance of mona monkeys. Transect A had the largest relative abundance of Mona monkeys, with a relative frequency of 0.353. With a score of 0.345, Transect B exhibited the second-highest relative abundance. At a value of 0.22, Transect C showed a moderate relative abundance of mona monkeys. At a value of 0.058, the relative abundance of mona monkeys in Transect D (the Ontoto market region) was comparatively low. Transect E had the lowest relative abundance of mona monkeys (0.024) of all the transects (Table 1).

3.3 Group Composition

During the investigation, the mean group structure of mona primates in Osun Osogbo World Heritage Site was noted. A balanced sex ratio within the mona monkey (Cercopithecus mona) groups is compatible with the research's findings, which showed an average of 48 adult females and 46 adult males in the survey. We witnessed eight Alpha Males in all. With an average of 21.25 infants during the survey, an average of 97.5 juveniles was also recorded.

3.4 Troop Size and Analysis of Variance for the Troop Size

The average troop size of mona monkeys seen in Osun Osogbo World Heritage Site was investigated during the survey. Table 3 also showed the average troop size for each troop, with the greatest estimated troop size being 48.5 ± 2.65 (T7) and the lowest estimated troop size being 5.25 ± 1.50 (T9).

3.5 Food and Feeding Habits

During the survey, observations about the eating and drinking behaviors of mona monkeys were looked at. Elaesis guineensis is the most consumed and favored plant, with its fruits being used as food (Table 5). On the other hand, Alstonia boonei was found to be the least used plant species in the grove by the mona monkeys, with its leaves being used as food.

3.6 Spatial Distribution of Mona Monkeys within the World Heritage Site

During the study, a survey of the spatial distribution of mona monkeys in Osun Osogbo World Heritage Site was conducted. It can be concluded that the distribution of Cercopithecus mona in the grove is primarily driven by food sources, such as fruit trees, and that the species was most abundant in habituated areas with humans. The transects that are closest to these habituated areas, such as transects A, B and C, are concentrated with more species of mona monkeys, whereas this species is slightly distributed at transect D and E (Figure 2).

4 Discussion

According to a survey carried out at the Osun Osogbo World Heritage Site, an average of 6.9 troops of mona monkey troops were found per kilometer using the line transect method. Put differently, we observed about 6.9 troops for every kilometer we went along the transects. This suggests a rather healthy mona monkey population in the research region. Compared to Uloko and Lameed (2019) in

Table 1: Relative Abundance and average population size of Mona Monkeys in Osun Osogbo WHS.

Transects	Replicate	No of colonies	No of individuals	Total no of individual per transect	Average no of individual per transects	Relative abundance	Percentage %
A	1	3	77	312	78	0.353	35.3%
	2	3	82				
	3	3	73				
	4	3	80				
B	1	3	82	305	76.25	0.345	34.5%
	2	3	78				
	3	3	75				
	4	3	70				
C	1	1	49				
	2	1	52				
	3	1	47	194	48.5	0.22	22%
	4	1	46				
D	1	1	17				
	2	1	8	51	12.75	0.058	5.8%
	3	1	11				
	4	1	15				
E	1	1	4				
	2	1	6	21	5.25	0.024	2.4%
	3	1	4				
	4	1	7				
Total				883	220.75	1	100

Note that Transect A= Main entrance gate, Transect B=from the metal gate along the first palace to the suspended bridge area, Transect C= from metal gate area to the boundary of Fountain University and the grove, Transect D= Ontoto market area and Transect E=second place area

the Omo Forest Reserve, the estimated mean encountered rate of 6.9 km^{-1} was higher. The average population size of mona monkeys in Osun Osogbo World Heritage Site appeared to be 220.75 which was higher than that of 57 mona monkeys reported by Uloko and Lameed (2019) in Omo Forest Reserve but was lower than that of 247 individuals reported by Williams (2017) in Lekki Conservation Centre. A high population size of mona monkey (Cercopithecus mona) observed in Osun Osogbo WHS could be attributed to its lack of predators as traditional activities have been used to protect the site from any form of threats such as traditional laws, customs, myths, and taboos that forbid and prohibit people from killing this species of monkeys in the grove. The highest relative abundance of aona monkeys was observed in Transect A(around the main entrance gate to metal gate), where we encountered the species at a relative frequency of 0.353. This suggests that Transect A had the most significant number of mona monkey (Cercopithecus mona) individuals or groups during the survey. Transect B (from the metal gate along the first palace to the suspended bridge area) had the second-highest relative abundance, with a value of 0.345. This indicates a substantial presence of mona monkeys in this transect, though slightly lower than in Transect A. Transect C (from metal gate area to the boundary of Fountain University and the grove) exhibited a moderate relative abundance of mona monkeys, with a value of 0.22. While this value is lower than those of Transects A and B, it still indicates a notable presence of the species in this area. Transect D (Ontoto market area) had a relatively low relative abundance of mona monkeys, with a value of 0.058. This suggests that the number of encounters in this transect was considerably lower compared to the other transects surveyed. Transect E (second palace area) showed the lowest relative abundance of mona monkeys among all the transects, with a value of 0.024. This indicates that the presence of mona monkeys was scarce in Transect E during the survey. The variation in relative abundance across the five transects suggests that mona monkeys are not uniformly distributed within the Osun Osogbo World Heritage Site. Transects A and B appear to be hotspots for the species, with the highest encounter rates and relative abundance, while Transects D and E seem to have lower numbers of mona monkeys. The areas with the highest relative abundance of species were those along the main road (transect A), the first palace (transect B), and Iya Mopo (transect C). Conversely, the areas with the lowest relative abundance were those near the second palace (transect E) and the Ontoto market (transect D). These differences can be attributed to factors such as the variation in fruit tree abundance across each transect, supplemental feeding provided by Osun Osogbo WHS management, and sufficient food provided by tourists. The population is growing because the research area is small and there is no hunting of mona monkeys, because they are well protected by customs, taboos, and beliefs. As an alpha male always leads a troop, it was easy to spot them in groups, and the presence of one in a troop signified that troop's seniority (Olaleru et al. 2020). A systematic social hierarchy exists within the mona monkey groups, as evidenced by the observation of eight Alpha Males in total. The number of alpha males in the research region corresponds to the number of unique social units or troops. Alpha males are dominant individuals who usually lead the group. Alpha men are essential to the upkeep of group cohesiveness and successful group functioning (Haus, 2018). A balanced sex ratio within the mona monkey (Cercopithecus mona) groups is consistent with the research's findings, which showed a total of 48 adult females and 46 adult males during the survey. There are comparatively many young people making the transition from infancy to maturity in the research region, as evidenced by the presence of 97.5 juveniles. Ensuring the survival and successful development of juveniles is crucial for maintaining balanced population dynamics, as they are essential for the future expansion of the population. The youngest and newborns are most vulnerable. Because mothers provide most of the care and protection for their infants, their survival is crucial to the long-term viability of the population. While larger than the 3 to 12 mona monkeys per group observed by Bukie et al. (2021), the nine (9) groups of mona monkeys observed in this study area and the estimated number per group, which ranged from aver-

Table 2: Group Composition of mona monkeys in Osun Osogbo World Heritage Site

Troops	Replicate	Alpha Male	Adult Female	Adult Male	Juvenile	Infant	Total
T1	1	1	4	3	2	2	12
	2	1	2	6	15	1	25
	3	1	3	5	6	2	17
	4	1	2	3	8	1	15
T2	1	1	12	6	6	3	28
	2	1	5	3	5	2	16
	3	1	4	4	7	2	18
	4	1	4	7	8	2	22
T3	1	1	10	7	15	4	37
	2	1	12	6	17	5	41
	3	1	10	8	15	4	38
	4	1	9	9	18	6	43
T4	1	1	4	2	10	0	17
	2	1	3	2	7	1	14
	3	1	4	3	7	1	16
	4	1	2	6	6	0	15
T5	1	1	10	6	15	3	35
	2	1	8	8	18	5	40
	3	1	6	7	13	4	31
	4	1	4	5	8	4	22
T6	1	1	4	7	16	2	30
	2	1	2	4	15	2	24
	3	1	7	5	13	2	28
	4	1	8	7	14	3	33
T7	1	1	13	10	20	5	49
	2	1	12	9	24	6	52
	3	1	13	6	22	5	47
	4	1	6	8	25	6	46
T8	1	1	3	5	7	1	17
	2	1	2	2	3	0	8
	3	1	2	4	4	0	11
	4	1	2	5	6	1	15
T9	1	0	0	1	3	0	4
	2	0	0	2	4	0	6
	3	0	0	1	3	0	4
	4	0	0	2	5	0	7
Total	32	192	184	390	85	883	
Average	8	48	46	97.5	21.25	220.75	

age of 3 to 49 individuals, were closely similar to the average of 7 and 51 individuals per group reported by Olaleru et al. (2020). As a survival tactic, these sizable groups, nevertheless, can be the result of the merging of multiple groups. This study has demonstrated that the mona monkey is, in fact, a problematic species, as previously thought (Bukie et al. 2021). Because of their proximity to the adjacent village, the people who were frequently discovered in this location appeared to be reaping the benefits of raids, and the troop in the second palace lacked an alpha male. At the Lekki Conservation Center, the largest troop size of 48.25 ± 2.65 was found to be greater than the 32.75 ± 4.11 recorded by Olaleru et al. (2020) as well as the 20 ± 1.9 reported by Odewumi and Ogunjemite (2016).

There was no significant change in T1, T2, T4, and T8; there was also an estimated non-significant difference in T3, T5, and T6. The results of this survey indicate that the primary food source for the Cercopithecus mona species found in the Osun Osogbo World Heritage Site is fruits and seeds. These findings are consistent with those of Olaleru et al. (2020), who found that the primary food source for mona monkeys in a strictly private nature reserve is fruits and seeds. The survey concluded that fruit pulp is a superior source of carbohydrates for monkeys Lambert et al (2015). Since most of the plant materials that are fed on have seasonal fruiting, while some, like palm trees, are available year-round, Elaeis guineensis was the most used species of flora in the grove. It may be because Alstonia boonei is not a major food source for the species, or because its fruit is not available all year round, that the mona monkeys appear to consume the least of it. The availability and accessibility of food may vary with the seasons. The monkeys' eating habits may change at different periods of the year depending on the availability of various fruits and food items. It can be concluded that the distribution of Cercopithecus mona in the grove is primarily influenced by food sources, such as fruit trees, and that the highest abundance of the species occurs in areas where humans have be-

Table 3: Average Troop Size of Mona Monkeys Sighted in Osun Osogbo World Heritage Site

Month	Troop 1	Troop 2	Troop 3	Troop 4	Troop 5	Troop 6	Troop 7	Troop 8	Troop 9
March	12	28	37	17	35	30	49	17	4
April	25	16	41	14	40	24	52	8	6
May	17	18	38	16	31	28	47	11	4
June	15	22	43	15	22	33	46	15	7
Average Troop Size	17.25±5.6	21±5.29	39.75±2.75	15.5±1.29	32±7.62	28.75±3.78	48.5±2.65	12.75±4.03	5.25±1.50

Significant differences in the study were found among the troops based on observations made from the analysis of variance results for troop size. As seen in (Table 4), it was demonstrated that there were no appreciable variations among all the soldiers

Table 4: Analysis of variance for Troop size of mona monkeys in Osun Osogbo World Heritage Site.

Troop	Average Troop Size
T1	17.25 ± 5.56^{b}
T2	21.00 ± 5.29^{b}
T3	39.75 ± 2.75^{cd}
T4	21.50 ± 13.03^{b}
T5	32.75 ± 8.14^{c}
T6	32.00 ± 8.21^{c}
T7	48.50 ± 2.65^{d}
T8	12.75 ± 4.03^{ab}
T9	5.25 ± 1.50^{a}

Table 5: *

Note: Mean with same superscript are not significantly different from each other (P = 0.05)

come accustomed, which is consistent with the availability of extra food provided by tourists. These findings are supported by Matsuda's research (2020). More species of mona monkeys are concentrated in the transects near human-habitat areas (first palace, main road, and Iya Mopo area). In contrast, this species was slightly dispersed in the Ontoto market and second palace area, which may be due to a lack of fruit trees and insufficient supplemental feeding, as suggested by (Wahab 2014). More significantly, Elaeis guinæensis was more common in Transects A, C, and B, which had more fruit trees. This species has been noted as the most exploited species of monkeys in the grove. Cercopithecus mona was found to be more prevalent in these locations (Wahab et al. 2017). Troops have been seen stopping by the side of the road at specific times, generally in the afternoon or early in the morning, to wait for farmers to arrive from fields close to the Osun Osogbo WHS buffer zone. Farmers typically pass the main road that runs to the outside of the grove and towards Fountain University. The primates have become accustomed to waiting for the farmers at the side of the road as they are returning from their agricultural settlements because these farmers kindly give away some of their gathered fruits and crops (such as maize, bananas, and mangos) to the animals.

5 Conclusion

The availability of food sources determines the distribution and abundance of the species (Cercopithecus mona). Data on the prevalence and distribution of the primate species, as well as factors affecting their range in connection to the kinds of vegetation and canopy layers that support their arboreal activities, were provided by the study. The study found that the relative abundance of mona monkeys at Osun Osogbo World Heritage Site is highly significant for conservation status, management, and development. It also illustrates the significance of the species in ecosystem dynamics and how they are seen as indicators of the ecosystem's overall health. The existence and abundance of this species act as markers for the condition of the forest and the availability of essential resources. Thus, the study's findings are relevant for the efficient and fruitful management of the forest reserve with comparable biological circumstances and the Osun Osogbo World Heritage Site. It is recommended that more research be done on population dynamics evaluation based on the number of criteria that best fit the population index, and the kinds of primates found in the Osun Osogbo World Heritage Site and Reserve. This will help grow ecotourism in areas with similar ecosystems.

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Table 6: Plants species and parts utilized by mona monkey (Cercopithecus mona) in the study area

Troop	Plant species	Common name	Local name	Parts Utilized	Plant Form	Family
T1	Bambusa vulgaris	Common bamboo	Oparun	leaves Fruit	Tree Tree	Poaceae Annonaceae
	Amona	African custard-apple	Arere			
	Albizia procera	White siris tree	Ayunre	Seeds Fruit	Tree Tree	Fabaceae
T2	Elaesis guineensis	Palm tree	Igi ope	Fruit	Tree Tree	Aracaceae Annonaceae
	Amona	African custard-apple	Arere	Fruit	Tree Tree	
	Albizia procera	White siris tree	Ayunre	Seeds Fruit	Tree Tree	Fabaceae
	Funtumia elastic	Silk rubber	Ire	Fruit	Tree Tree	Apocynaceae
	Cola millenii	Monkey Cola	Obi-edun	Fruit/seeds Fruit	Tree Tree	Sterculiaceae
	Anthocleista djalonensis	Cabbage tree	Sapo	Fruit/seeds Fruit	Tree Tree	Gentianaceae
T3	Elaesis guineensis	Palm tree	Igi ope	Fruit	Tree Tree	Aracaceae
	Cola millenii	Monkey Cola	Obi edun	Fruit/seeds Fruit	Tree Tree	Sterculiaceae
	Anthocleista djalonensis	Cabbage tree	Sapo	Fruit/leaves Fruit	Tree Tree	Gentianaceae
T4	Antiaris toxicaria	Sacking	Ooro	Fruit	Tree Tree	Moraceae
	Lecaniodiscus Cupanioides	Monkey Pot	Aka	Fruit	Tree Tree	Sapindaceae
	Elaesis guineensis	Palm tree	Igi ope	Fruit	Tree Tree	Aracaceae
	Celba pentandra	White-silk cotton tree	Araba	Fruit	Tree Tree	Malvaceae
	Lecaniodiscus cupanioides		Aka	Fruit	Tree Tree	Sapindaceae
	Anthocleista djalonensis	Cabbage tree	Sapo	Fruit/seeds Fruit	Tree Tree	Gentianaceae
	Elaesis guineensis	Palm tree	Igi ope	Fruit	Tree Tree	Aracaceae

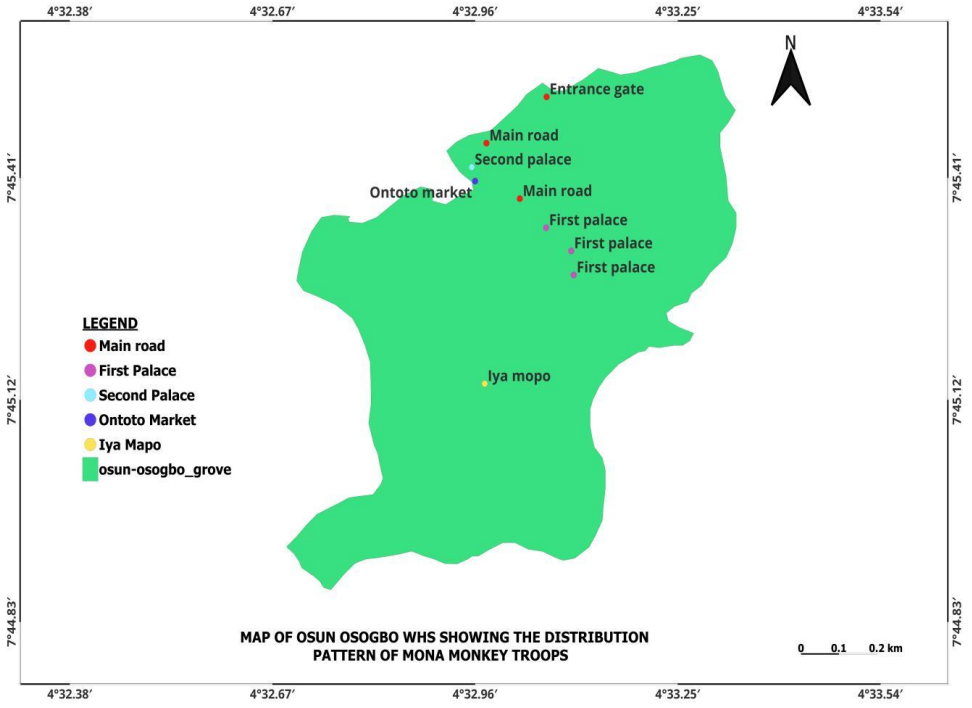

Figure 2: Map of Osun Osogbo Sacred Grove WHS showing the distribution pattern of mona monkey.

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Research Article

The impact of water hyacinth (*Eichhornia crassipes* (Mart.) Solms) infestation on physiochemical water quality of Lake Ziway, South Central Ethiopia

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Abstract

Water hyacinth (Eichhornia crassipes) is one of the most invasive weeds in aquatic ecosystems. It has been a serious threat to aquatic biodiversity. This study was conducted to investigate the impact of water hyacinth on the water physicochemical quality of Lake Ziway. Water physicochemical quality samples were taken at four sites in two triplicate and vertically stratified as surface, medium, or deeper, using an FL-2010N Digital multimeter and plastic water sampler. For PO_3 and NO_3 analyses, water samples were collected from the surface, stored in polyethylene bottles, and transported to the laboratory in an icebox. Two samples were taken from areas with dense water hyacinth cover (site 1), less dense (site 2), sparsely infested (site 3), and without water hyacinth (site 4). Furthermore, to investigate the distribution of water hyacinth, key informant interviews were conducted. The results showed that the amount of PO_3 between sites 2 and 3 was significantly different at p ¡ 0.05. The amount of NO_3 at sites 1 and 2 was significantly different from that at site 3, at p ¡ 0.05. There was a significant difference in the pH values among the sites. The pH value at site 1 was significantly different from those at sites 3 and 4 (p ¡ 0.05). The results of the study showed that there was a significant difference in dissolved oxygen (DO) among all sites at p ¡ 0.05. Pearson's correlation coefficient (r) analysis showed that water hyacinth coverage was positively correlated with PO_3 (r = 0.77, N = 4, P ¡ 0.05), NO_3 (r = 0.69, N = 4, P ¡ 0.05), pH (r = 0.16, N = 4, P ¡ 0.05), and temperature (r = 0.78, N = 4, P ¡ 0.05). On the other hand, a negative correlation was observed between DO and water hyacinth percent cover (r = -0.94, N = 4, P = 0.05). This implies that water hyacinth infestation in Lake Ziway adversely affects the water physicochemical quality of the lake. In addition, agrochemical nutrient inputs from the lake shore, intensive irrigation, and floricultural activities have been attributed by key informants to be the main sources of eutrophication in the lake, with consequent expiation of water hyacinth infestation. Therefore, an integrated management approach is urgently needed to control the infestation of water hyacinth and its further expansion into the lake.

Keywords: dissolved oxygen, invasive species, phosphate, nitrate, hydrogen potential (pH), Ethiopia

1 Introduction

Water hyacinth (Eichhornia crassipes (Mart.) Solms) is a free-floating aquatic plant widely regarded by many as one of the most highly invasive weeds in the world (van Wyk and van Wilgen 2002). Water hyacinth has been identified by the International Union for Conservation of Nature and Natural Resources (IUCN) as one of the 100 most aggressive invasive species (Téllez et al. 2008). The success of this invasive species is primarily due to its reproductive output. Water hyacinth flowers throughout the year and releases more than 3000 seeds per year (EEA 2012; Harun et al. 2021). The seeds are long-lived up to 20 years (Harun et al. 2021). It reproduces both sexually and asexually. Water hyacinth grows rapidly, doubling in population within 5–15 days (Craft et al. 2003).

Water hyacinth, due to its extremely rapid growth, has become a major floating water weed in tropical and subtropical regions (Yan and Guo 2017; Harun et al. 2021). It was introduced to Africa from South America in the early 1900s, but since the 1950s, it has become a problematic weed in Southern Africa, the Congo basin, and the Upper Nile (Lubembe et al. 2023). In the East African region, the weed was first noticed almost simultaneously in Uganda, Tanzania, and Kenya in 1987 (Ogwang and Molo 2001; Kiyemba et al. 2023).

Because of their rapid growth, massive biomass, and large surface coverage in natural water ecosystems, water hyacinth blocks sunlight, reducing the photosynthesis rate of aquatic plants (Yan and Guo 2017; Lekamge et al. 2020). Furthermore, water hyacinth has been shown to degrade water quality in lakes and rivers (Tobias et al. 2019), resulting in the loss of aquatic life (Gunaratne et al. 2009). Water hyacinth can reduce water clarity, phytoplankton production, dissolved oxygen, nitrogen, phosphorous, heavy metals, and other pollutants (Villamagna and Murphy 2010). Its rapid growth has clogged major waterways and created problems associated with navigation, national security, irrigation and drainage, water supply, hydroelectricity, and fishing in many countries (Tobias et al. 2019; Lekamge et al. 2020).

In Ethiopia, water hyacinth was officially reported in 1956 from Lake Koka and the Awash River (Stroud 1994). Infestations of water hyacinth in Ethiopia have also been manifested on a large scale in many water bodies of the country, including the Gambella area (Sobat, Baro, Gillo, and Pibor Rivers); Lake Tana, the Abay River just south of Lake Tana, and the Rift Valley (Wondenagegn et al. 2012). In varying magnitudes, it also predominated in most rift valley lakes, canals, reservoirs, and irrigation water supplies (Firehun et al. 2014). In September 2011, water hyacinth was officially recognized as one of the top ten ecologically dangerous and invasive weeds in Ethiopia (Wondie et al. 2012).

A freshwater lake in the central Rift Valley, Lake Ziway, is home to a variety of fish species (Gebremariam 1998) and water birds (Menegesha et al. 2015). Due to extensive irrigation projects brought on by the thriving flower farms in the area, the lake's volume has decreased, and its salinity has slightly increased (Ayenew & Legesse 2007; Benti 2021). Furthermore, evidence indicates that the lake is under severe anthropogenic pressure due to sediment loads from agricultural lands and heavy metal and plastic pollution due to ongoing rapid urbanization (Desta et al. 2015; Benti 2021). It has been noticed that water hyacinth has invaded the irrigation canal leading to water pump stations around Meki town (Benti 2021). In particular, the expansion of the invasive species into the lake suffocates fish and other biodiversity by preventing the penetration of oxygen through its thick mats to the bottom of the water body (King 2013). Deterioration of water quality, invasion of irrigation canals, and hampers fishery and recreational activities, impairing economic activity and aquatic ecosystem health (Desta et al. 2015; Benti 2021). However, little is known about the drivers of infestations and how infestations affect lake water quality and the health of lake ecosystems (Ayenew & Legesse 2007; Wondenagegn et al. 2012; Desta et al. 2015). Water hyacinth infestation is a relatively new phenomenon in Lake Ziway, and it is mainly caused by expansion of irrigation canals (Firhehun et al. 2014; Churko et al. 2023). However, little information exists on how the expansion of the irrigation canal affects the lake's water physiochemical quality, and there is a need for updated information on water hyacinth infestation and its impact on the water physiochemical quality of the lake to take sound management actions. Therefore, this study investigated how the infestation of water hyacinth affects the physiochemical quality of lake water.

2 Materials and methods

2.1 Study area description

The study was conducted at Lake Ziway in the Great Rift Valley zone of Ethiopia. It is situated in the eastern showa zone of the Oromia region, about 160 km from Addis Ababa (Figure 1). Lake Ziway has an open water area of 434 km^2, an average depth of 4 m, and an elevation of 1636 m asl (Zeray et al. 2016). Lake Ziway is located at 7°52' - 8°8' N and 38°40' - 38°56' E, close to Ziway town. The lake encompasses three main rivers; the two main rivers flowing into the lake are Meki and Katar, and the other river (Bulbula) flows out of the lake. Floriculture industries are situated between Lake Ziway and the main highway at altitudes between 1600–1700 m asl and are reported to draw a significant amount of water from the lake and are suspected to discharge industrial influents into the lake (MoWR 2006). The Bulbula River flows out of Lake Ziway to the south and feeds Lake Abijata. Groundwater flows from Lake Ziway toward the North-South gradient feeding Lakes Langano, Abijata, and Shala (Tenalem 2001). All of them lay at lower elevations, with Lake Shala being the final recipient. There is an irrigation canal that draws water from the lake and is used for the production of fruits around the lake, but the canal near the outlet of the lake is highly infested with water hyacinth.

The minimum and maximum annual precipitations are 729.8 mm and 1227.7 mm, respectively, while the mean annual temperature is 18.5 °C (Desta and Lema 2017). Much of the shoreline of Lake Ziway is covered with lush marshy vegetation. The islands have vegetation consisting of different trees and shrubs interspersed with climbers and herbs (Zegegye 2006).

The lake water, its shoreline, riverine woodland, and wet grassland

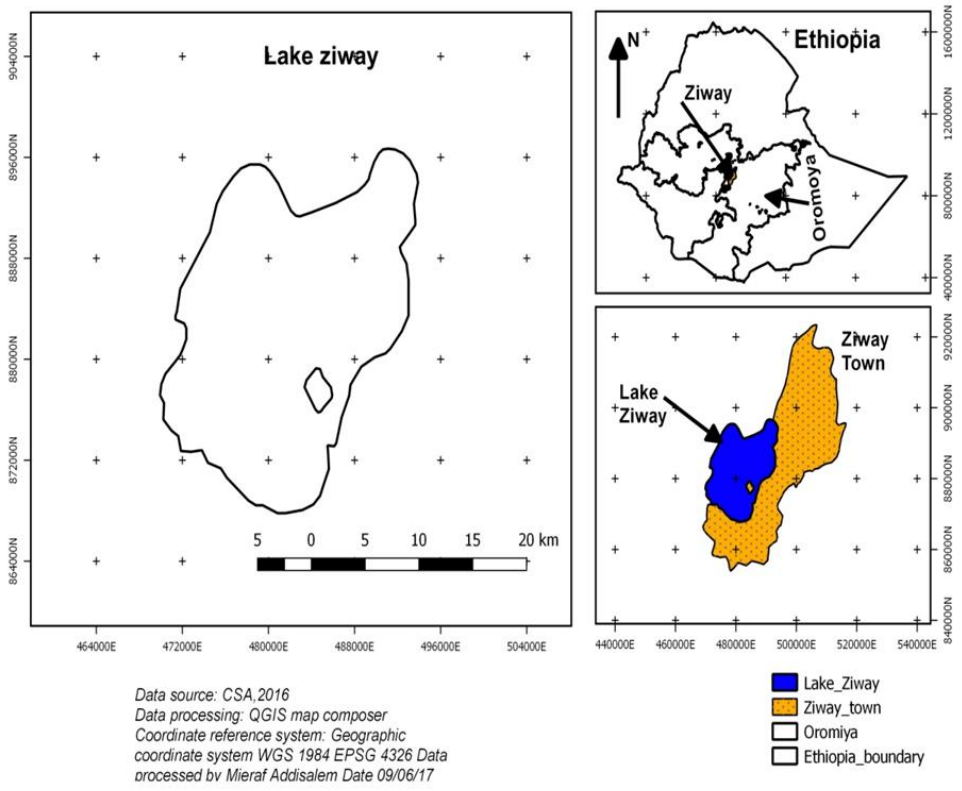

Figure 1: Location Map of Lake Ziway

habitats also serve as roosting and stopover sites for diverse and abundant resident and Palearctic migratory bird species (EWNHS 1996; Mengesha et al. 2015). Tilapia nilotica (Oreochromis niloticus) is the dominant fish species at Lake Ziway, but African catfish (Clarias gariepinus) and Crucian carp (Caracius caracius) are also occasionally encountered (Gebremariam 1998). A study reported that Phragmites australis, Typha latifolia, Cyperus articulates, Echinochloa colona, Cyperus papyrus, Echinochloa stagnina, and Schoenoplectus corymbosus were among the emerging macrophytes in Lake Ziway (Damtew et al. 2021). Furthermore, in some areas of the shoreline, two macrophytes with floating leaves and roots—Nymphaea lotus and Nymphoides indica—were also discovered. Pistia stratiotes and Potamogeton schweinfurthii were macrophytes found in the free lake-floating and submerged, respectively (Damtew et al. 2021). Mixed crop-livestock agriculture is the most significant economic activity in local communities. Rainfall is crucial to agriculture, but Lake Ziway is surrounded by irrigation. Fruits, tomatoes, onions, and maize are the main crops and vegetables grown near Lake Ziway (Desta 2021). Cattle, sheep, goats, horses, mules, and donkeys are among the animals that are raised, and the majority of crops are rain-fed (Desta et al. 2017). Small-scale trading and fishing are two more sources of income. Ziway Town is also an emerging city that is an important source of urban waste, mostly dumped in the lake. Furthermore, floriculture investment around the lake is also considered a source of pollution in the lake (Beneberu and Mengistu 2009).

2.2 Method

A reconnaissance survey was carried out to identify localities infested by water hyacinth. Following the reconnaissance survey, four sites were purposely selected based on the level of infestation. There were four sampling sites, where three had water hyacinth and one did not. Sampling sites were established along the length of the irrigation canal to establish sampling sites at different levels of water hyacinth infestation. Site 1 was a highly infested site, while Site 2 was moderately infested, and Site 3 was sparsely infested. The classifications of high, low, and medium were based on observation, expertise recommendations, and local communities' suggestions (Chruko et al. 2023). Each sampling site had two replicates of samples, making up a total of eight samples (Chruko et al. 2023). The distance between Sites 1 and 2 was 89.73 m, Sites 2 and 3 were 114.13 m and site three and four (control) was 13.4 km. The distance between two replicates of sampling plots ranged from 15.65 m to 24.19 m based on the width of the canal and level of infestation (Table 1). Each sampling plot was stratified vertically into three strata: surface, middle, and deep. The stratification height from sampling point to sampling point varied based on the depth of the water at each sampling site (Table 1). The depth of stratification varied from 0.22 at Site 2 to 1.75 m at the control site (site four) (Table 1).

From each sampling point and vertical strata (surface, middle and deep), an FL-2010N digital multimeter was used to measure pH, dissolved oxygen, and temperature on site. For PO_3 and NO_3 anal-

Table 1: Depth of each stratum at the sampling sites

Sample site	Geographical location	Distance between sampling plots	Sampling point	Depth (cm)		
				Surface	Middle	Deep
1	8°6'57.90"N, 38°4823.80"E					
	8°6'57"N, 38°48'24.26"E	15.65 m	1	0	0.35	0.7
			2	0	0.2	0.4
2	8°6'55.01"N, 38°48'22.96"E					
	8°6'54.95"N, 38°4823.57"E	18.94 m	1	0	0.3	0.6
			2	0	0.11	0.22
3	8°6'51.64"N, 38°48'21.77"E					
	8°6'8.82"N, 38°48'9.91"E	16.51 m	1	0	0.15	0.3
			2	0	0.3	0.6
4	8°6'8.82"N, 38°48'9.91"E	24.19 m	1	0	0.87	1.75

yses, water samples from each sampling point and vertical stratum were collected from the surface, stored in polyethylene bottles, and transported to the laboratory in an icebox. Water samples were collected using 3 mL plastic containers and rinsed with distilled water before use to remove any remaining contaminants. The water samples were temporarily stored in an ice-packed cooler to maintain the physical properties of the water, transported to Hawassa University General Chemistry Laboratory, and stored in a refrigerator at approximately 40 °C prior to analysis (Gangwar et al. 2012). The same sites established for physicochemical analysis were used. A total of 8 plots with a size of 1 m x 1 m ($1m^2$) were used to sample the extent of water hyacinth infestation. In each sampling plot, the percent cover of water hyacinth was estimated using the prepared sampling quadrant, which contains 100 squares; each square is 1 m x 1 m. The coordinates of each sampling plot were recorded using Gramin GPS.

Key informants (KI) from the surrounding kebele and Ziway Fishery research centers were selected based on their knowledge of water hyacinth, as informed by Ziway Agricultural Research Fishery experts, fishing experience, experience of involving in water hyacinth management, and duration of stay in the localities. Since the purpose of the key informant study was to supplement the correlation between water hyacinth infestation and the physiochemical quality of Lake Ziway, due to limitations in time and budget, this study focused on one kebele. Based on the information obtained from Ziway Agricultural Research Fishery experts, one kebele was the most important source of water hyacinth-infested water. The selection of these KIs from the kebele was carried out using the snowball method. Accordingly, six farmers from the kebele were randomly asked to give the name of 4 KIs. Out of the 24 candidate KIs, 10 top rankings were selected. On the other hand, from the Ziway Agricultural Research Fishery Center two experts with experience working on water hyacinth were purposively selected.

The key informant interviews focused on gathering information on the history of the water hyacinth invasion, possible causes of infestation, impacts, and management efforts. The interview also assessed the point and non-point agricultural activities performed by the local community that tend to facilitate water hyacinth infestation and the awareness of the control measures and possible impacts of water hyacinth. Interviews were conducted with pre-prepared questionnaires in English and were translated into Amharic.

2.3 Data analysis

Data were coded and entered a computer using Microsoft Excel 2013 and statistical software. The collected data were analyzed using SPSS (statistical package for social sciences) version 20. One-way ANOVA was used to compare the mean physicochemical parameter values among different sites. Pearson's correlation analysis was used to determine whether a correlation existed between physicochemical parameters and the percentage of water hyacinth cover.

3 Results and Discussion

3.1 Physicochemical parameters

The highest mean concentration (0.41±0.54) of phosphate was recorded at site 2, and the lowest (0.22±0.21) was found at site 3 (Table 2). There was a statistically significant difference (p¡0.05) in the concentration of phosphate between sites two and three. The highest mean concentration (1.76±0.25) of nitrate was found at site 2, and the lowest (1.35±0.29) was recorded at site 3. There was a statistically significant difference (p¡0.05) in the concentration of nitrate between sites two and three and between sites one and three (Table 2). The highest pH and DO were recorded at site 4. There was a statistically significant variation in the DO concentration among all sites (P¡0.05) (Table 2). The highest mean temperature (24.23±0.99) was recorded at Site 1 and the lowest (22.65±1.62) was recorded at Site 3 (Table 2). The differences in the mean concentration of nutrients among the sampling sites could be due to differences in the coverage of water hyacinth, where high water hyacinth abundance reduces the concentration of nutrients in the water.

Water hyacinth has a higher nutrient uptake capacity than other macrophytes (Rodríguez-Gallego et al. 2004). This may have a significant impact on the concentration and turnover rates of nutrients

in a lake (Pinto and Greco 1999). The authors also stated that water hyacinth can significantly reduce nutrient concentrations in water bodies depending on the extent of cover. Similarly, Lekamge et al. (2020) reported that the nitrate concentrations in infested areas were significantly lower (p¡0.05) than those on shorelines without water hyacinth. This indicates that water hyacinth took up nitrates from the lake water, which may have a significant impact on the concentrations and turnover rates of nutrients in the Lake. Various studies have indicated that water hyacinth concentrations reduce nitrate concentrations (Rommens et al. 2003; Greenfield et al. 2007; Lekamge et al. 2020).

The highest concentration of NO_3 at Site 2 compared to Sites 1 and 3 could probably be due to the dung from cattle in the catchment, since there is an animal ranch a few meters ahead from the canal. Consequently, livestock were more frequently observed at Site 2. It is believed that cattle fed (locally known as furshka) are mixed with urea, which is rich in nitrogen; thus, when the cattle's waste enters the water level of nitrate, it tends to increase. It has been widely reported that the main nitrate sources are animal waste, commercial fertilizer, and decaying organic matter (Mayer et al. 2002).

The ANOVA results showed that pH was significantly lower in water hyacinth-infested areas compared to shorelines without water hyacinth, and the mean pH of all sites was 7. This is in line with studies conducted by Yan and Guo (2017) and Lekamge et al. (2020), who reported that the optimum growth of water hyacinth occurs in eutrophic, still, or slow-moving fresh water with a pH close to 7. According to Melissa (2017), water hyacinth can tolerate acidic water but cannot survive in salt or brackish water. The lower concentration of dissolved oxygen in areas highly infested by water hyacinth could be due to the presence of water hyacinth affecting the quality of the lake by decreasing the amount of oxygen that is available in infested areas.

Because water hyacinth grows so rapidly, the mats constantly produce detritus, which decomposes and increases the oxygen demand in the water column (Tobias et al. 2019). The mats of the weed could avoid the transport of oxygen; also, decomposed parts of the weed could inhibit the transport of oxygen, which in turn threatens the biodiversity of the lake (Degaga 2018). Likewise, studies have reported lower levels of dissolved oxygen under water hyacinth canopies by average spot measures of below 5 mg/L in water hyacinth (the minimum level for fish survival) (Troutman et al. 2007; Miskella et al. 2021). Therefore, the presence of water hyacinth implies a continued decline in the levels of dissolved oxygen from the control group to highly infested sites (site 1), which threatens the biodiversity of the lake.

Along the depth of the water (surface to deep), the concentration of phosphate tended to slightly decrease (Figure 2), although no significant difference (p¿0.05). The results of the study showed that at the three strata, there is an optimal amount of phosphate for the growth of water hyacinth. Similarly, it has been reported that the half-saturation coefficient for water hyacinth grown under constant conditions ranges from 0.02 to 0.1 mg/L for phosphates (Acero 2019).

Along the depth of the water (surface to deep), the concentration of nitrate tended to increase at most sites but decreased at Site 3 (Figure 3). However, no significant differences were observed among the vertical stratifications of the sites (p¿0.05). The results of this study showed that at the three strata there is an optimal amount of nitrate for the growth of water hyacinth. A previous study pointed out that the half-saturation coefficient for water hyacinth grown under constant conditions ranges from 0.05 to 1 mg/mL for nitrogen (Prasetyol et al. 2021).

Along the depth of the water (surface to deep), the temperature concentration tended to slightly decrease at sites two and three (Figure 4). The slight increase in temperature was a result of the dense mats of water hyacinth over the water surface, which blocked the exchange of heat between the lake surface and the atmosphere (Navarro and Phiri 2000). At the same time, the decay of organic matter from water hyacinth results in heat generation and therefore the rise in temperature (Getahun and Kefale 2023). A similar study by Ndimele (2012) also showed that dense mats of water hyacinth over the surface block the exchange of heat between the water column and depth. The results show that all sites are favorable for water hyacinth growth. Similarly, According to Prasetyol et al. (2021), good growth can continue at temperatures ranging from 22°C to 35°C, and plants will survive frosting.

Along the depth of the water (surface to deep), the pH values tended to remain almost constant at all sites (Figure 5). This indicates that the pH value along each stratum is optimal for water hyacinth growth. This could be the reason why water hyacinth can grow over the range of acidity to alkaline. According to Nandiyanto et al. (2024), water hyacinth plants grow over a pH range of 4.0–10.0, and water hyacinth plants growing in either acidic or alkaline media tend to change their pH toward neutrality. However, According to El-Gendy (2004), water hyacinth plants do not survive in water media with pH $\leq$4.

Along the depth of the water (surface to deep), the DO concentration tended to slightly decrease at all sites (Figure 6). The fact that DO levels dropped from surface to depth could be due to the formation of a dense mat of water hyacinth in the infested sites and the metabolic activities of epiphytic organisms in the lake in the control group.

The high DO level near the water surface is probably attributed to the release of oxygen by phytoplankton during photosynthesis. According to Puyate and Rimrukema (2008), the intensity of sunlight in a water body decreases with depth, such that the photosynthetic activities of phytoplanktons decrease with depth. Generally, the DO level in water increases as the pressure in the water increases or as the temperature of the water decreases (Villamagna and Murphy 2010).

The abundance of water hyacinth began in the canal (Figure 7). The canal was located 1.5 km from the open lake, and the abundance was categorized as highly dense, less dense, and sparsely populated. The highly populated started from the beginning of the canal and was sparsely at the shore of the open lake. Based on the percent cover result, site one is found to be a highly infested site (99%), while site two is dense (91%) and three is sparsely allocated (31%). site four (control) had 0% cover infestation (Figure 7).

Table 2: The mean difference (Mean±Sd) values of water quality parameters at the sample sites

Parameters	Site one	Site two	Site three	Site four
PO_3 (mg/l)	0.28 ± 0.10^{ab}	0.41 ± 0.54^{b}	0.22 ± 0.21^{a}	0.29 ± 0.74^{ab}
NO_3 (mg/l)	1.73 ± 0.35^{b}	1.76 ± 0.25^{b}	1.35 ± 0.29^{a}	1.6 ± 0.22^{ab}
pH	8.02 ± 0.12^{a}	8.08 ± 0.34^{a}	8.78 ± 0.20^{b}	9.03 ± 0.07^{b}
DO (mg/l)	0.46 ± 0.21^{a}	3.25 ± 2.06^{b}	5.42 ± 1.23^{c}	7.43 ± 0.28^{d}
Temp (°C)	24.23 ± 0.99^{b}	24.08 ± 0.56^{b}	22.65 ± 1.62^{a}	22.77 ± 0.77^{a}

Table 3: *
Note: different letters on the mean value within a row indicate significant difference at p¡0.05

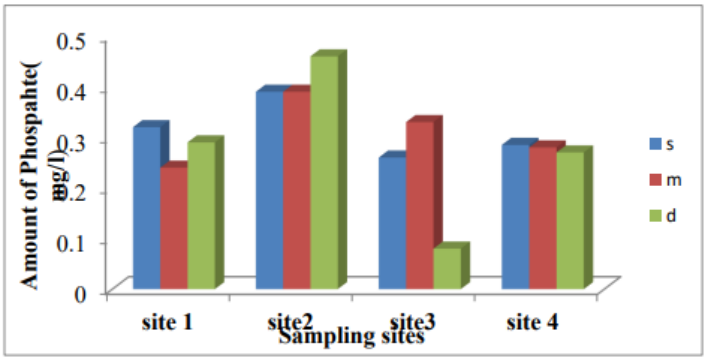

Figure 2: Concentrations of phosphates between sites along vertical stratification (surface, middle and depth). Note: s = surface, m= middle and d= depth

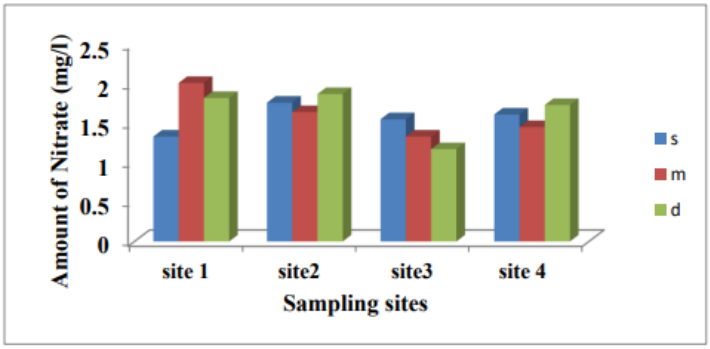

Figure 3: Nitrate concentrations along vertical stratification (surface, middle and depth) between sites at different depths. Note: s = surface, m= middle and d= depth

3.2 Water hyacinth abundance

Water hyacinth abundance (expressed as percent cover) was positively correlated with PO_3 (r = 0.77, N = 4, P ¿ 0.05), NO_3 (r = 0.69, N = 4, P ¿ 0.05), pH (r = 0.16, N = 4, P ¿ 0.05), and T (r = 0.78, N = 4, P ¿ 0.05) (Table 3). However, DO was negatively correlated with water hyacinth abundance (r = -0.94, N = 4, P¡0.05).

The positive correlation of PO_3 with water hyacinth abundance, because water hyacinth requires a sufficient amount of PO_3 for optimum growth. Consequently, if the water has sufficient phosphate, it will enhance the growth and percentage coverage of water hyacinth in the water body. Similar studies have shown that the colonial growth of water hyacinth is correlated with the nutrient levels of water bodies, especially phosphorus (Xie and Yu 2003; Acero 2019).

The positive correlation of NO_3 with water hyacinth abundance could be due to the fact that water hyacinth takes nitrates from the lake and uses them for growth and biomass production (Nandiyanto et al. 2024). Similarly, a study by Aoyama and Nishizaki (1993) revealed that plant nutrient content is a more accurate indicator of plant growth, with a linear relationship between the percentage of nitrogen in leaves and growth rate. Relatively lower pH was recorded in water hyacinth-infested areas. Similarly, Momanyi (2012) reported that pH was significantly lower (P¡0.05) in a water-hyacinth-infested area (6.92±0.04) than in open water (7.71±0.05).

The increase in temperature over areas with thick mats of water hyacinth is mainly attributed to dense mats blocking the exchange of heat between the water column and the atmosphere, thus increasing the water temperature (Prasetyol et al. 2021). Likewise, Bayu et al. (2024) indicated that Lake Tana experienced high temperatures in areas with high levels of water hyacinth infestation.

The negative correlation between DO and water hyacinth abundance could be due to the fact that when the mat of the weed covers the surface of the water body, the transportation of oxygen from the atmosphere to the lake decreases. Thus, the amount of DO inside the mat decreases, and when the large mats of the weed decompose, the amount of DO decreases as the heat generated from the decaying organic matter in water hyacinth increases. Furthermore, increases in temperature could also reduce the amount of oxygen dissolved in water because, in general, warmer water holds less oxygen than cooler water (Villamagna and Murphy, 2010). Similarly, Masifwa and Denny (2001) found an inverse relationship between dissolved oxygen concentrations and water hyacinth abundance in Lake Victoria (Uganda).

3.3 Drivers of water hyacinth infestation

According to UNEP (2012), the spread of invasive alien species is neither easy to manage nor reverse, and it threatens biodiversity, economic development, and human well-being. As key informants explained the impact of water hyacinth infestation on the social as-

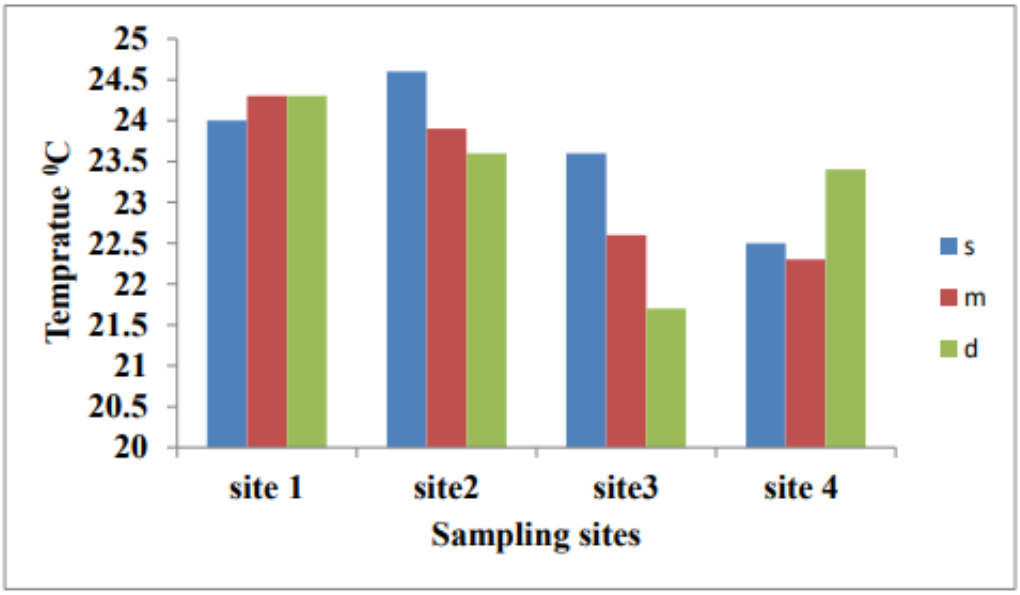

Figure 4: Temperature values between sites along vertical stratification (surface, middle and depth). Note: s = surface, m= middle and d= depth

Table 4: Pearson's correlation coefficients (r) for water quality parameters with water hyacinth coverage.

Water quality parameters	Water hyacinth coverage (Percent cover)	p-value
PO_3	0.77	0.232
NO_3	0.69	0.307
pH	0.16	0.837
DO	-0.94	0.059
Temp	0.78	0.222

Table 5: *
Note: PO_3, Phosphate; NO_3, Nitrate; pH Potential of Hydrogen; DO; Dissolved Oxygen; TEMP, Temperature

pects, the communities had a fear that after five years, the lake would be in a dangerous situation. The common social impact of water hyacinth in the study area is expressed as difficulties in boating access, navigability, recreation, and pipe systems for agriculture (Table 4). Similar studies by Ndimele and Jimoh (2011) and Patel (2012) showed that dense mats disrupt socioeconomic and subsistence activities such as ship and boat navigation and restrict access to water for recreation, fisheries, and tourism. If the waterways are blocked, water pipes are clogged. Water hyacinth increases mosquito habitat by providing larval breeding sites that mosquito predators cannot reach, creating microhabitats for the vectors of malaria, encephalitis, and schistosomiasis (Minakawa et al. 2012). From an economic perspective, when the lake is polluted, the amount of water is declining, thus directly decreasing the amount of fishing in cases where people depend on the sale of fish. According to a study conducted in South Africa, the estimated economic costs due to invasive alien species are currently above US700 million (R6.5 billion) per annum (Wilgen and Lange 2011).

Infestations of water hyacinth affect biodiversity. The dense mats of the weed covering the water surface lead to deoxygenation of the water, affecting all aquatic organisms. A dense water hyacinth cover enhances evapotranspiration.

Key informants informed me that from an environmental point of view, the color of the water is dark brown, especially in highly infested areas; this might be due to debris from dead water hyacinth. Similarly, Maliu (2001) stated that the death and decay of water hyacinth vegetation in large masses may create anaerobic conditions and lead to the production of badly smelled or even lethal gases. This is a major problem for the inhabitants since some of them still use this water for bathing and laundry.

Birds that rest on the water before emergence almost do not step on the infested area, and at last, the place is losing its recreational value. In line with this study (Minakawa et al. 2012), even smaller infestations of water hyacinth along shorelines can prevent ducks, turtles, snakes, and frogs from seeking shelter. Aquatic vegetation provides habitats and cover for aquatic invertebrates and fish, providing a prey base for many bird species (Menegesha et al. 2015). A study held in Florida (USA) showed that birds that were seen feeding on water hyacinth mats more frequently found prey around the perimeter of the mats than within the core of the mats (Villamagna and Murphy 2010).

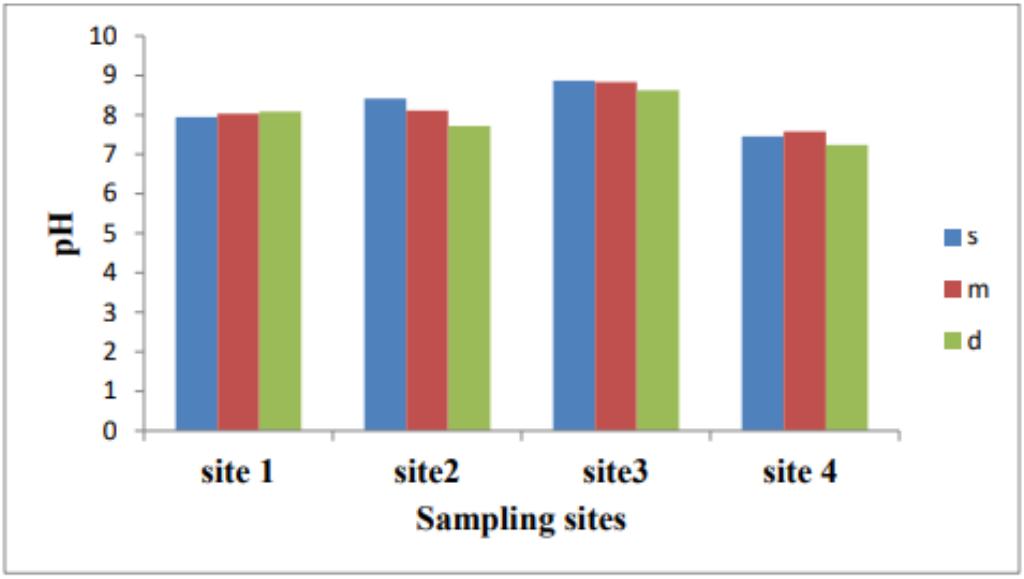

Figure 5: pH value between sites along vertical stratification (surface, middle and depth). Note: s = surface, m= middle and d= depth.

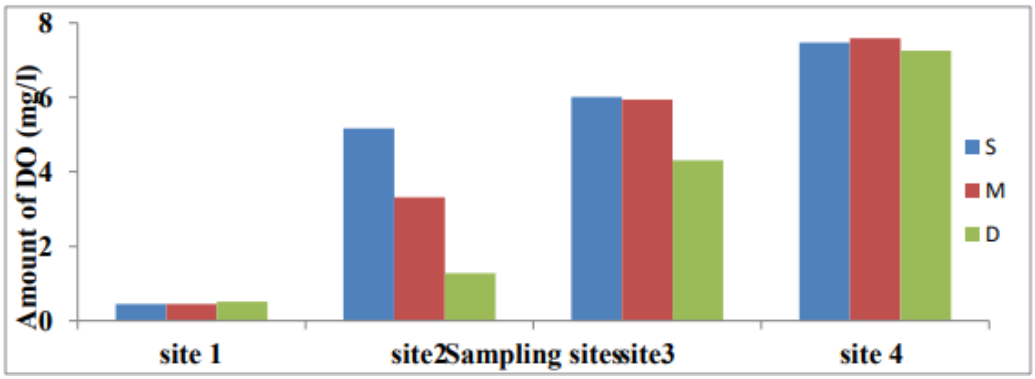

Figure 6: DO values between sites along vertical stratification (surface, middle and depth). Note: s = surface, m= middle and d= depth.

3.4 Conclusions and recommendations

The study revealed that water hyacinth infestation increased the levels of PO_3, NO_3, pH and T^0, whereas declining DO concentrations in Ziway Lake. High oxygen demand or depletion of oxygen due to high organic matter decomposition and low photosynthesis by masked benthic algae may lead to rapid expansion of water hyacinth. Low levels of dissolved oxygen catalyze the release of phosphorus from the sediment, which in turn accelerates eutrophication and can lead to an increase in water hyacinth. Furthermore, agrochemical nutrient inputs from the lake shore, intensive irrigation, and floricultural activities have been attributed by key informants to being the main sources of eutrophication in the lake. Therefore, the presence of water hyacinth implies a continued decline in the levels of dissolved oxygen from the control group to highly infested sites (site 1), which will lead to threats to the biodiversity of the lake.

Finally, an integrated control method for water hyacinth was recommended to stop further expansion of the weed into open lakes. The management of water hyacinth in Lake Ziway should involve a multidisciplinary approach and should be designed in a way that the highest political and administrative levels recognize the potential seriousness of weed infestation. When using water facilities, such as dams, lakes, and rivers, it is recommended that all clothing, boats, trailers, water vessels, and any related equipment be free of plant material before use. This requires better management of urban waste, agricultural productivity inputs, and soil and water conservation practices.

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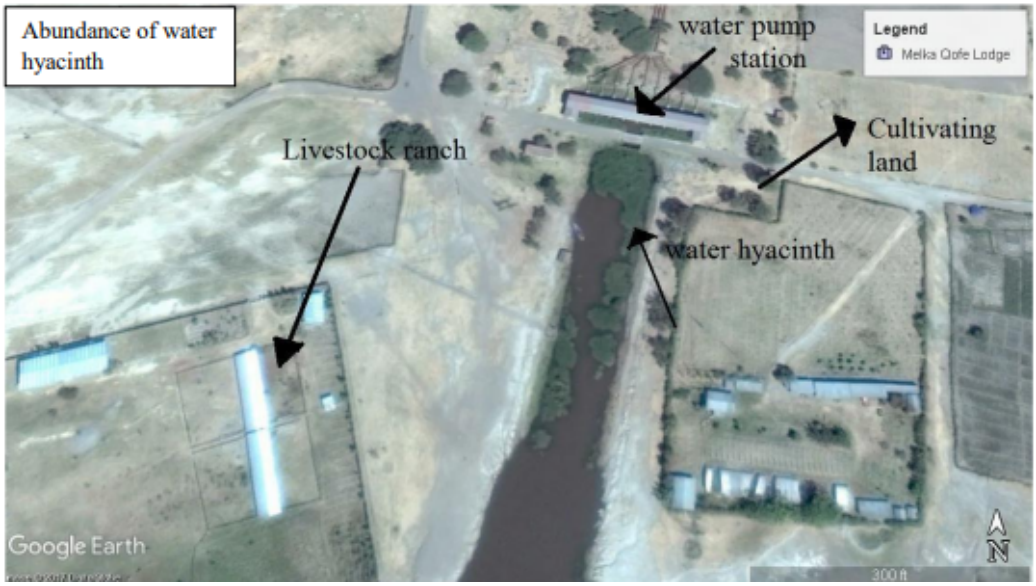

Figure 7: Map showing abundance of water hyacinth along the irrigation canal and the major agricultural drivers of water hyacinth infestation.

Table 6: Key informant interview responses regarding drivers of water hyacinth infestation of Lake Ziway.

	Responses	Yes	No
1	Water hyacinth infested the area in 2008 E.C	11	1
2	An excavator from the Koka Dam brought the invasive species to the irrigation canal	10	2
3	The invasion of water hyacinth has affected fishing	9	3
4	Water hyacinth invasion affected water turbidity	9	3
5	100-kg fertilizer per hectare per year is applied on farm lands around the lake.	8	4
6	Solid and liquid wastes are dumped into the lake or lake's tributaries	7	5
7	Approximately 90% of the farmers used pesticides and herbicides every time they cultivated crops.	11	1
8	We assume that the source of disease-causing organisms infested lakes	11	1
9	The water hyacinth is growing	10	2
10	Water hyacinth appearance affects laundry and bathing around infested areas	11	1
11	Water Hyacinth infestation affected swimming, fishing, and boat movement	12	0
12	Water hyacinth has social, economic, and ecological impacts	12	0

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Research Article

Traditional knowledge and attitude of the local communities towards wildlife conservation in and around fragmented Forest of Germeba Mountain in southern Ethiopia

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Article Info

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Abstract

The role of traditional knowledge and attitude of the local community about wildlife conservation is fundamental for sustainable wildlife conservation. Therefore, the study investigated the traditional wildlife conservation knowledge and factors that determine attitudes towards wildlife conservation in and around fragmented Forest of Germeba Mountain in southern Ethiopia. A total of 108 respondents were randomly selected and interviewed using structured questionnaire. Data were also collected using key informant interviews and focus group discussions. Descriptive statistics and binary logit model were employed to analyze the data. The results of the study revealed that the majority (77.8%) of the local community could identify wildlife species in the study area. 87 % of the respondents perceived a change in wild animals' abundance in their area. Generally, the vast majority of respondents (96.5%) had positive attitude towards wildlife conservation. Binary Logistic regression analysis indicated that educational status (p=0.05), age (p=0.01) and traditional knowledge (p=0.010) were significant variables in explaining attitude of local community towards wildlife conservation. The study revealed that the local community demonstrated a considerable level of traditional knowledge and positive attitude about wildlife conservation. Hence, the indigenous knowledge about wildlife conservation can be used as an input for knowledge-based conservation in the area.

Keywords: attitude, Nensebo, indigenous knowledge, wildlife conservation

1 Introduction

Traditional ecological knowledge is defined as a cumulative experience of knowledge and beliefs, handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment (Cheveau et al. 2008; Neuman 2021). Local ecological knowledge is a subset of local knowledge that passed down through generations and derived from the long duration of the know-how interacting with nature especially with wildlife through trial and error by virtue of their closeness with nature (Davis and Wagner 2003; Berkes 2018; Haq et al. 2023). People have traditional knowledge and customs practiced about the traditional values of wildlife such as cultural, medicinal and nutritional values (Ocholla et al. 2016).

Multiple forms and sources of knowledge are needed to support complex decisions regarding natural and human dimensions (Kadykalo et al. 2021). Inadequate details of ecological knowledge of a species indicate that more knowledge is likely to come from local knowledge than wildlife professionals would expect. The use of indigenous knowledge systems in wildlife management has now caught the interest of global scientists and policy makers (Sobrevila 2008; Aswani et al. 2018; Abukari and Mwalyos 2020).

Local ecological knowledge plays a vital role in ecological monitoring by providing early warning signs of ecosystem change and is valuable in validating scientific hypotheses and suggesting new research directions. It entails detailed observations of population ecology and species interactions, which arise from long-term association with a particular flora and fauna (Kimmerer 2002; Cebria´n-Piqueras et al. 2020; Haq et al. 2023). Therefore, including communities' traditional knowledge should be the starting point in any wildlife management endeavor because this knowledge is useful

to improve management system and to make wildlife conservation more participatory (Bajracharya et al. 2007; He S et al. 2020).

Attitude is either a positive or a negative response towards one or more stimuli or a rational evaluation of a particular entity, which reflects the beliefs or possible conduct and behavior that people hold about certain activities such as wildlife conservation (Karanth et al. 2008; Bragg and Reser 2012). Attitude can also relate to the point of views of communities about the benefits and problems they associate with the wildlife conservation and socio-economic variables (Redford and Stearman 1993; Ochieng et al. 2021; Duan et al. 2022; Legese 2024). Attitude is understood to be the major antecedent of people's behavior in relation to designing proper strategies and policies that can address local residents' needs and expectations and can be explored by further asking the indigenous people whether they like or dislike the conservation activities (Allendorf 2010; Tesfaye 2017).

Understanding and documentation of existing local people's attitudes towards wildlife management are needed to address the wildlife conservation problems such as resource over exploitation and human-wildlife conflict and play a major role in the success of wildlife conservation (Charnley et al. 2007; Mogomotsi et al. 2020). Involving local communities in conservation activities often reduces conflict between local communities and conservation authorities (Holmes 2013; Ochieng et al. 2021). Participation of the local people can prevent problems such as increased illegal hunting, habitat encroachment or destruction, violence and would help to identify what kind of programs would facilitate the participation of people and to develop community-based conservation (Pimbert and Pretty 1997; Angwenyi et al. 2021). Previous studies have indicated that local communities around protected areas received less benefit from the wildlife conservation and poorly participated in management of protected areas (Bauer 2003, Gandiwal et al. 2014, Mekonen et al. 2017, Abukari and Mwalyosi 2018, Abukari and Mwalyosi 2019, Kegamba et al. 2022). Over decades this approach has been tested and proved to be ineffective for sustainable wildlife conservation. On the other hand, some studies have pointed out that active community participation in protected area management incorporating their traditional knowledge handed down through generations have promoted sense of ownership and positive attitude towards wildlife conservation (Epandaa et al. 2019; Park et al. 2020; Sinthumule and Mashau 2020; Ochieng et al. 2021; Werdel et al. 2024).

In developing countries, like Ethiopia, indigenous ecological knowledge is important because 85% of the people depend on natural resources which are found in wild areas for economic development and food security (Abebe et al. 2011; Wassie 2020; Kidane and Kejela 2021). Recently, conservation agencies in Ethiopia have begun to recognize the importance of incorporating local people's attitude in wildlife conservation, although in most conservation areas, limited efforts have been made to involve local people in wildlife management (Nishizaki 2005). Few studies have been conducted in Ethiopia to explore the opportunities and challenges of participatory wildlife conservation with emphasis on traditional knowledge and attitude towards wildlife conservation (Kumssa and Bekele 2014; Biru et al. 2017; Mekonen et al. 2017). However, considering the wildlife resources, topographic, agro climatic and socio-economic diversity in Ethiopia, more studies have to be carried out in different parts of the country. As a result, there is a need to document the local community indigenous knowledge and attitude towards wildlife conservation in different parts of the country to develop sustainable national wildlife conservation.

Fragmented Forest of the Geremba Mountain is an area with vegetation characteristics of remnant dry evergreen Afro-montane Forest in the lower altitudes, dominated by alpine bamboo in the middle altitudes and sparsely covered by Erica scrubland in the higher altitudes (Getachew 2019). The mountain is a home for diverse large wild mammals and birds including the endemic Menelik bushbuck and Bale Monkey (Jemal 2018; Worku and Girma, 2020). The area is mainly managed by the district environment and forest office with some participation of the local communities. Despite the fact that the area is home for diverse wildlife species, it is surrounded by human dominated landscape often encroaching in to the locations of wildlife habitat. However, there is no study that attempted to explore the traditional knowledge of the local communities and other actors that determine attitude of the local people towards wildlife conservation. Hence, this study investigates the existing indigenous knowledge and factors that affect the attitude of local communities towards promotion of sustainable wildlife (mostly large wild mammals) conservation in the study area.

2 Materials and methods

2.1 Description of the study area

Fragmented Forest of the Geremba Mountain is located in Arbegona district which is one of the 31 districts of the Sidama National Regional State of Ethiopia. It is located 74 km and 349 km from Hawassa (the capital city of the Sidana Region) and Addis Ababa, respectively. Geographically, Arbegona is situated between 6°38' to 6°49 ' N and 38°34' to 38°49' E (Figure 1).

Arbegona district is found in the southern two agro-ecological zones namely; Dega (86%) Ethiopia highland and mainly characterized by and Woyna Dega (14%) (Abel et al. 2016). The Annual rainfall ranges between 1250 to 1300 millimeter per year (Worku and Girma 2020) and the temperature ranges between 14 to 18 °C. The altitude extends from 2200-3336 m above sea level (Worku and Girma 2020).

The vegetation of the area is characterized by dry ever green Afromontane Forest with dominant plant species such as Erica arborea, Yushania alpina and Hagenia abyssinica (Getachew 2019). A total of 10 species of large wild mammals that included two endemic species (Chlorocebus djamdjamensis, Tragelaphus scriptus meneliki), Panthera pardus, Canis aureus, Crocuta crocuta, Felis serval, Papio anubis, Sylvicapra grimmia, Hystrix cristata and Orycteropus afer were documented in the area (Worku and Girma 2020). A total of 74 species of birds were found in the area (Jemal 2018).

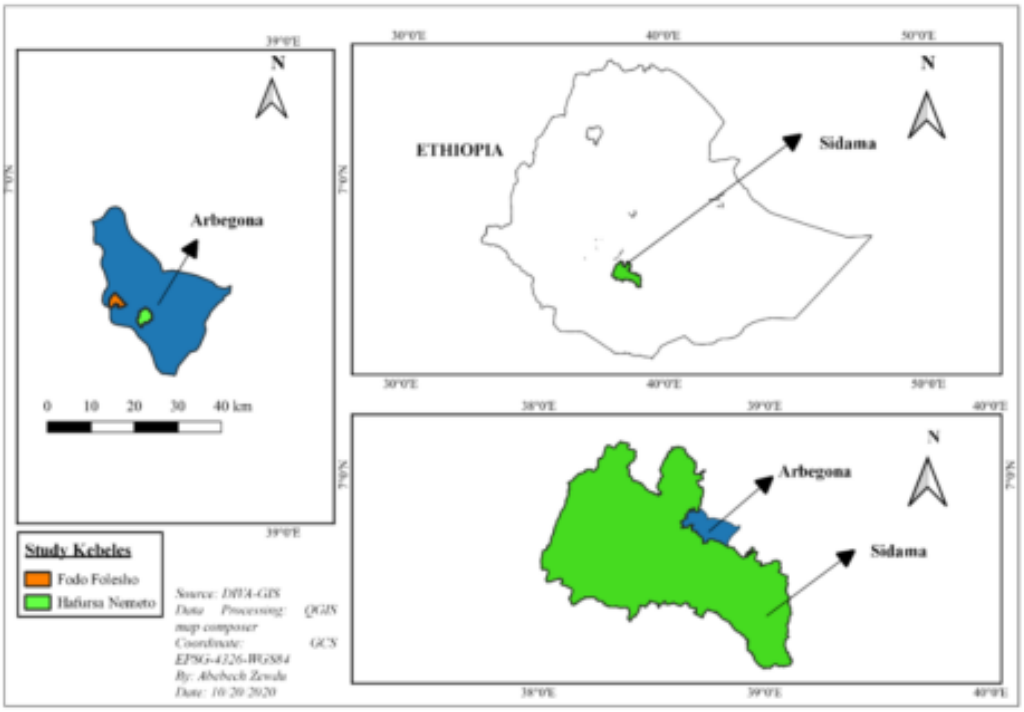

Figure 1: Location map of the study area.

Among the documented species, Wattled ibis (Bostrychia carunculata), Thick billed raven (Corvus crassirostris), Alpine chat (Cercomela sordida), Black winged love bird (Agapornis taranta) and Rouget's Rail (Rougetius rougetii) were endemic to Ethiopia and Eritrea (Jemal 2018).

Arbegona district has one urban and 38 rural kebeles (kebele is the lowest administration unit in Ethiopia). The economic activity of the district is mainly agriculture and rearing farm animals and cultivation of land. The majority of the community members practice mixed subsistence agriculture, and the study area receives substantial rainfall. There was a very low risk of crop loss (Quinlan et al. 2015) in the study area. Crops cultivated in the district are maize (Zea mays), wheat (Triticum aestivum), enset (Ensete ventricosum), barley (Hordeum vulgare), pea (Pisum sativum) and bean (Phaseolus vulgaris) (AWTCO 2003).

Fragmented Forest of the Geremba Mountain (i.e. Geramba Community Conservation Area) is home for unique flora and fauna adapted to high altitudes (Gezahagen et al. 2024). It also serves as a watershed, as it is a source of different rivers in Sidama National Regional State. There are more than 100 natural water springs within the mountain (AWTCO 2003). The natural beauty and biodiversity of Geremba Community Conservation Area make it an ideal destination for ecotourism.

2.2 Reconnaissance survey

We carried out a reconnaissance survey to be familiarized with local community life style, to know the area better, to understand the biophysical and socioeconomic characteristics of the study area as well as to gain understanding about the forest resource and wildlife conditions of the study area.

2.2.1 Sampling technique and sample size determination

Two study kebeles namely; Fidefolisho and Hafursa-Nemeto surrounding the community conservation areas were selected purposively based on the wildlife resource availability (the area is home for unique flora and fauna including Bale Monkey) and presence of wildlife human interactions (there are evidences of human-wildlife conflicts through crop-production and livestock harm and reactive killings of wildlife species) (Jemal, 2018; Worku and Girma 2020; Fekadu et al., 2022). The sample size was determined by using the formula developed by Yamane (1967).

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

Where, n = number of sample size, N = total number of population, e = is the level of precision for this study (9% precision was used). Using the formula above, 108 respondents/households were determined from the total number of 846 households in the two kebeles. Following the total number of households, the total number of respondents in each kebele was proportionally calculated (46 households in Fidefolisho and 62 in Hafursa-Nemeto).

Snowball selection method was used to identify the key informants

(Bernard 2002). From each kebele, we randomly selected five individual farmers and who were requested to provide us with names of 3 key informants (elderly people who have a good knowledge of community, wildlife relations and long histories of the area). Accordingly, a total of 15 key informants were nominated in each kebele, but the top ranking 5 key informants were selected in each kebele. In addition, 4 key informants were purposively selected from Arbegona district environmental protection office. Overall, a total of 14 respondents; 10 key informants from the two kebeles were selected. Two focus group discussions (one in each keble) were also carried out. A total of seven discussants comprising kebele officials, youth, women, wildlife professionals and religious/cultural leaders participated in the discussion (Krueger and Casey 2002).

2.3 Data collection

Quantitative (household survey) and qualitative (key informant interview and focus group discussion) data collection methods were used to collect data from the total of 108 households using structured questionnaire surveys that was conducted between December 2017 and January 2018. In the context of this study household includes one or more persons living together under the same roof or several roofs within the same dwelling that share common resources. The household heads were targeted as respondents. The household survey employed both closed and open-ended questionnaires. The questionnaire was prepared in English and translated into local language 'Sidamu Afu'.

A trial survey was conducted to test the household questionnaires' survey for clarity and understandability. We tested the questionnaire survey by interviewing 10 respondents (5 from each kebele) randomly selected and the trial survey feedback was used to improve the clarity and understandability of the questionnaire. The household survey was administered with close assistance of 2 local interviewers (enumerators) in each kebele that received secondary education and fluently speak the local language and Amharic, the national language of Ethiopia. The researchers could speak and write Amharic and English. Two days of training was given for the enumerators on how to administer the interview and collect data. The questionnaire was divided into four general parts: (1) household characteristics (gender, age family size, level of education, marital status, and migration status; (2) income and natural resource use questions (3) attitude of local community and (4) traditional knowledge of local community about wildlife conservation.

Community attitudes towards wildlife conservation was defined as human psychological tendencies to favor or disfavor in this case, agree or disagree to the statements given (Ajzen and Fishbein 1980; Abukari and Mwalyosi 2018). Focus group discussions were carried out to supplement and verify the data collected from the household interviews. Through the focus group discussion, in-depth information was extracted on the attitude of peoples towards wildlife conservation and the local knowledge of the local people during the discussion with knowledgeable elders, district agriculture and wildlife experts and kebele leaders.

Key informants' interviews were conducted after household interview and focused group discussion for triangulation of data obtained in household survey and focus group discussion. Issues that could be raised during focus group discussion such as dishonesty, which could lead to lack of in-depth answers about issues that would have been too sensitive or divisive, were addressed during the key informant interviews. The key informants' interview also targeted at exploring further information not addressed through the household survey. The interviews focused on obtaining information about traditional and ecological knowledge on wildlife conservation attitude towards wildlife conservation, status of human–wildlife conflict and their traditional mitigation measures. Information from key informant's interview was obtained using a pre-prepared checklist of open-ended questions.

2.4 Data analysis

The data were entered in Microsoft Excel spreadsheet 2013 and exported into SPSS version 21.0. Demographic characteristics of respondents were summarized using descriptive statistics. The findings from the key informant interviews and focus group discussions were analyzed using qualitative analysis methods. Likert scale was used to measure the attitude of the local community towards wildlife conservation (Likert 1932). In this study, the Likert scale was limited to three points because it is most frequently used in African contexts (where 1 = disagree, 2 = neutral, and 3 = agree) (Bless and Higson-Smith 2000). A multicollinearity assessment was also performed among the predictor variables, and it was found that intercorrelation levels were appropriate for analysis (mean Variance Inflation Factor ¡ 1.22) by calculating the variance inflation factors (VIFs), where (VIFs ¡ 5) implies the absence of collinearity (Akinwande et al. 2015).

Logistic regression analysis was carried out to determine which demographic variables such as gender, age, and level of education helped to explain why some respondents held a positive attitude and others held a negative attitude towards wildlife conservation in the community conservation area as depicted in the model.

The model is represented as:

$$P = \frac{e^{-}}{1 + e^{-}} \quad \text{(Equation 2)}$$

Where, P = Probability of an individual saying 'no' (zero = unwilling) or 'yes' (1 = willing) for the statement wildlife conservation is important (the dependent variable). The assumption in this model is that the probability that an individual supports wildlife conservation is independent of their demographic and socio-economic characteristics, i.e.,

$$\ln\left(\frac{P_i}{1 - P_i}\right) = \beta_0 + \beta_1 X_1 + \cdots + \beta_k X_{ki} \quad \text{(Equation 3)}$$

Where: i denotes the i^{th} observation in the sample; P is the probability of supporting wildlife conservation is important. β_0 is the intercept term, $\beta_1 \ldots \beta_k$ are the coefficients associated with each explanatory variable $X_1 \ldots X_k$ (Scott and Willits 1994; Hosmer and Leme 2000). The independent variables that affect attitude are described in Table 1 below.

3 Results

3.1 Demographic and socioeconomic characteristics of the respondents

Out of a total of 108 respondents, 91 were males (84.3%) and 17 (15.7%) were females. In those households represented by females, females are the heads of the households. Among the respondents, 86 (79.6%) didn't go to school, while 22 (20.4%) received formal education. 106 (98.1%) of the respondents were predominantly farmers by occupation. The fact that respondents were mainly farmers might have a direct impact on the local communities' attitude towards wildlife conservation due to the fact that their livelihood is entirely dependent on subsistence agriculture, which is influenced by human-wildlife interactions. Likewise, nearly all (105, 97.2%) of the respondents were born in the area and spent their life there, while only 3 (2.8%) respondents lived in the area for 11-15 years. As residents stay longer in the area, they have the opportunity of developing more knowledge and skills on traditional ecological knowledge since they are closer to the wildlife resources and their interactions with humans.

3.2 Income and forest resource utilization

Greater than 96% of respondents' income was from mixed agriculture (crop cultivation and livestock rearing), whereas crop cultivation only (0.9%), trade (0.9%), and civil servant or employment (1.9%) contributed as sources of income for few respondents. In both kebeles, all respondents had their own grazing area for their livestock. The local community perceived that the community conservation area renders the following ecosystem services in order of importance; fresh air and water, grass for livestock, firewood, shade, construction material, and honeybee and wild fruits (Table 1).

3.3 Knowledge of local community towards wildlife conservation

The respondents could list names of mammal species in the community conservation areas and around their settlement areas. The number of species listed was used as an indicator of knowledge about wildlife. The number of listed wild animals ranged from 3 to 9 with a mean of 5.0 ($\pm$0.12). The majority (83.3%) of respondents were able to list the names of more than 4 wildlife species correctly (Fig. 2).

Respondents use color, size, sound, footprint, and bite mark or feed leftovers to identify wildlife species. About 5% of respondents stated only animals' color and size help them to identify species, 17.6% use color, and 77.8% use color, sound, and size combined. Eighty-seven percent of respondents reported a change in wildlife species abundance over the last decade.

The majority of the respondents (89.4%) perceived the values of wildlife conservation. The reported values of wildlife conservation in the community conservation area as perceived by respondents were economic, ethical, medicinal, nutritional, aesthetic, bequest, and option values. Option value, economic value, ethical value, and medicinal values were the top four ranked (66.6%) values of wildlife conservation in the area. The key informants (elderly and traditional healers) mentioned that spotted hyena dropping is used for an anti-abortion remedy for domestic animals. Dried meat of crested porcupine (Hystrix cristata) is said to be used for the cure of lung disease of cattle and humans. More than half (61.1%) of the respondents had traditional knowledge of controlling crop raiders and livestock depredators. Around the community conservation area, most of the crop damage was caused by crested porcupine (Hystrix cristata) and common duiker (Sylvicapra grimmia). The focus group discussion revealed that the local people employed species-specific traditional wildlife damage mitigation methods. For instance, burn horn of cow to prevent porcupine damage as an odor repellent, fence crop land, construct watch out towers in the crop land as a protective measure against most crop raiders. Other crop raiding measures include the use of sound-making materials, put visual signs inside the crop field to scare away the animals, plant thorny plants, spray sheep and goats' pea to some crops, and spray soap and gas in the crop fields so that animals may assume there is a human being standing around.

3.4 Attitude of local community towards wildlife conservation

Greater than 93.5% of the respondents agreed that poachers should be punished. A great number of respondents (91.7%) felt an increase in wild animals' number is important for the future generation. Others stated that it is important to protect and conserve wildlife because these wild animals are endangered in the wild and they could face extinction (Table 2). On average, the majority of respondents (84%) expressed a positive view of wildlife conservation despite incurring significant costs in terms of livestock and crop losses from wild animals (Table 2).

Although local people had a positive attitude, 96% of households experienced crop damage and livestock depredation. Crested porcupine was the most frequently mentioned species (84.3%) that caused damage to crops and vegetables, followed by common duiker (51.9%). Baboons and monkeys also caused considerable damage to crops.

Table 1: Descriptions of independent variables used in the model.

Variable	Type	Categories/Details	Expected signs/remarks
Age of respondent	Continuous	Youth (18-24), Adult (25-64) and Elderly (>65)	Positive
Family size of household	Continuous	Few (4 to 7), Moderate (7 to 12) and large (above 12)	Negative
Total land holding size of respondent	Continuous	small (¡1 hectar), Moderate (1 to 2 hectares), large (¿3 hectares)	Positive
Distance from the forest	Continuous	near (¡1 km), moderate (1 to 3km), far (¿3km)	Positive
Tropical livestock unit	Continuous	Few(¡10), moderate (10-30), large (¿30)	Negative
Gender of respondents	Dummy	Male (0), Female (1)	Positive towards male
Educational level of respondent	Categorical	Illiterate (0), Literate (1)	Positive
Benefits from forest resources	Categorical	No (0), Yes (1)	Positive
Incidence of human-wildlife conflict	Categorical	No (0), Yes (1)	Negative
Knowledge about wildlife conservation	Categorical	No (0), Yes (1)	Positive

Table 2: Local communities' view on ecosystem services obtained from fragmented forest of Geremba Mountain.

Kebele	n	Grass for livestock	Honeybee and wild fruits	Shade	Construction material	Firewood	Clean air and water
Fide Folisho	46	30.4	4.3	28.3	23.9	26.1	63
Hafursa Nemeto	62	29	16.1	24.2	14.5	30.6	35.5
Total		59.4	20.4	52.5	38.4	56.7	95.5

3.5 Factors affecting attitude of local community towards wildlife conservation

Binary Logistic regression analysis indicated that educational status ($p = 0.05$), age ($p = 0.01$), and traditional knowledge ($p = 0.010$) were significant variables in explaining the attitude of the local community towards wildlife conservation. Age and traditional knowledge were the strongest variables influencing the attitudes of local people. However, variables like gender, family size, land holding size, length of residence, distance from the forest, conflict, benefits from the forest, and TLU were not significant variables (Table 3).

4 Discussion

4.1 Traditional ecological knowledge of local community towards wildlife conservation

Local ecological knowledge is important for sustainable natural resource management. Various studies have pointed out the importance of local ecological knowledge for participatory decision-making of natural resource management (Asah et al. 2014; de Freitas et al. 2015; Boafo et al. 2016; Cummings and Read 2016; Gouwakinnou et al. 2019; Cebria´n-Piqueras et al. 2020; Cronkleton et al. 2021; Haq et al. 2023). The results of the study have indicated that respondents demonstrated good knowledge of ecosystem services that Geremba Mountain renders. The respondents recognized the area's several ecosystems' services. First and foremost, the fresh air provided by the natural surroundings contributes to a healthier environment, enhancing overall well-being. The lush grass in the area serves as grazing land for livestock.

Additionally, the availability of firewood is crucial for many households, as it is a primary energy source for cooking and heating. This reliance on local resources fosters a sense of resource availability in their surroundings, as families can gather firewood without the need for extensive travel. Together, these elements underscore the area's value, highlighting its role in supporting both the daily lives and cultural practices of the respondents. This community awareness about the values of wildlife conservation can be an important input for wildlife managers to promote the sustainable conservation of wildlife resources (Calfukura 2018; Song et al. 2021). The local communities were also very familiar with wildlife species in the area and could identify those using scientific taxonomic features such as size and color. Studies have revealed that local communities are traditionally wildlife ecologists who could assist professionals during scientific species identification in the field (Brooks et al. 2008; Padmanaba et al. 2013; Stern and Humphries 2022; Werdel et al. 2024).

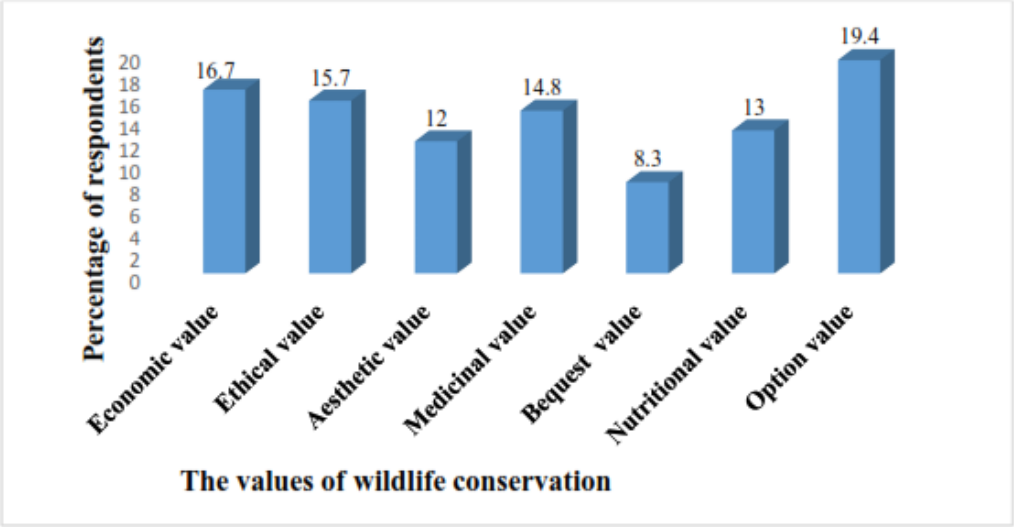

Figure 2: The values of wildlife conservation in Geremba mountain forest fragment

Table 3: Respondent views on wildlife conservation (percentages)

Statements/views	Likert scale category		
	Agree	Undecided	Disagree
Conservation of Wildlife is important for ecosystem health	88.0	8.3	3.7
Wild animals are important for the community	56.5	17.6	25.9
Wild animals should be managed well in your area because they are becoming more endangered	90.7	0	9.3
Current generation should take responsibility for increasing wildlife populations for the sake of future generations	91.7	0	8.3
People who poach should be punished	93.5	0	6.5

The respondents also perceived well the values of wildlife conservation such as economic, ethical, medicinal, and future values of conserving wildlife. This indicates that the community has a good understanding of the values of wildlife conservation that is advocated by wildlife managers. This, in turn, greatly helps to design a more participatory approach to wildlife conservation in the area. In participatory wildlife conservation, the community role is central, and the community participates in all regards of wildlife management, including actively involving in decision-making (Abukari and Mwalyosi 2018; Dawson et al. 2021; Werdel et al. 2024). Many authors contemplated that community-based wildlife conservation is the most promising approach to modern wildlife management (Songorwa et al. 2000; Holmes 2013; Abukari and Mwalyosi 2019; Gouwakinnou et al. 2019; Ochieng et al. 2021). The traditional medicinal applications of these animals, as highlighted by the respondents, also pave the way for more in-depth exploration of indigenous knowledge regarding their contributions to wildlife conservation (Abebe et al. 2022). This might also be a good tip for sustainable conservation of the wildlife resource in the area (Kendie et al. 2018).

However, the respondents have agreed that some wildlife species such as spotted hyena, crested porcupine, olive baboon, and grivet monkey have caused crop damage. The community might not be tolerant to crop raiders and livestock depredators as the number increases and the problem intensifies (Tufa et al. 2018; Nuili et al. 2019). This interaction can lead to escalated human-wildlife conflict that, in turn, poses retaliatory killing of animals and wildlife habitat destruction. As a result, there must be mitigation measures to promote human-wildlife coexistence sustainably (Biset et al. 2019; Epandaa et al. 2019; Ochieng et al., 2021). For example, the community has some traditional mitigation measures against these damages such as fencing, guarding, and the use of different repellents. Therefore, it is essential to incorporate these traditional mitigation strategies into contemporary human-wildlife conflict management techniques to minimize damage and foster positive perceptions within the local community (Tufa et al. 2018). Similar studies elsewhere have demonstrated that human-wildlife conflict is among the top-ranking factors that negatively affect local people's attitude towards wildlife conservation and sound mitigation measures (Graham et al. 2005; Hariohay and Roskaft 2015; Tufa et al. 2018; Biset et al. 2019; Mekonen 2020).

4.2 Factors affecting attitude of local community towards wildlife conservation

The logistic regression analysis revealed that age, education and traditional knowledge about wildlife conservation significantly affect respondents' attitude towards wildlife conservation. The impor-

Table 4: Binary logistic regression analysis results of the relationship between demographic and socio-economic factors that influence the attitude of the local community in fragmented Forest of Geremba Mountain.

Independent Variables	B	SE	Sig.
Gender	-0.04	0.15	0.78
Age	-0.44	0.17	**0.01***
Education level	1.05	0.54	**0.05***
Family size	0.26	0.34	0.44
Length of residence	-0.24	0.47	0.61
Distance from forest	0.23	0.31	0.41
Conflict	-0.69	0.73	0.34
Land holding size	0.26	0.41	0.52
TLU	0.08	0.091	0.33
Traditional knowledge	2.38	0.923	**0.01***
Benefits from the forest	0.01	0.26	0.98

tance of education and awareness creations programs for prompting positive attitude towards wildlife conservation among local community have been reported by many authors (Kideghesho et al 2007; Gandiwa et al. 2014; Biru et al. 2017; Ardoina et al. 2020). Education and traditional knowledge about wildlife conservation increased positive attitude, whereas age inversely favored positive attitude (older respondents demonstrated negative view than younger ones). The observed less interest of old people in wildlife conservation could be related to the limited education that old people received. Furthermore, old people may know the historic damage of wildlife to crops and livestock, which was rarely recognized and compensated. Awareness creation is very important tool in wildlife conservation to promote positive attitude towards wildlife conservation (Browne-Nuñez and Jonker 2008; Wu et al. 2020; Legese, 2024). Higher level of education could create the opportunity for better knowledge towards the environment in general and wildlife resources in particular. Hence, those people with higher level education have better knowledge on wildlife conservation (Biru et al. 2017; Mekonen, 2020). Furthermore, information on importance of wildlife conservation can be acquired through awareness campaigns organized by local wildlife/natural resource professionals (Browne- Nuñez and Jonker 2008; Tufa et al. 2018; Umar and Kapembwa 2020). However, the negative attitude of respondents towards wildlife conservation among older age respondents, unlike some studies (e.g. Ochieng et al. 2021) is mainly due to lack of formal education and not able to perceive well the awareness campaign effort made in the area.

5 Conclusion

Form the results of the study it can be concluded that the local communities have some indigenous knowledge and awareness about wildlife and wildlife conservation. This in turn has created a positive attitude towards wildlife conservation. However, the results at the meantime pointed out that there were some incidences of human-wildlife conflict that might cause economic loss in the long run and jeopardize the attitude of the local people towards wildlife conservation. The study has also clearly revealed the importance of education and awareness creation for sustainable wildlife conservation.

Traditional human-wildlife conflict mitigation schemes such as guarding and fencing crops, deterring wildlife species. In addition, modern approaches towards mitigating human-wildlife conflicts such as buffer zone management and modern livestock husbandry practices that avoid free grazing of livestock should be implemented. To maintain a positive attitude towards wildlife conservation among local communities, human-wildlife conflict incidences should be mitigated in a sustainable manner. Awareness creation programs by local relevant government should be strengthened well and in-reach all community members through community workshops and with partnerships with local schools.

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Research Article

Effects of land use practices on the spatial variability of soil physicochemical properties across a landscape in Wondo Genet, Southcentral Ethiopia

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Article Info

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Abstract

This study investigated the changes in physical, chemical and microbiological soil properties resulting from different land use practices. Soil samples were collected from two different depths, 0–30 cm and 30–60 cm, in three adjacent land use types: agricultural land, plantation forest and natural forest. A total of 15 samples were collected for analysis from each land use type. Key soil parameters, including total nitrogen, soil organic carbon and microbial biomass, were quantified using the micro-Kjeldahl and fumigation-extraction methods, respectively. In addition, geostatistical analysis using kriging interpolation techniques was performed within a GIS framework to visualize the spatial variability of soil parameters. The results showed that agricultural land/khate farm had the highest bulk density ($0.96 \pm 0.018\%$), followed by plantation forest/Cupressus ($0.93 \pm 0.012\%$) and natural forest (NF) ($0.81 \pm 0.03\%$). Natural forest had the highest soil organic carbon content ($4.25 \pm 0.28\%$), followed by plantation forest/Podocarpus ($2.77 \pm 0.49\%$) and Coffee based agroforestry ($2.92 \pm 0.16\%$). Furthermore, the total nitrogen content was highest in the top layer of natural forest (0.37 ± 0.024 μg/g), showing significant differences compared to plantation forest and agricultural land. Microbial biomass carbon was also highest in natural forest (939.84 ± 46.0 μg/g), followed by plantation forest/Grevillea (712.8 ± 48.4 μg/g) and agricultural land/Enset (570.2 ± 38.8 μg/g). Similarly, microbial biomass nitrogen was highest in natural forest (81.0 ± 3.9 μg/g) and showed significant variations with plantation forest/Grevillea (60.08 ± 4.2 μg/g) and agricultural land/Enset (40.96 ± 3.3 μg/g). Overall, our results indicate a strong correlation between microbial biomass and soil physico-chemical properties, which are significantly influenced by vegetation type and soil depth.

Keywords: Spatial distribution, land use types, soil properties, soil mapping, geostatistical analysis

1 Introduction

Most Ethiopians rely on agriculture as their primary source of income and livelihood (Zeleke et al. 2023). This heavy dependence on agriculture has increased the susceptibility to land degradation, leading to socioeconomic and environmental challenges due to inappropriate farming practices, unfavorable terrain, erratic rainfall, low vegetation cover, water erosion, and poor land management (Holmatov 2017; Belachew et al. 2020). To meet the growing global food demand, particularly in developing nations, it is crucial to gradually enhance agricultural productivity while also systematically manag-

ing the expansion of agricultural land and integrating it with existing natural resource conservation systems (Hansen et al. 2010; Dokoohaki et al. 2021; Ayoubi et al. 2021). Globally, unsustainable land-use change, and resource exploitation have led to a 0.6% annual loss of forest cover (Hansen et al. 2010; Khormali et al. 2009; Mokhtari et al. 2011; Bargali et al. 2018). The key mechanisms involved in nutrient transformation and cycling, soil organic maintenance, and macro-aggregation for optimum water and aeration are all controlled by soil microbial biomass (Jenkinson and Rayner 2006; Pereira et al. 2013). The soil has a significant nutrient-labeled pool, accounting for 1%–5% of organic carbon and more than 5% of total nitrogen (Bargali et al. 1993; Manral et al. 2020).

The quantity of microorganisms in soil affects its nutritional status and transformation (Norouzi et al. 2010). These microorganisms are important for the breakdown of plant and animal residues and the release of nutrients (Bargali et al. 1993), and their activities are highly susceptible to management measures, including irrigation, fertilizer application, and conventional tillage (Arunachalam and Arunachalam 2002; Kara and Bolat 2008; Bargali et al. 2015). Therefore, the number of soil microorganisms is a key determinant of soil health (Bargali et al. 2019; Tajik et al. 2020). Forest cover with native and nonnative species influences the soil's physical and chemical qualities and ecology and economics (Bargali et al. 1993; Tilman et al. 2001). The transformation of forestland to agricultural land to meet the global economy impacts not only climate change but also the dynamics of soil organic matter, biodiversity, and changes in ecosystem services in general (Tripathi et al. 2007). Moreover, it has a significant influence on soil functions (Kelishadi et al. 2014; Havaee et al. 2014; Ayoubi et al. 2018), including microbial activity, nitrogen, soil organic carbon, and other soil physical qualities (ITTO 2002). Massive collection of wood and non-timber forest resources, overgrazing (Ayoubi et al. 2014), and land-use pattern changes are important factors in land degradation, which modifies soil quality and vegetative cover and disrupts or even inhibits natural forest regeneration (Tripathi et al. 2007; Ayoubi et al. 2011).

During the last two decades, the conversion of land use, for example, from natural forest to cultivated ecosystems has been a common process throughout the world (Vagen et al 2006; Kara and Bolat 2008; Khormali and Nabiallahy 2009), particularly in the tropics. Several scholars have focused on the effects of increasing anthropogenic disturbances, decreasing C budgets (Tilman et al. 2001; Yang et al. 2009; Don et al. 2011), and land-use changes on forest ecosystems in these regions. Moreover, dry and rainy seasons are extreme conditions in tropical ecosystems that have a major influence on productivity, nutrient cycling, microbial biomass, and physicochemical properties of soil (Ayoubi et al. 2018). Hardwood forest areas have been converted to farmland at an alarming rate in recent decades due to increased demand for firewood, timber, pasture, food, and residential dwellings (Ye et al. 2009). In recent decades, ecologists have focused on soil SOC, microbial features, and microbial activity because of the effect of the land-use shift from natural forests to agricultural land and plantation (Ayoubi et al. 2011; Li et al. 213). Total soil quality, including physicochemical and microbiological performance, is recognized as a driver of soil organic matter (Kumar and Ghoshal 2017; Ayoubi et al. 2018). To put it another way, the physicochemical qualities of soil are inextricably linked to soil organic matter (Jackson 1973). Soil microbial properties respond more readily to soil disturbance in any ecosystem than soil chemical or physical properties (Allen et al. 1974; Ashagrie et al. 2007). Studies have demonstrated that changes in land use, especially in temperate climates, substantially affect soil microbial populations (Tripathi and Singh 2009). Land-use change affects important ecosystem functions, including carbon sequestration, climate regulation, and water purification, and all of these are intimately connected to microbial activities. The major land-use change in the study area, the conversion of natural forests to other land-use types, leads to not only climate change, loss of biodiversity, change in ecosystem services, etc but also affects soil biological and physicochemical properties (Tilman et al. 2001; Ashagrie et al. 2007; Allen et al. 1974 and Tripathi et al. 2007). Several studies have documented that the conversion of natural forests to other land-use types significantly influences soil health and quality, particularly in temperate regions (Kumar and Ghoshal 2017). However, the restoration of forests poses a major challenge globally, particularly in the tropics, as the forests in these regions are more vulnerable to land-use change (Kumar and Ghoshal 2017; Jones 2018). Therefore, how land-use changes affect community composition in terms of disturbance and ecosystem restoration in the dry tropics has not yet been studied (Kumar and Ghoshal 2017).

The application of appropriate management approaches for sustained agricultural production necessitates timely and reliable soil information; however, spatial knowledge of soil microbiological and physicochemical parameters at the smallholder farming level is severely restricted (Fikadu et al. 2012). By offering an accelerated, repeated, spatiotemporal view, geospatial technologies have opened new options for improving soil knowledge and show great potential for the gathering and analysis of soil data. GIS and remote sensing are useful methods for assessing large amounts of geographical problems and can enable spatial analysis; hence, there is a tremendous opportunity to enhance the accuracy of soil surveys via the use of GIS and remote sensing technologies. Therefore, the main objective of the present study was to assess the effect of land-use change and to analyze and map the spatial variations in soil microbial and physicochemical properties under different land- use practices in the Wondo Genet, Ethiopia.

2 Methods and Materials

2.1 Description of the study area

The study was conducted in Ethiopia's Wondo Genet, specifically in the Wondo Genet watershed. The watershed is located 13 km from the surrounding town of Shashemene, West Arsi, Oromia Regional State, 38 km from the Sidama regional capital Hawassa, and 263 km from Addis Ababa. It is located between $7^0$02'-$7^0$07'N latitudes and $38^0$37' and 38^0 42' E longitudes (Figure 1). The region lies between 1600 meters and 2500 meters above sea level. The area comprises a series of hills that form the southwestern spur of the Bale Mountains. The agro-climatic zone of the district is traditionally categorized as Woyina-Dega (mid-highland). The mean minimum

and maximum monthly temperatures of the study area are 13.8 °C and 27.8 °C, respectively (NMA 2017). The area receives a bimodal rainfall pattern (short rains between February and April, and long rains between June and September) with a mean annual total rainfall of 935 mm (SZPED 2004). According to Erikson and Stern (1987), the main parent materials are volcanic deposits of ignimbrite, ash, lava, and tuff. The geological bedrock of the area consists mainly of acidic rocks, sometimes interbedded with basaltic lava of tertiary origin (Brady and Weil 2002).

The soil of the study area was identified as Mollic Andosol. Andosol is characterized by a soil bulk density of less than 0.9 kg dm3, more clay and Alox, high phosphate retention of 70 % or more, volcanic glass content in the fine earth fraction of less than 10 percent; and thickness of at least 30 cm (; FAO 1998; Brady and Weil 2002; Fantaw 2017). The soil pH of the study area varied between 5.6 and 6.5 (Ashagrie et al. 2007). Natural forest land: This is an area of land made up of bigger trees that are generally taller than 3 m and have a canopy cover of more than 30% (Brady and Weil, 1996). Of the total watershed area, this land-use group comprises 405 hectares, or 14.3% (Figure 1). Plantation forest**:** An area of land consisting of mostly Euqlyputus, Podocarpus, Cupressus, and Grevillea trees. This land-use category accounts for 405 hectares (14.3 percent) of the overall catchment area (Figure 1). Agricultural Land: The plot of land was used to grow various crops and irrigate cash crops, including sugarcane, enset, coffee, and khat, using traditional irrigation schemes. Maize, carrots, potatoes, onions, and other crops are also grown with irrigation. Agricultural land accounted for 174 ha (6.2 percent) of the study area

2.2 Soil sampling techniques

A total of 96 composite soil samples (3 land use types*4 replication* 4 sample plots* 2 soil depths: 0-30 and 30-60cm) were collected from the land-use types: Natural Forest, Plantation Forest, and Agricultural land. The forest area was further divided into six subsites of 100 m × 100 m each. Four soil samples were collected from each subsite and combined to form a single composite sample representing each subsite. The plantation forests were also further divided into Grevillea, Cupprusses, Eucalyptus, and Podocarpus, whereas Khat (*Catha edulis*), Enset (*Ensete ventricosum*), coffee (*Coffea arabica*), and sugarcane (*Saccharum officinarum*) plantations were considered under agricultural land. The soil samples were air-dried at room temperature and passed through a 2-mm sieve before analysis.

2.3 Soil analysis

Standard laboratory procedures for measuring soil physical and chemical parameters (pH (H_2O), organic C, moisture content (%), Porosity, and Bulk density) were followed as proposed by Lam (1983) and Li and Heap (2011). The microbial biomass C was estimated using the chloroform fumigation–extraction method with purified $CHCl_3$ treatment (Hengl 2009; Goovaerts 2012). Using a Gerhardt digester and distillation unit, the N content of the microbial biomass was measured using the micro Kjeldahl method (Bernardi et al. 2017). Microbial biomass C (μg dry soil) and nitrogen were calculated using the following formulas:

$$\text{Microbial Biomass C} = (NF - F) \times 3168$$

$$\text{Microbial Biomass N} = (Fu - NFu) \times 207.407$$

Soil Aggregates: The dry method developed by Khormali and Nabiallahy (2009) was used to estimate soil aggregates. A dried soil sample (100 g) was piled on a set of seven sieves and sieved on a horizontal shaker (92 rpm) for 3 min, separating three dry aggregate size classes: 1000 μm (macro-aggregate), 212–500 μm (meso-aggregate), and 53–150 μm (micro-aggregate) (Singh et al. 2009). To estimate and map soil quality over space, geo-statistics were employed. Kriging is a precise geostatistical approach (Horneck et al. 2007) that is frequently used in various fields (Paudel and Sah 2003). Ordinary kriging is a good spatial model for predicting geostatistical-statistical studies of environmental variables (Nsabimana et al. 2004), such as soil parameters (Hadgu et al. 2009; Manral et al. 2020), in the QGIS 3.8 environment. Finally, using distinct soil parameter ratings, the resulting raster layers of each soil parameter were categorized using the spatial analyst tools of the QGIS 3.8 program (Vibhuti et al. 2020).

3 Results and Discussion

3.1 Physical and chemical properties of soil

3.1.1 Bulk density, porosity, and aggregates

Many soil parameters change as land-use patterns and treatment systems change (Jackson 1973; Ayoubi et al. 2014; Tajik et al. 2020). The study revealed a higher bulk density in soil under agricultural land (0.9 ± 0.064 g/cm^3), followed by plantation forest (0.86 ± 0.32) and natural forest (0.81 ± 0.3). Among land use categories and soil depth, soil porosity exhibited the opposite tendency as bulk density. The natural forest has the highest porosity (0.69%), followed by the plantation forest (0.66%) and agricultural land (0.66%). The values of bulk density and porosity did not differ between land-use categories and along soil depths. Agricultural land, on the other hand, has a higher bulk density than forest soil and plantations. This was most likely related to the reduction of carbon content and improvement of soil because of repeated cultivation and biomass harvesting (Tripathi et al. 2007). The bulk density was likewise lower in soils with significant organic matter concentrations (Kumar and Ghoshal 2017). The high porosity of forest soil allows for optimal oxygen diffusion and water penetration. This demonstrates high structural quality, which is beneficial to the effective development of biological communities (Bot and Benites 2005).

Soil aggregates are naturally formed collections of soil particles that determine the formation of organo-metal complexes in soil (Bot and Benites 2005; Pereira et al. 2013). Across all land-use categories, macro-aggregates comprised 53.9%–67.6% of the soil, followed by meso-aggregates (29.3%–41.9%) and micro-aggregates (4.4%–12.2%) (Table 1). In the top layer of the soil, macro aggregates

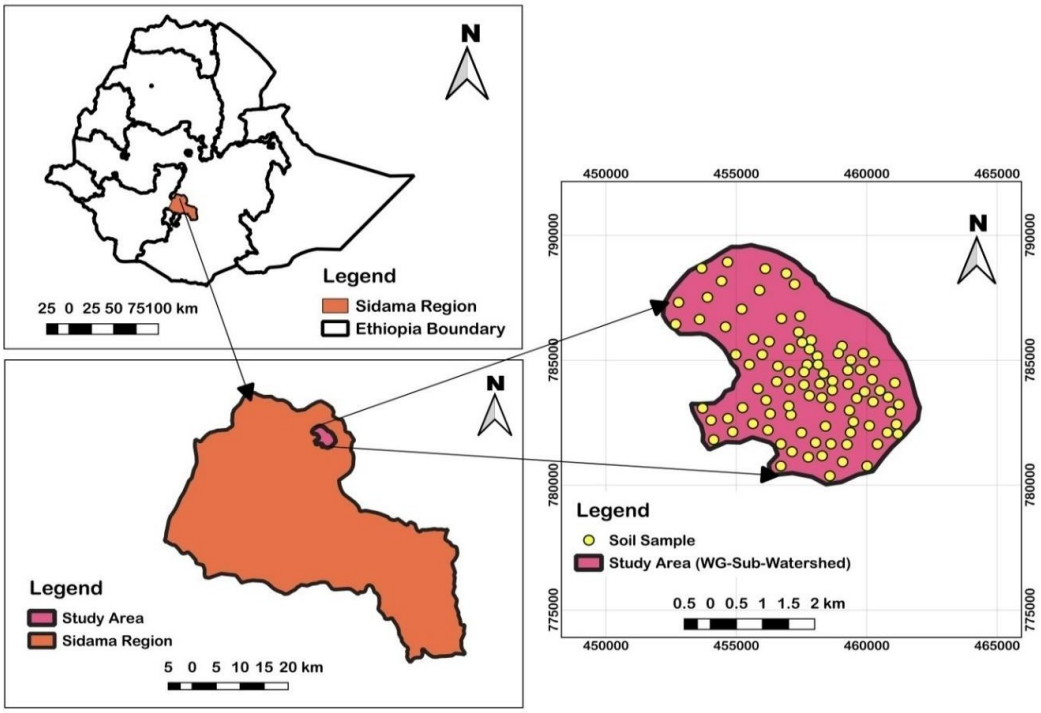

Figure 1: Map of the Wondo Genet sub-watershed with sampling locations

were found at 67.6% on the Khate plantation, whereas the eucalyptus plantation had the lowest percentage at 48.1%. In eucalyptus plantations and natural forests, meso and micro aggregates were greater (41.9%) and (12.1%). The Khate plantation had the highest number of macro-aggregates (67.6%), but the lowest number of meso (25.7%) and micro-aggregates (25.7%) among the plantation land use categories (6.6%). The meso-aggregates (41.9%), micro-aggregates (9.9%), and macro-aggregates (48.1%) were highest in the eucalyptus plantations. Soil aggregates in the natural forest accounted for 53%, 33%, and 12% of the macro, meso, and micro-soil aggregates in the upper soil layers, respectively. This was lower than that of the Cupressus, Podocarpus, and coffee, Khate, Sugarcane, and Enset farms but higher than that of the Eucalyptus and Grevillea. This might be because in a planted forest, there is less interference, and there is a high organic matter content (litters and root biomass) that binds soil aggregates together, leading to better soil structure development. Natural forests, on the other hand, had lower aggregates due to soil disturbance and a higher percentage of micro-aggregates, which were attributed to continuous SOM distribution and quick oxidation, respectively (Gorems and Ghoshal 2020).

Soil structural stabilization is directly related to organic matter inputs (Caravaca et al. 2002). Singh et al. (2009) reported a significant increase in the stability of aggregates with the application of wheat straw. This might be due to the application of organic inputs to soil increasing the cohesion of aggregate binding forces between mineral particles and organic polymers, which decreases the wettability of aggregates and thus the extent of slaking (Spaccini et al. 2004). Tillage accelerates aggregate turnover and increases the decomposition of organic residues when exposed to soil microbes (Singh et al. 2009).

pH, Soil Organic Carbon, and Total Nitrogen

The mean soil pH ranged from 5.6 to 6.8 in the surface layer (0–30 cm) and 5.9 to 6.9 in the subsurface layer (30–60 cm) (Figure 2). The highest soil pH was recorded in sugarcane, whereas the lowest pH was recorded in Cupressus. Cupressus land-use soils were somewhat acidic compared to other land-use types. The soil organic carbon (SOC %) and total nitrogen (tot N %) are presented in Table 2. Soil organic carbon and total nitrogen varied according to land use type and soil depth ($p < 0.05$). Soil organic carbon varies across all land-use types and soil depths, ranging from 1.1% to 4.25%. Natural forests had the highest organic carbon content, followed by plantation forests and agricultural land. The mean topsoil SOC in the natural forest was 4.25%, followed by coffee (2.92%), podocarpus (2.77%), grevillea (2.73%), enset (2.56%), Cupressus (2.50%), eucalyptus (2.25%), and sugarcane (1.56%). Similar studies indicated that forest areas had more OC than Jatropha plantations/reforested areas and the lowest OC levels in the agroecosystem, according to Go (2009) and Gorems and Ghoshal (2020), whereas others

[1]

[1]textValues are mean ± SE. Values with distinct superscripts in each column and rows are substantially different from each other at 5% level of significance ("Letter" indicates among the land use types; "Number" indicates along the soil depths for each aggregate size). Note: C, coffee; K, hat; Su, sugarcane; E, enset; N, natural forest; Eu, eucalyptus; Cup, cuprussus; G, grevillea; Pod, podocarpus; MBC, microbial biomass carbon; S, soil organic carbon; B, bulk density; Mc, moisture content; Po, porosity Note: The superscript letter indicates significance among the land use types in each row, whereas the superscript number indicates significance along the depth in each aggregate size. The superscripts are (number and letter) independent

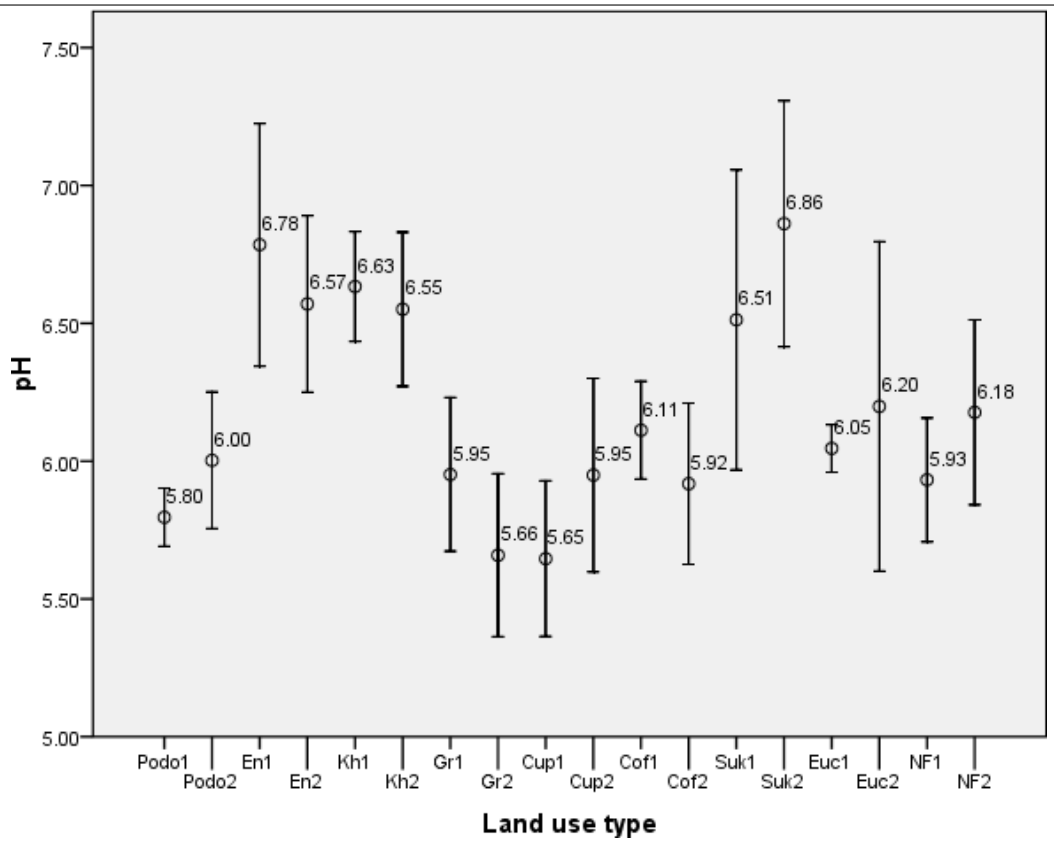

Figure 2: Impacts of land-use change on soil pH.
NB: Podo1- Podocarpus 0-30cm; Podo2- Podocarpus 30-60cm; En1-Enset 0-30cm; En2-Enset 30-60cm; Kh1-Khate 0-30cm; Kh2-Khate 30-60cm; Gr1-Gravillea 0-30cm; Gr2- Gravillea 30-60cm; Cup1- Cupressus 0-30cm; Cup2-Cupressus 30-60cm; Co1-Coffee 0-30cm; Co2-Coffee 30-60; Suk1-Sugarcane 0-30cm; Suk2-Sugarcane 30-60cm; Euc1-Eucalyptus 0-30cm; Euc2- Eucalyptus 30-60cm; Nf1-Natural forest 0-30cm; Nf2-Natural forest 30-60cm.

observed better SOC concentrations in natural forests than in tilled farmlands (Iqbal et al. 2015). Similarly, Srivastava et al. (1991) found that agroforestry yielded the highest SOC, followed by cropland, grassland, and fallow land. Because of the regular buildup of plant biomass and limited intervention in the natural forest, the conversion of natural forest to plantation forest, as well as cash agriculture, resulted in a considerable decrease in SOC (Saha et al. 2010). Furthermore, greater root biomass contributes to the preservation and stability of SOC in aggregates by increasing the return of residues (Paudel and Sah 2003; Ayoubi et al. 2014). Moreover, the presence of diverse leaf litter on the forest floor contributes to the replenishment of SOM and provides better habitats and food for soil organisms, thereby enhancing SOC accumulation.

In the case of OC, soil total N significantly varied according to land use practices and soil depth. The top layer of the natural forest soil had the highest soil total N concentration (Table 2). The order of the concentration of total N along the land use types in the upper layer was NF (0.37%), Gr (0.24%), Podo (0.24%), Coffee (0.25%), Enset (0.22%), Cupr (0.22%), Euc (0.19%), Khate (0.16%), and sugarcane (0.13%) at $p < 0.05$. Several studies have confirmed that agricultural practices reduce soil total N content (Ayoubi et al. 2011; Iqbal et al. 2015). In addition, Goni et al. (2015) demonstrated that under comparable site conditions, natural lands often preserved more soil organic carbon than croplands because of larger residual inputs and lower turnover. Furthermore, soil OC and total nitrogen losses from agricultural land can be due to its removal by crops (Tripathi et al. 2007); and continuous tillage practice (accelerates organic matter oxidation by destroying soil aggregates and exposing newer sites to microbial attack) (Brady and Weil 1996). Although not statistically significant, the total N content derived from coffee and the Enset farm is equivalent to that from the planted forest. This is most likely because there is less intensive agricultural activity than in sugarcane and Khat fields, as well as inputs from broadleaf litter (Li and Heap 2011).

Soil organic carbon and total nitrogen contents were higher in soils from plantations than in agricultural land and cash croplands, but lower than the contents in soils from natural forests (Table 2). The conversion of natural forests to agricultural land for coffee, khat, sugarcane, and enset agriculture resulted in considerable reductions in SOC content, with values of 31.29%, 57.6%, 63.2%, and 39.7%, respectively. In comparison to agricultural land, the increase in SOC and total nitrogen in plantation forests was likely attributable to the addition of nutrient-rich leaf litter to the soil, as well as the recycling of these nutrients (Ye et al. 2009; Vesterdal and Leifeld 2010). The natural forest conversion to eucalyptus, cupressus, graveled, and podocarpus resulted in considerable reductions in SOC content, with lower values of 47%, 41%, 37.5%, and 34.8%, respectively. The Podocarpus plantation (2.77 $\pm$ 0.49%, 0.24 $\pm$ 0.042%) in the top

Table 1: Percentage distribution of dry aggregate soil types according to land-use types

Soil depth (cm) F-Value	Natural forest		Plantation forest			Agricultural Land				Enset
			EuC	Cupr	Gr	Podo	Coffee	Khat	Sugarcane	
Macro-aggregates (%)										
0-30	53.9±4.6^{1a}	48.1±6.1^{1b}	59.3±8.6^{1c}	48±4.3^{1c}	62.6±8.3^{1a}	62.7±7.6^{1a}	67.6±4.4^{1a}	66.9±6.1^{1c}	62.2±8.7^{1a}	1.736
30-60	48.2±8.9^{1a}	61.7±11.4^{1bc}	70.1±8.1^{1c}	51.9±7.1^{1c}	70±8.7^{1bc}	55.1±8.8^{1c}	79.2±2.9^{1b}	81.5±2.3^{1b}	63±8.9^{1bc}	
Meso-aggregates (%)										
0-30	33.9±1.8^{1ac}	41.9±2.3^{1a}	30.8±5.8^{1ac}	39.7±1.5^{1c}	29.3±5.5^{1c}	25.3±2.1^{1c}	25.7±5.7^{1c}	28.6±5.1^{1c}	29.9±4.2^{1ac}	1.825
30-60	37.5±7.2^{1a}	29.6±7.3^{1b}	19±4.8^{1b}	35.6±7.2^{1c}	24.4±9.9^{1bc}	32.5±7.8^{1ac}	16.1±1.8^{1b}	12±4.7^{1b}	28.1±6.2^{1c}	
Micro-aggregates (%)										
0-30	12.1±4.1^{1a}	9.9±4.5^{1a}	9.8±2.9^{1a}	12.2±5.2^{1a}	7.99±2.9^{1a}	11.9±6.1^{1a}	6.6±2.8^{1a}	4.4±1.4^{1a}	7.8±4.9^{1a}	0.637
30-60	14.2±4.1^{1a}	8.6±4.4^{1a}	10.8±5.8^{1a}	12.4±3.8^{1a}	5.58±1.2^{1a}	12.3±5.1^{1a}	4.6±1.24^{1a}	6.4±2.5^{1a}	8.8±3.15^{1a}	

layer soil had the highest organic carbon and total N, whereas the Eucalyptus plantation (2.25 $\pm$ 0.1%, 0.19 $\pm$ 0.01) in the upper layer soil had the lowest organic carbon and total N. The higher contents of soil organic carbon and nitrogen might be due to a higher input of leaf litter from the podocarpus, as well as fewer disturbances (Singh and Ghoshal 2006; Ashagrie et al. 2007). Studies on nutrient cycling have shown that low-quality Cupressus and Eucalyptus litter, which decompose slowly and restricts organic matter intake, eventually results in a decrease in SOC compared with natural forests and other plantations (Erikson and Stern 1987; Ayoubi et al. 2011).

Soil Microbial Biomass Carbon and Nitrogen

Microbial biomass

The level of soil microbial biomass carbon (MBC) showed significant variation with land-use type, ranging from 94.7 μg/g to 939.84 μg/g (Table 3). The mean soil MBC ranged from 131.1 to 939.8 μg/g in the surface layer and from

11.3 to 81 μg/g in the subsurface layer. Soil MBC was the highest (939.84 μg/g) in the upper layer of soil in natural forests, followed by Grevillea, Podocarpus, Cupressus, Enset, Sugarcane, Eucalyptus, and Khat farms. In the lower layer, the highest MBC was observed in the natural forest, whereas the lowest was recorded in the Cupressus plantation. Likewise, the mean microbial biomass nitrogen (MBN) values under natural forest, plantation forest, and agricultural land at both depths were (16.37, 8.11 μg/g; 13.64, 6.97 μg/g; 11.10, 5.3 μg/g), respectively. It was observed that soil MBN tended to decrease with soil depth for all land-use types (Table 3). The order of the level of MBN among the land use types was natural forest, grevillea, enset, podocarpus, eucalyptus, coffee, Khate, Sugarcane, and cupressus. The results for MBC and MBN are similar to those of previous reports (Zeraatpisheh et al. 2021; Ayoubi et al. 2012), with both MBC and MBN differing considerably across forest, pasture, and agricultural areas. The conversion of natural forests into plantation forests and farmland reduces soil organic carbon (SOC) and total nitrogen (tot. N), thereby lowering microbial biomass concentrations (Singh and Ghoshal 2006). Increased availability of resources such as soil organic matter, more diversified organic matter input, and related processes are believed to be the cause of the higher MBC and MBN in natural forests (Hadgu et al. 2009; Bargali et al. 2018).

The findings of the present study revealed a close relationship between MBC and SOC or tot N. In general, there is a direct correlation between the amount of soil microbial biomass and the quantity and quality of C inputs (Fikadu et al. 2012; Fang et al. 2014). Large microbial biomass increases the quantity of nutrients in the organic pool and, depending on soil management, might constitute either a sink or a source of plant-available nutrients. Higher SOC and total N levels in soil microbial biomass may be attributable to the increased ability of microorganisms to immobilize nutrients from decaying cover species residues. Microorganisms use organic waste left in the soil as a source of energy and nutrients. Various land covers contain different chemical elements that can affect microbial characteristics in various ways and to varying degrees. The higher microbial biomass in natural forests that maintain native vegetation provides ideal conditions (macro porosity, litter dry mass, and K and P levels), which help the soil microbiota thrive and establish (Paudel and Sah 2003; Chaudhary et al. 2008). The presence and activity of microbial biomass may result in enhanced plant litter decomposition, soil aggregate formation and stability, enhanced nutrient cycling and transformation, slow release of organic nutrient storage, and disease prevention, among other benefits (Kara and Bolat 2008; Goovaerts 2012).

Among the plantation forests, the highest microbial biomass of C and N was obtained from grevillea, whereas the lowest was obtained from Cupressus. Among the agricultural land, the highest microbial biomass of carbon and nitrogen was obtained from the Enset farm. This is most likely due to an increase in the supply of resources such as soil organic matter, more diversified soil organic input, and related processes that sustain microbial activity (Kara and Bolat 2008; Bhuyan et al. 2013). Moreover, opening of the canopy cover on agricultural land, especially on sugarcane and khat, increases the interference of physical components like moisture content, wind speed, and light intensity. Incident light intensity and wind velocity increase when the canopy opens, lowering moisture content and stimulating organic matter mineralization (Solomon et al. 2024).

Table 2: Soil microbial biomass under three major land-use types: natural, plantation, and farm forests

Soil depth (cm)	NF	Plantation forest					Agricultural Land		
		EuC	Cupr	Gr	Podo	Co	Kh	Suk	En
MBC ($\mu g/g$)									
0-30	939.8±46.0^{a}	422.4±27.9^{e}	131.1±21.1^{f}	712.8±48.4^{b}	538.6±48.3^{c}	387.8±22.5^{e}	372.2±37.4^{e}	240.3±25.2^{c}	570.2±38.8
30-60	475.2±9.2^{c}	242.9±41.2^{e}	94.7±7.8^{f}	211.2±10.5^{d}	211.8±31.6^{d}	278.6±37.1^{e}	293±26.3^{e}	145.7±36.4^{f}	332.6±12.9
MBN ($\mu g/g$)									
0-30	81.0±3.9^{c}	36.4±2.4^{e}	11.3±1.08^{f}	60.0±8.3^{d}	46.4±2.4^{e}	33.4±3.1^{f}	32.0±9.3^{c}	20.7±2.2^{c}	40.9±6.3^{d}
30-60	40.9±0.9^{c}	25.3±5.2^{e}	8.16±0.62^{f}	18.2±10.9^{d}	19.1±2.7^{d}	24.0±13.2^{f}	25.2±6.2^{c}	12.5±6.3^{f}	37.8±11.1^{b}

Values are mean ± SE. Values with distinct superscripts in each row differ substantially from each other at 0.05 level of significance.
Abbreviations: Co = coffee, Kh = khat, Suk = sugarcane, E = enset, NF = natural forest, Eu = eucalyptus, Cup = cupressus, G = gravelica, Pod = podocarpus, MBC = microbial biomass carbon, S = soil organic carbon, B = lump density, Mc = moisture content, Po = porosity.

Table 3: Soil chemical properties under different land use types and depths

	pH (H_2O)	N (%)	P (emol+/kg)	K (Cmol/kg)	CEC (emol(+)/kg)	OC g/kg	SAR	ESP %
Land use								
NF	5.5	0.37	3.68	0.23	4.31	6.37	0.043	0.63
PF	5.6	0.35	2.74	0.16	3.87	5.42	0.035	1.67
AL	6.5	0.29	2.96	0.14	5.02	5.03	0.035	1.47
LSD	0.341	0.054*	1.125	0.017	2.202	0.280	0.005*	0.289
Depth								
0–30 cm	5.57	0.30	2.85	0.06	4.46	8.61	0.086	1.182
30–60 cm	6.42	0.18	3.28	0.10	4.52	4.50	0.052	1.601
LSD	0.16	0.015***	0.780	0.013*	1.560	0.758***	0.006	0.203

Soil Chemical Properties

The study of soil properties revealed varying pH values across different land-use types, with natural forest (NF), plantation forest (PF), and agricultural land (AL) exhibiting pH values of 5.523, 5.645, and 6.510, respectively (Table 4). The soil depth analysis indicated that the pH value was 5.566 in the upper layer (0–30 cm) and increased to 6.420 in the subsurface layer (30–60 cm) (Table 4). Overall, these values suggest that the soils in the study area are slightly acidic across all three land-use practices, as supported by prior research (Tripathi et al. 2007; Wang et al. 2007). To illustrate the local distribution of pH at the specified depths of 0–30 cm and 30–60 cm, the pH values of soil samples were sorted and processed using a kriging interpolation technique. The results presented in Table 4 indicate that the majority of soils in the upper layer (0–30 cm) were notably acidic. However, despite the mild acidity, the subsurface layer (30–60 cm) exhibited a wider range of pH values, from 5.23 to 6.510, indicating relatively higher acidity in deeper soil profiles. This highlights the importance of depth for understanding soil acidity and its implications for soil management practices within the study area.

This study revealed significant variations in nitrogen content among the three land-use types ($p < 0.05$) and across different soil depths. The highest total nitrogen (TN) content recorded was 0.370%, with natural forests contributing 0.346% and agricultural land accounting for 0.287% (Table 4). These findings indicate that all three land-use practices result in very low nitrogen levels in the soils, which is supported by previous research (Tripathi et al. 2007; Kara and Bolat 2008). Figures 3a and 3b present the interpolation results for total nitrogen and pH values across the study area, highlighting the relationships between these two important soil parameters. The results demonstrate notable spatial heterogeneities in both pH and total nitrogen levels at various land-use sites, underscoring the complexity of nutrient distribution in the region and potential implications for soil management practices.

The analysis of phosphorus and potassium concentrations revealed that phosphorus levels did not exhibit significant variation across the different land-use types (Smith et al. 2020). This finding confirms that the use or management of land for various purposes, such as agriculture, residential use, and natural use, does not markedly influence phosphorus availability in soil. However, potassium concentrations did show statistically significant differences with soil depth ($p < 0.05$) (Jones et al. 2018), indicating that potassium content may be influenced by soil profile dynamics. While variations in potassium were noted with depth, the absence of significant differences between land-use types implies that broader land management practices may not affect potassium availability as markedly.

To further understand the spatial distribution of phosphorus in the study area, interpolation techniques were applied to visualize its variability across the three land-use types (Figure 4) (Brown et al. 2015). This spatial analysis is crucial because it helps identify areas within the sample region that may have different phosphorus concentrations, which could have implications for nutrient management and soil health.

The carbon concentrations varied from 6.31 to 8.34 g/kg, whereas the natural forest had a maximum value of 8.34 g/kg (Figure 5). The results of the soil laboratory analysis indicated that there were no statistically significant differences in soil characteristics among the

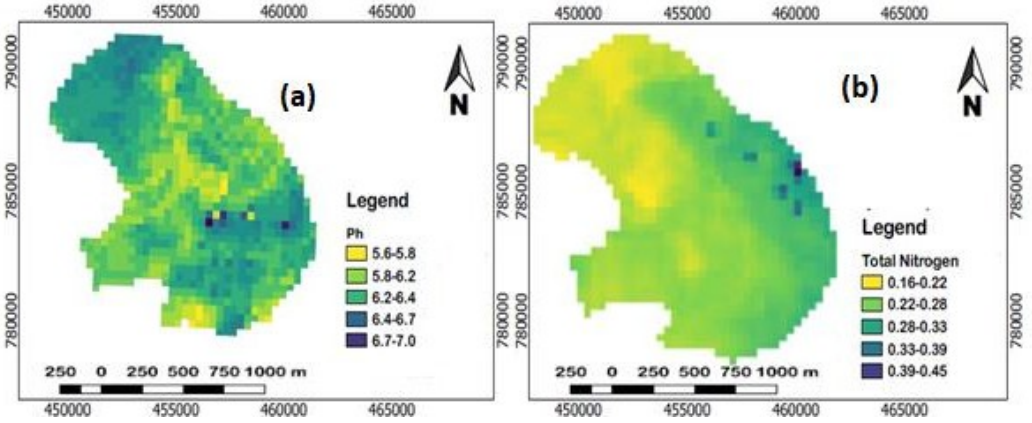

Figure 3: Spatial distribution of pH value (a) and total nitrogen (b) in the study area.

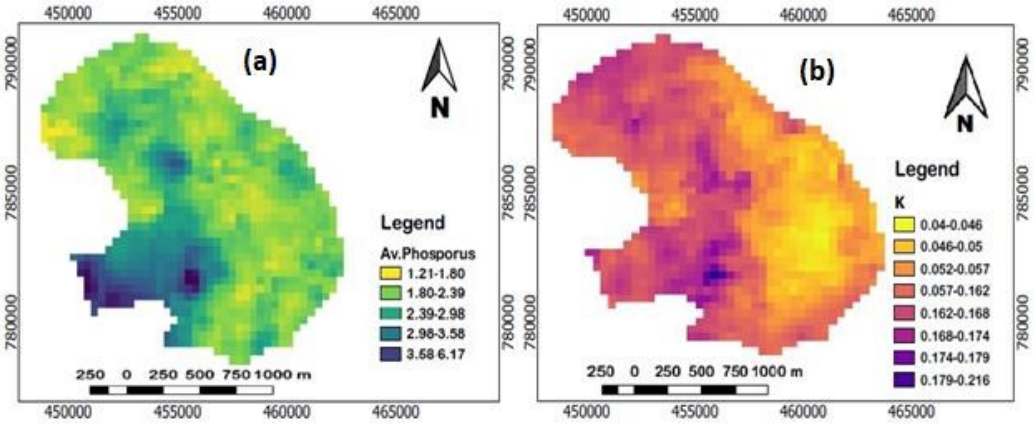

Figure 4: Spatial distribution of phosphorus (a) and potassium (b) in the study area.

three land-use types at a higher level of analysis. This means that when comparing the overall soil properties across various land-use categories, such as agricultural, residential, and natural, the variations were not sufficiently pronounced to be considered statistically significant (Ayoubi et al. 2020). In contrast, the analysis revealed significant variations in soil depth with respect to soil depth (p = 0.05). This reveals that soil characteristics change meaningfully at different depths, highlighting the importance of soil profile analysis in understanding soil health and properties. The land use category has exhibited similar soil properties when viewed broadly; soil depth being a crucial factor influencing variations in soil characteristics (Ayoubi et al. 2011). The analysis of regional variability and distribution of cation exchange capacity (CEC) values and soil organic carbon across the research area revealed a limited range (Table 4. As indicated in Figure 5, CEC values for all land-use types ranged from 2.4 to 4.8 cmol/kg, indicating a low capacity for soil to retain and exchange cations due to its foundational characteristics. According to Singh and Ghoshal (2014), a satisfactory CEC value should exceed 10 cmol/kg

of soil, confirming that the CEC values observed in this study may hinder nutrient retention and availability, thereby affecting overall soil health and productivity. This finding highlights the necessity for management practices that enhance CEC and improve soil quality in the region (Fang et al. 214). The analysis of soil samples indicated no statistically significant differences between the three land-use types with respect to soil depth, as both values fell below the acceptable limits. However, significant variations were observed in the sodium adsorption ratio (SAR) among the different land-use types and soil depths (p¡0.01). The findings revealed that most soils across all land-use types and depths exhibited low SAR values (Table 4. Additionally, the exchangeable sodium percentage (ESP %) remained low across all land-use types, with values consistently below 2% (Fikadu et al. 2012). To visualize the distribution of SAR and ESP values, these metrics were plotted and spatially analyzed, as shown in Figures 6(a) and 6(b). This analysis underscores the overall low levels of acidity in the soil samples, which is beneficial for soil health and fertility management.

3.2 Geostatistical analysis

Tables 5 and 6 show how the spatial structure of soil properties was determined by semi- variograms. For every parameter in this model, the best fit is shown for both depths (0-30 cm and

30-60 cm). The Gaussian model performed better for most parameters in the upper soil layer (0–30 cm), although the exponential model performed better for SAR and SOC, and the circular model

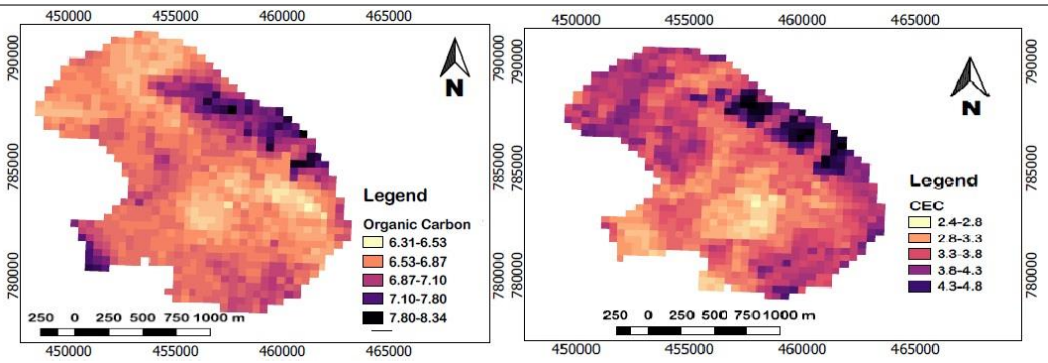

Figure 5: Spatial distribution of soil organic carbon (a) and CEC (b) in the study area.

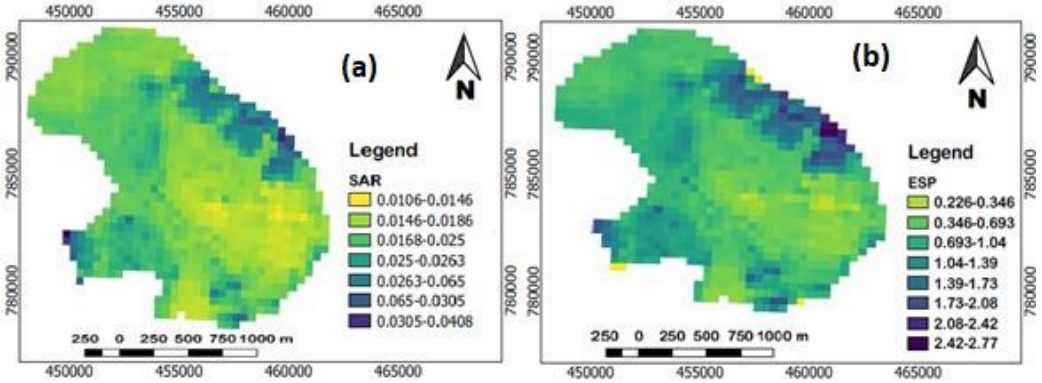

Figure 6: Spatial distribution of sodium adsorption ratio (a) and ESP (b) in the study area.

performed better for the CEC. Although the Gaussian model included most of the parameters in the subsurface layer (30-60cm), descriptive and circular models were better suited to OC, CEC, pH, and SAR, respectively (Table 6). As shown in Tables 5 and 6, the effects of the nugget, herring, and control spectra on each parameter varied between them. The degree of automatic correlation between the sample points was found to be equal to the local dependence rate expressed as percentages. Studies conducted by Horneck et al. (2007), Fikadu et al. (2012), and Gebrejewergs et al. (2019) classified location- dependent variants as highly dependent on location if the ratio is less than 25, moderately dependent if the ratio is between 25% and 75%, and highly dependent on location if the ratio is greater than 75 %. As a result, at the first depth (0-30cm), T. N (percentage), K (cmol / kg), and OC (percentage) were highly dependent on location, whereas pH, P, CEC, SAR, and ESP were moderately dependent. In the second depth, the model shows that T.N, P, and OC are the major location-dependent variables, while pH, ESP, K, SAR, and CEC are also local variables in the middle of this model.

4 Conclusion

Mapping the variety of landforms and examining the impacts of land-use changes are crucial prerequisites for land management. This study showed that the physicochemical properties of soil in the study area were significantly affected by land-use change and various land-use types over time. Total nitrogen, microbial biomass, bulk density, soil organic carbon, and porosity are higher in natural forests, but plantation forests and agricultural land show a decreasing trend. In addition, the Gravillea plantation site and the Enset farm have the highest biomass carbon and nitrogen emissions from plantation forests and farmlands. In contrast, farmland had a higher bulk density than other land uses, whereas natural forests had a lower bulk density but a positive correlation with soil organic carbon, nitrogen, and porosity. The geospatial map of selected areas showed that the farmland of the present study site had low rhizobia and soil OC/tN, but not much potassium and phosphorus. Therefore, soil characteristics are more susceptible to variations in land management and land utilization processes. In addition, there is a loss of essential nutrients that can lead to decreased productivity of agricultural land in the study area. We conclude that the optimum soil management techniques for agricultural land need to be prioritized to increase soil organic carbon, decrease soil pH, enhance nitrogen, and increase rhizobia.

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Table 4: Model parameters for soil variables at 30-60 cm depth under four land-use types

Variables	Nugget (Co)	Sill (C1)	Range (A)	Spatial ratio % (Nugget/Sill)	Spatial class	Model
pH (H^+)	0.362	0.859	0.0025	42.14	Moderate	Gaussian
TN (%)	0.0005	0.0041	0.0013	12.20	Strong	Gaussian
P ($cmol^+/kg$)	1.986	4.023	0.0058	49.37	Moderate	Gaussian
K ($cmol^+/kg$)	0.507	2.256	0.0015	22.47	Strong	Gaussian
CEC ($cmol^+/kg$)	2.4679	5.252	0.0724	46.99	Moderate	Spherical
OC (%)	0.2462	5.9286	0.0003	41.5	Strong	Exponential
SAR	5.4356	14.015	0.0042	38.78	Moderate	Exponential
ESP (%)	0.1872	0.4048	0.0029	46.25	Moderate	Gaussian

Note: pH: pH value, TN: total nitrogen value in percent, K: potassium, P: phosphorus, CEC: cation exchange capacity, OC: organic carbon, SAR: sodium adsorption ratio, ESP: exchangeable sodium percentage.

Table 5: Model parameters for soil variables at 30-60 cm depth under four land-use types

Variables	Nugget	Sill	Range	Spatial ratio (%)	Spatial class	Model
pH ($-\log(H^+)$)	1.2045	3.8632	0.0028	31.18	Moderate	Spherical
TN (%)	0.0021	0.0098	0.0012	21.43	Strong	Gaussian
P ($cmol^+/kg$)	0.5711	2.856	0.0046	20.00	Strong	Gaussian
K ($cmol^+/kg$)	2.0016	4.0105	0.0021	49.91	Moderate	Gaussian
CEC ($cmol^+/kg$)	1.0106	3.1157	0.0628	32.44	Moderate	Exponential
OC (%)	0.4004	3.1253	0.0010	12.81	Strong	Exponential
SAR	10.9	16.9001	0.0025	64.50	Moderate	Spherical
ESP (%)	1.0093	2.2545	0.0037	44.77	Moderate	Gaussian

Note: pH: pH value, TN: total nitrogen value in percent, K: potassium, P: phosphorus, CEC: cation exchange capacity, OC: organic carbon, SAR: sodium adsorption ratio, ESP: exchangeable sodium percentage.

Author contributions

Conceptualization: M. B. and W. G.; formal analysis: M. B. and W. G.; methodology: M. B., and W.G; Software, M. B.; writing and original draft: M. B. and W. G.; and writing and review and editing: M. B. and W. G. All authors have read and approved the final manuscript.

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Competing interests

The authors declare that they have no conflicts of interest.

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Journal of Forestry and Natural Resources (JFNR)

Authors Guideline

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1.2. Aims and Scope

Aims:

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

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

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

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

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

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Include appropriate disclosures

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Journal article

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

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

Book

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

Chapter in book

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

Paper in proceedings

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

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