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External debt servicing, foreign exchange constraint and import demand: evidence from Ethiopian economy

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Abstract
This study examines whether the country's foreign exchange availability influences import demand and provides empirical evidence about the impact of servicing external debt on the foreign exchange reserve. A yearly basis data starting from 1982 up to 2021 is employed. The World Bank's World Development Indicator (WDI) database is the primary source of the necessary data. The auto regressive (ARDL) method of econometric estimate is employed in the data analysis. The long-run result shows that repayment of foreign borrowing is insignificant in affecting the foreign exchange reserve of the nation. However, foreign aid, foreign borrowing and export growth are significant in increasing the foreign exchange reserve of the country. A sufficient supply of foreign currency in an economy is important to deal against instability and uncertainty of foreign capital flows. So, the government of Ethiopia can enhance the foreign exchange reserve through capital inflows and export growth. The findings from the import demand function of Ethiopia show that the foreign currency reserve is significant in driving import demand of the country. It is known that import enables unfettered access to capital goods from abroad and for improving the domestic welfare. So, the government should have stable and sufficient foreign exchange reserves to finance import of goods and services from abroad.

Keywords/Phrases: Ethiopian economy, External debt servicing, Foreign exchange reserve, Import demand

1 Introduction

Different economic development theories highly emphasize that developing countries, in general, are trapped by a vicious circle of poverty, which accounts for the existence of low levels of income, which results in low saving and investment activity in the nation. This implies that there are only little prospects of future growth in per capita income and development of the industrial sector which arises from lower level of investment. Therefore, existence of this situation does not stop at one period since it involves a vicious circle in which poverty and low development lead to more poverty and underdevelopment (Todaro and Smith, 2012).

External debt financing is viewed as a mechanism to escape from the poverty trap and relieve bottlenecks in the development process for many developing countries. In practice, there are sound theoretical reasons why it may be entirely rational for developing countries to borrow from abroad (Ghatak, 2005). To some extent, the accumulation of external borrowing for developing countries arises from their interest in stabilizing the domestic financial market through foreign currency reserves. In this regard, external borrowing contributes to increasing the foreign exchange reserve of developing countries. However, the effect of foreign borrowing in developing countries might not be reflected directly rather first, it boosts the foreign exchange accumulation of countries and could lead to economic growth and more import demand since import of goods and services requires the availability of foreign exchange reserve in the economy. But, this borrowing, in turn, results in repayment, including the interest, which is difficult for most developing countries because developing countries are characterized by foreign exchange constraints combined with the high import of capital goods and heavy types of machinery (Obsfeld *et al.* 2008).

Ethiopia is among those developing countries that borrow from the rest of the world such as the Western World and China, to finance the saving-investment gap, export-import gap, and tax-government spending gap. This borrowing result in repayment of the debt, including interest for the lender country, and Ethiopia has been paying a substantial amount of foreign currency over the last few decades. For instance, the country is paying a total of external debt to different lender countries and institutions, which amounts to 30.4 Million USD in 1990 with a foreign exchange reserve of 202 Million USD; paid 138.6 Million USD in 2000 with a foreign exchange reserve of 490 Million USD; paid 88.3 Million USD in 2005 with foreign exchange reserve of 1.04 Billion USD, paid 1.8 Billion USD in 2010 with foreign exchange reserve of 2.2 billion USD, paid 1.4 USD in 2015 with foreign exchange reserve of 3.8 Billion USD, paid 2.1 Billion USD in 2018 with foreign exchange reserve of 3.9 Billion USD (World Bank, 2021). Hence, the main debate here is "Has external debt servicing eroded foreign exchange accumulation of Ethiopia?" and "Does the country's limited foreign exchange accumulation affect its import demand?" Hence, the need of this study is to answer the above two main questions and draw harmonized policy implications regarding the issues.

The empirical findings by Obstfeld *et al.* (2008) for 134 countries and Aizenman *et al.* (2016) for 100 countries from advanced, emerging, and developing economies concluded that the increase in foreign exchange reserve is a response to domestic financial protection (exchange rate stability) and to get relaxed from policy trilemma . A study by Ayunku and Markjackson (2020) found that external debt servicing is insignificant in affecting the foreign exchange reserve of the Nigerian economy. On the other hand, various research works are done to show how the growth performance of nations is affected by the availability of foreign exchange reserves. In this regard, Lensik (1995), Tariq *et al.* (2013), Cheng (2013), and Krušković & Maričić (2015) tried to answer the question "Why do countries accumulate foreign exchange reserve?" Those studies confirm the positive impact of the supply of foreign currency on growth. However, all the above studies neglected the impact of the supply of foreign currency on import demand. Specifically, in Ethiopia, no one is devoted to the impact of foreign currency supply on import demand. Moreover, although empirical investigations are done to assess the effect of external borrowing on foreign currency supply, some of research cannot devote to figuring out the effects of repayment of external borrowing on the supply of foreign currency in Ethiopia.

Hence, this study aims to assess how the accumulation of foreign currency is affected by the external debt repayment practice of Ethiopia and, in turn, how this foreign exchange reserve affects the country's import demand by using ARDL technique of estimation This might help to draw alternative policies and import strategies with the prevailing foreign exchange constraint in the country.

2 Materials and Methods

2.1 Data Source and Type

A supplementary form of macroeconomic data covering the years 1982–2021 is gathered primarily from the World Bank's World Development Indicator (WDI) database in order to meet the study's goals.

2.2 Model specification and method of data analysis

A new model, initially created by Pasaran, Shin, and Smith (2001), can offer a number of benefits over conventional time series estimate methods for studying time series research. This newly developed model is known as an autoregressive distributive lag model and can give a valid, unbiased, and reliable output because of the following advantages. This method can be applied to a mixture of first-difference and level-stationary variables. Second, it is more suitable for small sample size data in time series regression (Pesaran *et al.* 1998; Narayan, 2005). Third, it deals with even some of the endogenous independent variables. (Pesaran *et al.* 1998). Fourth, this technique uses only a single reduced form equation, which is impossible in other co-integration estimation techniques.

According to Green (2003), the simple generalized ARDL (*p*, *q*) equation can be shown as:

$$\begin{aligned} Y_t = {} & C + \gamma T + \alpha_1 Y_{t-1} + \ldots + \alpha_p Y_{t-p} + \\ & \beta_0 X_t + \beta_1 X_{t-1} + \ldots + \beta_q X_{t-q} + \\ & \theta D + U_t \end{aligned} \tag{1}$$

Based on the above generalized equation, the two equations of this study which are going to be estimated are specifies as follows.

Equation one: A composition of traditional and financial stability models used by Obstfeld, *et al.* (2008) is applied to show how the foreign exchange reserve is affected by external debt servicing. Moreover, according to Gosselin and Parent (2005), foreign reserve function can be affected also by economic size which can be real GDP growth rate, export volume, external borrowing. Hence, the foreign exchange reserve function can be expressed as:

$$FER = f(GDPgr, EB, AID, Ex) \tag{2}$$

Where, *EB* is external borrowing has its counterpart of repaying. As a result, external debt servicing (EDS) should be included in the model. *AID* is foreign official aid; *Ex* is export, which is a proxy for structure of the economy.

Then the final foreign exchange reserve equation can be expressed as:

$$FER = f(GDPgr, EB, EDS, AID, Ex) \tag{3}$$

Then, the auto regressive form of equation three which is going to be estimated can be expressed as:

$$\begin{aligned} \Delta FER_t = {} & \beta_0 + \theta_1 GDPgr_{t-1} + \theta_2 EB_{t-1} + \\ & \theta_3 EDS_{t-1} + \theta_4 AID_{t-1} + \theta_5 Ex_{t-1} + \\ & \sum_{j=1}^{n} \beta_{1j} \Delta GDPgr_{t-1} + \sum_{j=1}^{n} \beta_{2j} \Delta EB_{t-1} + \\ & \sum_{j=1}^{n} \beta_{3j} \Delta EDS_{t-1} + \sum_{j=1}^{n} \beta_{4j} \Delta AID_{t-1} + \\ & \sum_{j=1}^{n} \beta_{5j} \Delta Ex_{t-1} + U_t \end{aligned} \tag{4}$$

Table 1. Measurement and source of dependent and independent variables for equation one

Variable	Code	Measurement	Expected Sign	Data source
Foreign exchange reserve	FER	Foreign exchange reserve in USD at time t		World Development Indicator
Real GDP	GDPgr	Growth rate of real GDP at time t	+	World Development Indicator
External debt	EB	External borrowing in USD at time t	+	World Development Indicator
External debt servicing	EDS	External debt servicing in USD at time t	-	World Development Indicator
Aid received	AID	Net official aid received in USD at time t	+	World Development Indicator
Total Export	EX	Total export in USD at time t	+	World Development Indicator

U_t is the error term of the function;
n, is the lag length of the auto regressive process of the equation;
Δ stands for the first difference operator;

θ_1, θ_2, θ_3, θ_4, θ_5 are long run parameters the function; and
β_{1j}, β_{2j}, β_{3j}, β_{4j}, β_{5j} are short run parameters of the function.

Equation two: To show whether the country's foreign exchange constraint is affecting import demand or not, a simple open economy model is used, and the import demand function, which is presented based on the theory of balance of payment and national income identity equation as follows.

The national income equation states that national income is expressed as:

$$Y = f(C, I, G, X, M) \tag{5}$$

Where, Y- national income, C- consumption, I- investment, G- government spending, X- export value and M- import. By rearranging equation five above, import demand is expressed as:

$$M = f(Y, I, G, X) \tag{6}$$

Export is one source of income for import and it can be explained by the availability of foreign exchange reserves. Then, by expanding the above function and including other variables according the country's context and economic literature, the following import demand equation can be specified.

$$M = f(PCI, RP, FER, REER) \tag{7}$$

Where M is import as a share of GDP, PCI is per capita income (a proxy for national income), RP is the relative price, which is a share of domestic price to the world price, FER is foreign exchange reserve, and $REER$ is the real effective exchange rate.

Then, the auto regressive form of equation seven to be estimated is expressed as:

$$\begin{aligned}\Delta M = {} & \beta_0 + \theta_1 PCI_{t-1} + \theta_2 RP_{t-1} + \theta_3 FER_{t-1} + \\ & \theta_4 REER_{t-1} + \sum_{j=1}^{n} \beta_{1j} \Delta PCI_{t-1} + \\ & \sum_{j=1}^{n} \beta_{2j} \Delta RP_{t-1} + \sum_{j=1}^{n} \beta_{3j} \Delta FER_{t-1} + \\ & \sum_{j=1}^{n} \beta_{4j} \Delta REER_{t-1} + U_t\end{aligned} \tag{8}$$

Table 2. Measurement and source of dependent and independent variables for equation two

Variable	Code	Measurement	Expected Sign	Data source
Import Demand	M	Total import as a share of GDP at time t		World Development Indicator
Per Capital Income	PCI	Per capital income in USD at time t	+/-	World Development Indicator
Relative price	RP	A share of domestic price to world price at time t	+	World Development Indicator
Foreign exchange reserve	FER	Foreign exchange reserve in USD at time t,	+	World Development Indicator
Real effective exchange rate	REER	Real effective exchange rate at time t,	-	World Development Indicator

U_t is the error term of the function;
n, is the lag length of the auto regressive process of the equation;
Δ stands for the first difference operator;

θ_1, θ_2, θ_3, θ_4, θ_5 are long run parameters the function; and
β_{1j}, β_{2j}, β_{3j}, β_{4j}, β_{5j} are short run parameters of the function.

For both equations, to test whether there is co-integration between the dependent and independent variables, a bound testing approach is used, which is proposed by Pesaran, Shin, and Smith (2001). The hypotheses of the test can be presented as:

H_0: $\theta_1 = \theta_2 = \theta_3 = \theta_4 = \theta_5 = 0$, implies no co-integration among the variables.

H_1: $\theta_1 \neq \theta_2 \neq \theta_3 \neq \theta_4 \neq \theta_5 \neq 0$, shows co-integration among the variables

3 Results and Discussion

Discussion of Findings

Foreign exchange reserve and import demand equations are specified for the Ethiopian economy, and the results of both equations are discussed intensively. In doing this, pre-estimation and diagnostic tests are employed before the findings.

3.1 Foreign Exchange Reserve Equation of Ethiopia

3.1.1 Unit Root Testing

This model requires unit root testing to make sure that none of the variables stay stagnant at the second difference or higher. By doing this, the foreign exchange reserve equation's unit root test result is shown as follows. It makes use of both the Philips-Perron (PP) and Augmented Dicky-Fuller (ADF) tests.

According to the results, the external borrowing and real GDP growth rate are stationary at level, while the other variables are stationary at first difference. This outcome provides compelling evidence in favor of using the autoregressive regression approach for the foreign exchange reserve function.

Table 3. Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) test results

Variables	Augmented Dickey Fuller (ADF) and Phillps Perron (PP) Test		
	ADF	PP	Decision
	T-statistics	T-statistics	
FER	-6.587295***	-7.716360***	I (1)
GDPgr	-3.683762**	-4.397673***	I (0)
EB	-3.877499**	-3.326784**	I (0)
EDS	-5.047035***	-4.137477***	I (1)
AID	-6.835964***	-6.828706***	I (1)
Ex	-5.007812***	-4.960542***	I (1)

Note: *** and ** indicates significance at 1% and 5% level of significance.

Source: Own computation using EViews 9.0

3.1.2 Bound testing approach of co-integration for foreign exchange reserve function

To test whether there is a co-integration between the foreign exchange reserve and its explanatory variables; a bound testing approach is used. The result for checking this long-run co-integration between the foreign currency supply and its explanatory variables is presented in the table 4 below.

At a significance level of 5%, the F-statistic value (9.71) is higher than the upper bound critical values. This suggests that the foreign exchange reserve and other independent variables in the function have a long-term relationship. This is an example of Ethiopia's co-integrated foreign exchange reserve function.

Table 4. Bound testing result for equation 1

Bounds Testing Result		
Null Hypothesis: No long-run relationships exist		
Test Statistic	**Value**	**K**
F-statistic	9.709534	5
Critical Value Bounds		
Significance	**Lower Bound**	**Upper Bound**
5%	2.62	3.79
1%	3.41	4.68

Source: output from E-views 9 econometric software.

3.1.3 Other pre-estimation tests for foreign exchange reserve function of Ethiopia

In addition to the functional form test confirming that the model is fully described and that there is no issue with omitted variable bias, table 5 above suggests that there is no serial correlation problem in the function at a 5% level of significance. The results of the normality test show that the foreign exchange reserve function does not have a heteroscedasticity issue and that the errors are normally distributed.

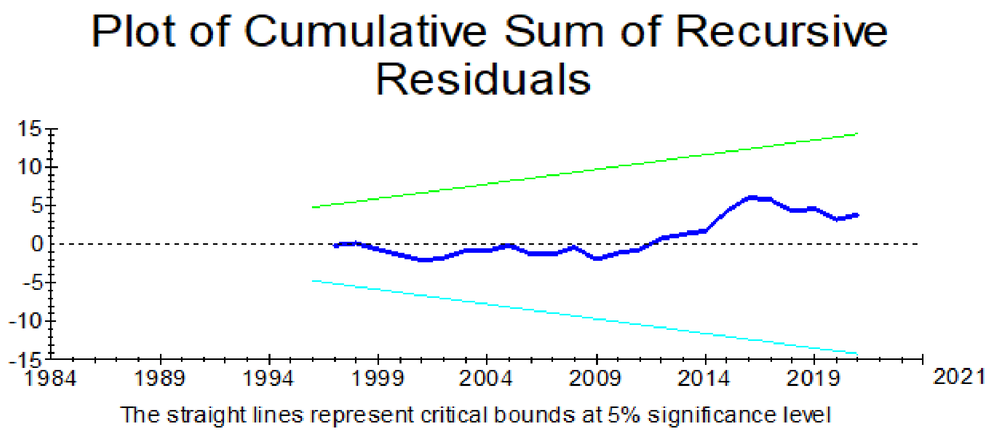
The CUSUM and CUSUM square tests recommended by Pesearon and Shin (1997) are used to verify the model's stability. By graphing the test statistics of these stability tests, we may determine whether a structural break issue exists.

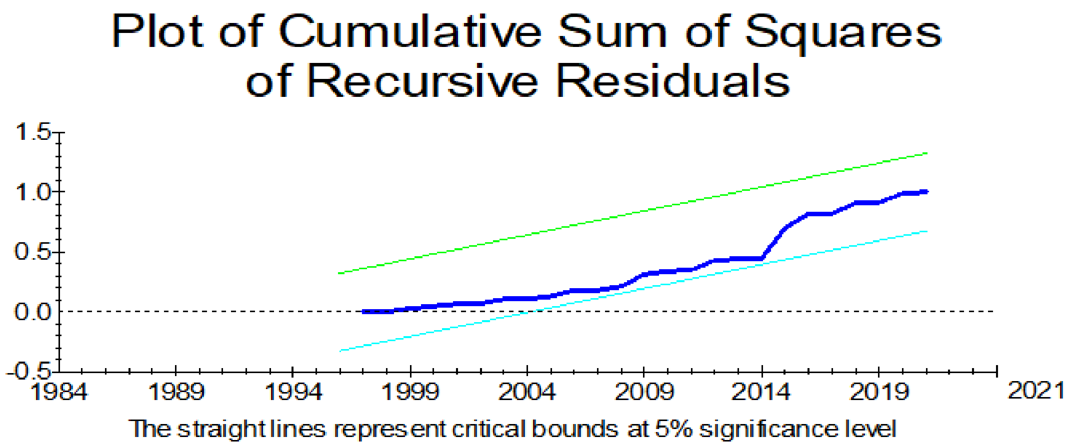
Table 5. Pre-estimation diagnostic tests result for the foreign exchange reserve function

Test statistics	**LM version**	***F* version**
Serial Correlation	CHSQ (1) = 2.5521[.110] **	*F* (1, 25) = 1.7999[.192] **
Functional Form	CHSQ (1) = .24652[.620] **	*F* (1, 25) = .15859[.694] **
Normality	CHSQ (2) = .40651[.816] **	Not applicable
Heteroscedasticity	CHSQ (1) = 2.6427[.104] **	*F* (1, 36) = 2.6907[.110] **

Source: Output from Microfit 4.1 ARDL (0, 0, 1, 1, 2, 2).

Note: 5% level of significance is used.





The two graph plots above demonstrate how, at the 5% level of significance, the recursive residual static curves for the foreign exchange reserve equation fluctuate between the critical boundaries. This suggests that there are no structural break issues with the model, which displays both short- and long-term associations.

3.1.4 Long run and short run estimates of foreign exchange reserve equation of Ethiopia

After making sure that there is long-run co-integration between foreign currency supply and its explanatory variables, it is possible to estimate the function. In doing this, the following table summarizes the long-run estimation result for the foreign exchange reserve function of Ethiopia.

Table 6. Long-run and short-run estimates of foreign exchange reserve equation

Method: ARDL				
Model selected: ARDL (0, 0, 1, 1, 2, 2)				
Variables	**Coefficients**	**Standard error**	***t*-statistics**	***p*-values**
Long-run coefficients				
GDPgr	-17502.6	8225028	-0.0021280	0.998
EB	0.064788	0.020606	3.1441	0.004***
EDS	-0.29866	0.28472	-1.0489	0.304
AID	0.45467	0.073786	6.1620	0.000***
Ex	9.35E+07	1.92E+07	4.8796	0.000***
C	-1.18E+09	2.03E+08	-5.8140	0.000
Short-run coefficients				
D(GDPgr)	-17502.6	8225028	-0.0021280	0.998
D(EB)	0.15199	0.033061	4.5974	0.000***
D(EDS)	1.6047	0.48382	3.3166	0.002***
D(AID)	-0.16780	0.16400	-1.0232	0.315
D(Ex)	5.44E+07	3.27E+07	1.6661	0.106
D(C)	-1.18E+09	2.03E+08	-5.8140	0.000***
ECM-1	-0.78726	0.16434	-4.79043	0.000***

Note: *** and ** indicates the rejection of a null hypothesis of statistical insignificance of the coefficients at 1%, and 5% levels of significance.

Source: Output from Microfit 4.1

The long-run estimates show that foreign borrowing, official foreign aid, and the export sector are strongly significant in affecting the foreign exchange reserve of Ethiopia. This result is consistent with a theory of capital flows. That is, a rise in foreign borrowing is one of the mechanisms to finance funds from abroad and directly increases the foreign currency availability. Another reason is foreign borrowing is likely to lead to greater investment activity in domestic and abroad, which, in turn, might affect the volume of trade. This confirms the finding by Andriyani *et al*., (2020). This result is also consistent with the short-run result. However, borrowing cannot be a persistent way to increase foreign exchange reserves since it can cause serious difficulties. External borrowing beyond the threshold level might cause a debt trap, economic instability, limited fiscal space, vulnerability to external shocks, and low opportunities for private sector growth. Managing borrowing levels and ensuring debt sustainability are crucial for developing countries to ensure long-term economic stability. So, borrowing to increase the foreign exchange reserve of a country should be managed carefully. If the central bank wants to increase the foreign currency reserve, especially during a crisis period, it should seek to identify and utilize other sources of foreign exchange reserve enhancement mechanisms.

Export and foreign aid are strongly significant and favorably influence the foreign currency supply of the country. This is because the export of goods and services is a way to fund sources from abroad in the form of foreign currency. So, countries with abundant natural resources should increase their export in terms of volume and diversification to accumulate a sufficient amount of foreign currency. This finding is also parallel with the findings by Rahmawati and Setyowati (2018) and Andriyani *et al*., (2020). This is one of the reasons why Ethiopia and other sub-Saharan African countries have accumulated substantial foreign currency supply in recent years, mostly from the export sector as well as foreign aid flows although it is not at a satisfactory level. But both export and foreign aid are found to be insignificant in the short run.

The speed of adjustment of any disequilibrium towards long-run equilibrium, which can be shown by the error correction coefficient, is significant. This estimated error correction coefficient for the foreign exchange reserve equation in Ethiopia implies a high speed of adjustment to equilibrium after a shock. Approximately 78.72% of the disequilibrium from the previous year's shock converges back to the long-run equilibrium in the current year.

In the long run, GDP growth rate and external debt servicing are insignificant in affecting the foreign currency reserve of a country. The insignificant effect of external debt servicing on the foreign currency supply of the country might be because of the huge amount of concessional loans over recent decades. But, in the short run, external debt servicing is significant in affecting the foreign exchange reserve of the country. The GDP growth rate is also insignificant in affecting foreign currency accumulation of the country both in the short run and the long run, which is inconsistent with the findings of Kashif & Thiyagarajan (2017). This result implies that Ethiopia is unable to build up foreign currency reserves from a pro-growth approach.

3.2 Import demand equation of Ethiopia

The second function to be estimated in this study is the import demand equation. Before presenting the long-run estimates of all parameters, the necessary pre-and post-estimation tests are checked as follows.

3.2.1 Unit root testing

The unit root test result for the import demand function is presented on the table seven below.

The result shows that relative price (RP) is stationary at level and other variables are stationary at first difference. Like that of the former foreign exchange reserve function, the unit root test result of the import demand function implies a strong justification for employing the autoregressive (ARDL) regression technique.

Table 7. Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) test results

Variables	Augmented Dickey Fuller (ADF) and Phillps Perron (PP) Test		Decision
	ADF	PP	
	T-statistics	T-statistics	
M	-5.275265***	-5.266011***	I (1)
PCI	-3.265249**	-3.229117**	I (1)
RP	-5.262737***	-5.267288***	I (0)
FER	-6.587295***	-7.716360***	I (1)
REER	-5.580210***	-5.635874***	I (1)

Note: *** and ** indicates significance at 1% and 5% level of significance.
Source: Own computation using EViews 9.0

3.2.2 Bound testing approach of co-integration for import demand equation of Ethiopia

The import demand function of Ethiopia is tested for the existence of co-integration between the import demand and its explanatory variables by using a bound testing approach. The result for checking this long-run co-integration between the import demand and its explanatory variables is presented in the table below.

Table 8 below shows that the value of the F-statistic (6.84) is greater than the upper bound critical values at a significance level of 5%. This implies that there is the existence of a long-run relationship between import demand and other independent variables in the function. This represents a co-integrated import demand function in Ethiopia.

Table 8. Bound testing result for import demand function in Ethiopia

Bounds Testing Result		
Null Hypothesis: there is no long-run relationship between the variables		
Test Statistic	**Value**	**K**
F-statistic	6.846409	4
Critical Value Bounds		
Significance	**Lower Bound**	**Upper Bound**
5%	2.62	3.79
1%	3.41	4.68

Source: output from E-views 9 econometric software.

3.2.3 Diagnostic testing for import demand equation of Ethiopia

The following diagnostic tests are presented for import demand function of Ethiopia.

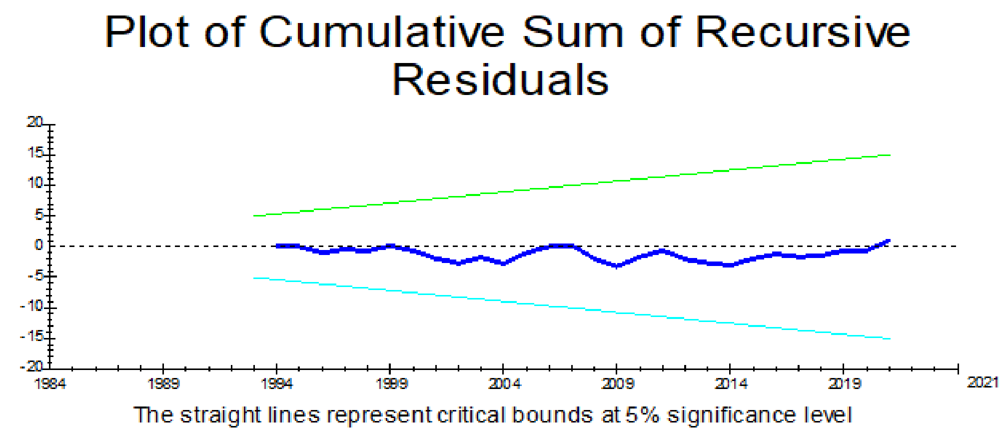
The result in Table 9 implies that there is no serial correlation problem in the function at a 5% level of significance, and the functional form test also confirmed that the model is well specified and there is no problem of omitted variable bias. The normality test reveals that the errors are normally distributed, and there is no heteroscedasticity problem in the import demand function of Ethiopia.

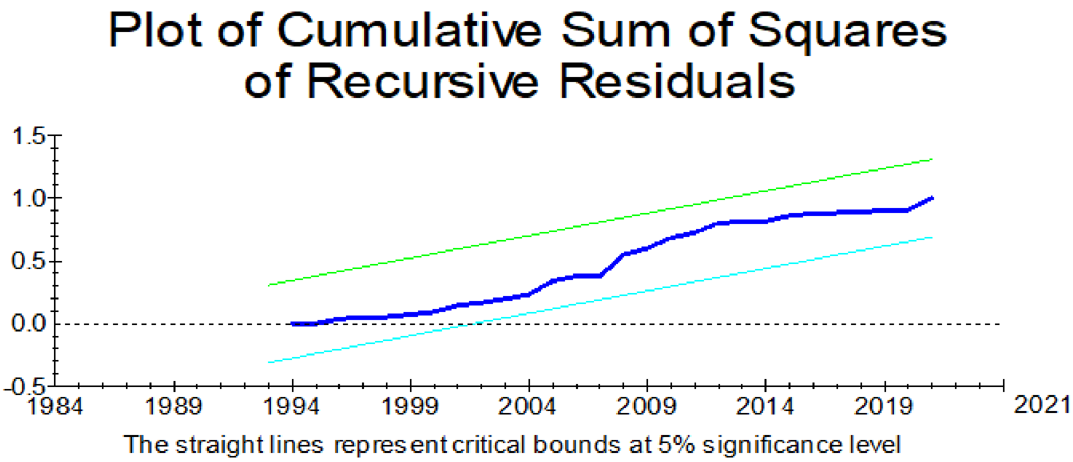
Table 9. Pre-estimation diagnostic tests result for import demand function of Ethiopia

Test statistics	**LM version**	***F* version**
Serial Correlation	CHSQ (1) = 1.2504[.263] **	*F* (1, 28) = .95269[.337] **
Functional Form	CHSQ (1) = .013297[.908] **	*F* (1, 28) = .0098011[.922] **
Normality	CHSQ (2) = .67625[.713] **	Not applicable
Heteroscedasticity	CHSQ (1) = .330624[.861] **	*F* (1, 36) = .028948[.866] **

Source: Output from Microfit 4.1 ARDL (2, 0, 0, 1, 1) .5% level of significance is used

The following plot of graphs is showing the stability and structural problem test for the import demand function in Ethiopia.





The recursive residual static curves for the import demand equation imply that the residual curves move between the critical bounds at a 5% level of significance. This implies that the model, which shows short-run and long-run relationships, is stable, and there is no structural break problem in the model.

3.2.4 Long run and short run estimates of import demand function of Ethiopia

After making sure that there is an existence of co-integration between import demand and its explanatory variables, it is possible to estimate the function. In doing this, the following table summarizes the long-run and short-run estimation results for the import demand function in Ethiopia.

Table 10. Long-run and short-run Estimates of the import demand equation

Method: ARDL

Model selected: ARDL (2, 0, 0, 1, 1)

Variables	Coefficients	Standard error	*t*-statistics	*p*-values
Long-run coefficients				
PCI	-0.13204	0.049339	-2.6762	0.012**
RP	1.0468	1.0454	1.0013	0.325
FER	0.2027E-7	0.6834E-8	2.9665	0.006***
REER	-0.019265	0.051816	-0.37180	0.713
C	40.8159	7.5747	5.3885	0.000***
Short-run coefficients				
D(PCI)	-0.45161	0.13724	-3.2907	0.002***
D(RP)	-0.021853	.0037493	-5.8285	0.000***
D(FER)	0.17323	0.17575	0.98569	0.332
D(REER)	-0.024949	0.0099976	-2.4955	0.018**
D(C)	6.7549	2.1256	3.1779	0.003***
ECM-1	-0.68041	0.14305	-4.75644	0.000***

Note: *** and ** indicates the rejection of a null hypothesis of statistical insignificance of the coefficients at 1%, and 5% levels of significance.

Source: Output from Microfit 4.1

The result from estimates of the import demand function for Ethiopia presented in Table 10 shows that in the long run, foreign currency reserve is significant in increasing the aggregate import demand of the country. Keeping other things constant, a 1 unit increase in foreign currency reserve at the national bank results in a 0.2 unit rise in import demand of the country. This suggests that a significant portion of foreign exchange reserves are used to finance imports. This is due to the fact that a rise in foreign exchange reserves boosts the nation's purchasing power and ensures uninterrupted international transactions. This result contradicts the study conducted by Vacu & Odhiambo (2019) and is in line with a study conducted by Vacu (2021) & Farayibi (2016). This call for a sufficient amount of foreign currency reserve is important to increase imports, which in turn enables countries with constrained production capacity, to unfettered access to capital goods from abroad and to improve domestic welfare. But in the short run, it is found to be insignificant in affecting the import demand in Ethiopia.

Per capita income has a major negative impact on Ethiopia's import demand over the long and short terms. When all else is held constant, a one unit increase in the nation's per capita income causes the demand for imports to decline by 0.13 units. According to the standard demand imperfect substitution theory, the consumer's goal is to maximize utility while staying within their means.

In other words, the import demand function is primarily determined by the income of the importing country and the relative price of goods. This finding might be because as per capital income is improved, domestic investment can be expanded, and infant domestic industries become strong and competitive at the international level, which can substitute imported items from abroad by enabling them to be produced in domestic. Moreover, an increase in per capital income can increase domestic production, domestic saving and investment, shift in consumer preferences, and those in turn can reduce aggregate import demand of the country. This result is consistent with Narayan & Smyth (2005) and inconsistent with a study by Vacu & Odhiambo (2020).

As indicated by the error correction coefficient, the rate at which any disequilibrium adjusts to long-term equilibrium is noteworthy. A high rate of equilibrium adjustment following a shock is implied by this calculated error correction coefficient for Ethiopia's import demand function. About 68.04% of the shock-related disequilibrium from the prior year converges to the long-term equilibrium this year. Although the relative price of goods and services and the real effective exchange rate are found to be significant in negatively affecting the aggregate import demand, in the long run, both are insignificant in affecting the import demand function of Ethiopia. This might be because of price inelastic nature of Ethiopia's imported items from the rest of the world.

4 Conclusion and Implications

According to the findings, a nation's foreign exchange reserves can be considerably raised over time via export expansion, overseas borrowing, and international aid. The capital flow theory is to blame for this. The outcome can be used to support the theory that foreign commerce and capital inflows may be the cause of a sizable foreign exchange reserve. However, over time, Ethiopia's foreign exchange reserve is not significantly impacted by GDP growth rate or external debt servicing.This might be because of the huge amount of concessional loans over the last decades and the inability to build up foreign currency reserves from a pro-growth approach in Ethiopia. It is known that reserving a sufficient amount of foreign currency in an economy is essential to deal with the instability and uncertainty of external capital flows. The implication of this result is the government of Ethiopia can enhance the foreign exchange reserve through capital inflow, such as borrowing and working on export growth. The government policy should be designed by focusing on increasing exports in terms of volume and diversification.

However, borrowing cannot be a persistent way to increase foreign exchange reserves since it can cause severe difficulties, especially during a crisis when it becomes almost impossible to refinance. Borrowing above the threshold level can lead to a debt trap, economic instability, limited fiscal space, vulnerability to external shocks, dependence on foreign lenders, and reduced opportunities for private sector growth. Managing borrowing levels and ensuring debt sustainability are crucial for developing countries to ensure long-term economic stability and growth. So, foreign borrowing should be managed carefully, and most of the time it is not recommended as a persistent way of gaining foreign exchange reserves from abroad.

The results of Ethiopia's import demand function demonstrate that, over time, per capita income has a negative impact on the nation's overall import demand equation. This is due to the fact that rising per capita income can lead to changes in consumer choices, domestic production, saving, and investment, all of which can lower the nation's overall import demand. However, foreign exchange reserves are strongly significant in positively affecting the import demand of the country because an increase in foreign exchange reserves increases the purchasing power and provides stability in international transactions without disruptions. So, the government should have a stable foreign exchange reserve to finance the import of goods and services from abroad since import enables unfettered access to capital goods from abroad and to improve the domestic welfare and human development.

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Conflicts of Interest

The authors of this research state that they have no conflicts of interest with regard to its publication.

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Assessing spatial accessibility of bus stops and user satisfaction with transportation services: a case of Dilla Town, South Ethiopia Region, Ethiopia

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Abstract

Bus stop accessibility is a vital component of a successful transportation system. This study aimed to investigate the network characteristics of bus stop locations and evaluate bus service users' satisfaction. The road networks were digitized from aerial photographs and the locations of the bus stops were collected by Handheld GPS to assess the accessibility of bus stops. Additionally, an administered questionnaire related to service quality was collected to evaluate the bus transportation service quality provided by Dilla University. Network analysis techniques were employed to analyze the spatial distribution and accessibility of bus stops. The bus stop coverage ratio index was determined from the ideal access coverage and the actual access coverage of bus stops. The SCRI result indicates Getsmart Bus stop has the highest value (0.96), suggesting that it has a high level of functionality for its surrounding area. On the other hand, the bus stop with the lowest value (0.60) is 'Molla Golja'. The findings of the study highlighted significant variations in bus stop coverage, indicating differences in accessibility among the stops. The questionnaire survey results showed that passengers were not generally satisfied with the bus service. In summary, the network analysis is useful for identifying areas with low accessibility and areas where improvements are needed.The significance of this study extends beyond providing solely to the needs of Dilla University administrators for creating a more efficient and user-friendly transportation system for their workers and the wider community. It is useful for the Dilla Town Administrative Road Transport Office and other organizations seeking to improve transportation systems.

Keywords/Phrases: Accessibility, Bus stop, Dilla Town, Network analysis, Passengers satisfaction

1 Introduction

Public transportation is an essential mode of transportation in urban areas. It plays a crucial role in fostering sustainable and efficient urban mobility (Ambrosino *et al*., 2016; Pojani & Stead, 2015), providing a viable alternative to private vehicles,and reducing traffic congestion (Liu *et al*., 2017). It promotes social inclusion by ensuring affordable and accessible transport options for all, irrespective of income and ability (Kett *et al*., 2020; Pereira *et al*., 2017).

Access to public transport plays a vital role in an individual's ability to carry out daily activities effectively. Transportation infrastructure and land use systems are essential to model accessibility in a given area (Yigitcanlar *et al*., 2007). Urban transportation planning encompasses information regarding bus stops, road networks, transport routes, and their frequencies (Martínez *et al*., 2014). The absence of bus stops at the peripheries of town leads to humble accessibility on foot (Hernandez & Titheridge, 2016). When bus stopsare easily accessible, it becomes more convenient for people to use public transportation (Borhan *et al.*, 2019), leading to increased ridership and reduced reliance on private vehicles (Jansuwan *et al.*, 2013). This, in turn, can have several positive impacts on the community and the environment. Convenient bus stops encourage a modal shift from private vehicles to public transportation. By ensuring that bus stops are strategically located within communities, close to residential areas, workplaces, educational institutions, and commercial centers, people are more likely to choose buses as a preferred mode of transport (Chakour & Eluru, 2013). This accessibility is determined by how close the passenger's origin or destination is to the nearest transit stop (Pan *et al.*, 2017; Wang *et al.*, 2011), which can be reached by walking a 400-meter distance as an acceptable standard (Daniels & Mulley, 2013). Overall, the accessibility of Bus stops significantly impacts passenger convenience and their ability to utilize public transportation services effectively (Litman, 2015).

The success of any organization hinges on the quality of services provided. Service quality is the critical link between customer expectations and their actual perception of the service received (Gilaninia *et al.*, 2013). Nowhere is this more evident than in the realm of public transportation. Imagine the frustration and disappointment when reliability falters, pushing away both existing and potential clients. Universities, in particular, face the critical challenge of ensuring the reliability and comfort of their bus services, all while ensuring that drivers' attitudes are up to par. These factors, as highlighted by the insightful works of (Md Yusof *et al.*, 2014; Osman & Sentosa, 2013), remain constant concerns in the pursuit of excellence.

The Ethiopian Higher Education sector needs significant improvements in service quality despite ongoing efforts by universities (Lemmalodesso, 2012). Various complaints from the university community have emerged, highlighting issues such as inadequate availability and reliability of buses, substandard bus facilities, unsatisfactory attitudes of bus drivers, long waiting times, and a lack of prompt responses to concerns (Oljira, 2022; Phooriphokhai & Jitpraphai, 2016). To ensure the effective utilization of public transportation services, it is crucial to assess the satisfaction of passengers, particularly the Dilla University workers.

While several studies have been conducted in Ethiopia to assess bus service satisfaction (Aniley & Negi, 2010; Belay & Kenei, 2019; M. Girma & Woldetensae, 2022; Lemmalodesso, 2012; Mammo, 2010; Oljira, 2022; Woldeamanuel & Woldetensae, 2021), they have often overlooked the crucial factor of spatial accessibility of bus stops, which plays a significant role in shaping passenger experiences.

By integrating the evaluation of spatial accessibility with service user satisfaction, the study aimed to provide a more comprehensive understanding of transportation services. This approach allowed for a deeper assessment of how convenient and easily accessible bus stops contribute to passenger convenience, time efficiency, and safety. It is useful for the Dilla Town Administrative Road Transport Office and other organizations seeking to improve transportation systems.

2 Materials and Methods

2.1 Description of the Study Area

Dilla town, located between $10^0 14'$ North latitude and $38^0 10'$ East longitude (Minota, 2014), serves as the administrative center of the Gedeo Zone in the South Ethiopia Region. It is situated approximately 359 km away from Addis Ababa city and is renowned for its local coffee industry (Girma & Wube, 2014). 11 bus stop locations in the town are spread along different routes, as shown in Figure 1. Dilla University, a public institution, is also based in Dilla town. As of 2023, the Human Resource Directorate Office reported a total of 5,376 academic and administrative employees at the university.

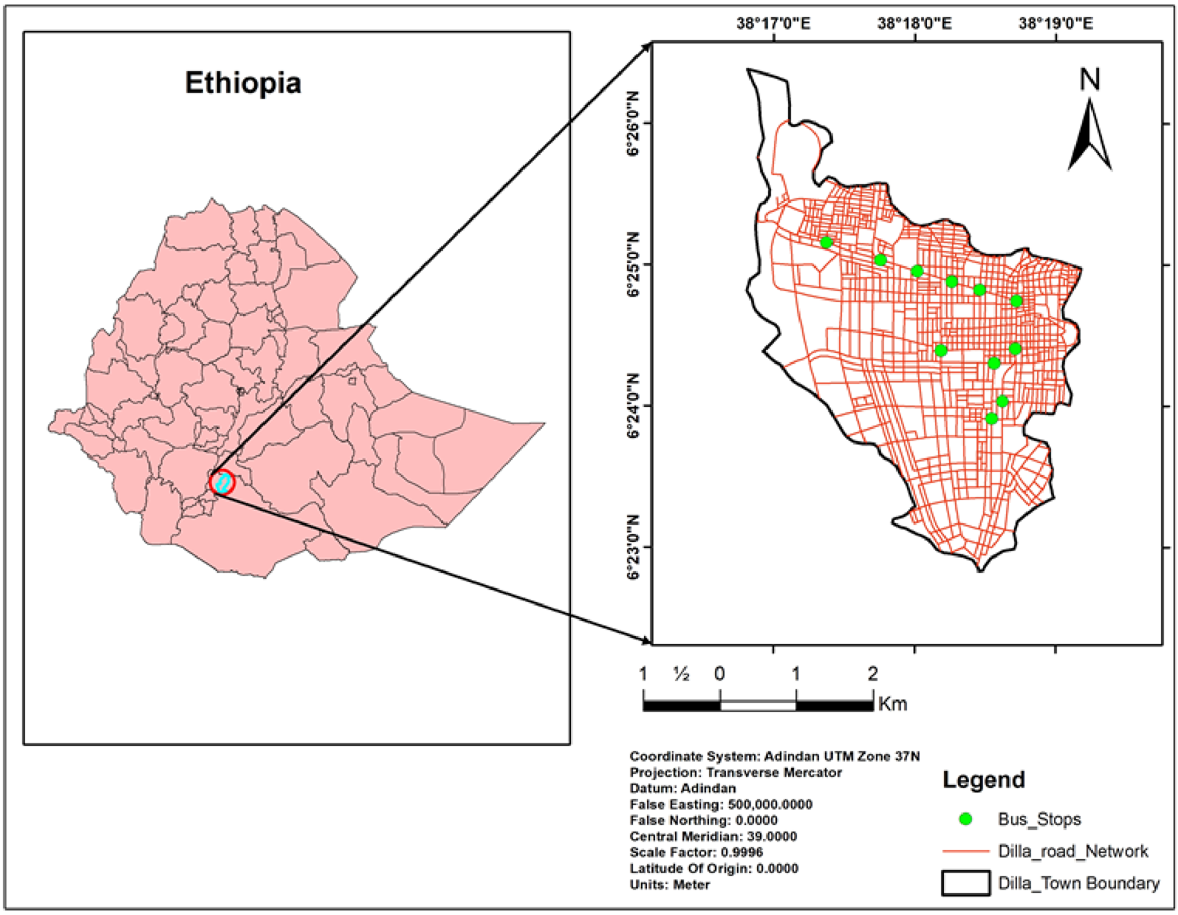

Figure 1. Study area map showing the distribution of bus stops

2.2 Data Source and Method of Data Collection

To assess the accessibility of bus stops in Dilla Town, the survey employed primary data collection techniques. The researcher utilized a Handheld GPS device to gather the coordinates (X and Y) of eleven bus stops located within the town boundaries along the bus route, aiming to assess the spatial accessibility of the stops. The names of each bus stop utilized in this research were taken from prominent landmarks in the respective area. Before digitizing the road networks, the aerial photographs were first georeferenced to align them with the known coordinate system. Additionally, orthorectification was applied toremove distortions caused by terrain relief. The preprocessed aerial photographs were used for the digitization of Dilla Town road networks using ArcGIS Pro. The road network topology was initially created, followed by a correction and validation process to assurance accuracy and consistency. Subsequently, the network dataset was generated by integrating the topologically refined road networks with the gathered GPS points, enabling the determination of the service area.Furthermore, we have developed structured questionnaires to evaluate users' satisfaction with the bus transportation service offered by the university. The details of data used in this study are shown in Table 1.

Table 1. Data and Data Source

Data	**Data source**	**Purpose**
GPS Point	Field survey	To locate the existing bus stop
Aerial Photograph	Dilla Town municipality	To digitize road networks (for network analysis)
Questionnaires	Researchers	To assess the user's satisfaction

2.3 Sample Size and Sampling Method

The target population for the study was Dilla University workers, faculty and administrative workers who rely on the university's bus service for transportation. The researchers selected 384 workers out of 5376. The objective was to gather feedback and opinions from experienced bus users working at the university. The participants were chosen using stratified random sampling to address the involvement of both academic and administrative workers in the survey and provided informed consent after receiving a pre-tested interviewer-administered questionnaire. All statistical analyses were performed using SPSS 22.0 software.

2.4 Determining Accessibility of Bus Stops

Bus stop access coverage is used to evaluate the Bus stop position from the area included in the polygon and the road network lying within the polygon. The Ideal stop access coverage can be determined by creating a simple circular buffer with a standard threshold around each bus stop using the equation (1), which overestimates the coverage access (Foda & Osman, 2010), ignoring the actual road network near the stops. On the other hand, the Actual Area Coverage (AAC) is a complete polygonal representation surrounding all road segments within a 0.4 km radius of the bus stops (Daudu *et al.*, 2022). The computation of AAC involves generating service areas using network analysis methods.

$$IAC = \pi r^2 \tag{1}$$

Where: IAC - Ideal Area Coverage and r - Buffer radius; 0.4km.

The Ideal Stop Accessibility Index (ISAI) is determined by calculating the road network density within a circular buffer. This is achieved by dividing the total length of the road network by the area of the circular buffer, as expressed in the equation (2). On the other hand, the Actual Stop Accessibility Index (ASAI) is calculated by dividing the total length of the road network by the area of the generated polygon (Foda & Osman, 2010). This relationship is mathematically represented by an Equation (3).

$$ISAI = \frac{\sum LI}{IAC} \tag{2}$$

$$ASAI = \frac{\sum LA}{AAC} \tag{3}$$

$$SCRI = \frac{ISAI}{ASAI} \tag{4}$$

Where: ASAI- Actual Stop Area Index, ISAI- Ideal Stop Area Index, SCRI- Stop Coverage Ratio Index, LI- Ideal Length of road segments within 0.4km buffer, LA- Actual Length of road segments within 0.4km, IAC- Ideal Area Coverage, AAC- Actual Area Coverage. The overall methodology of the study is presented in the flowchart (Figure 2).

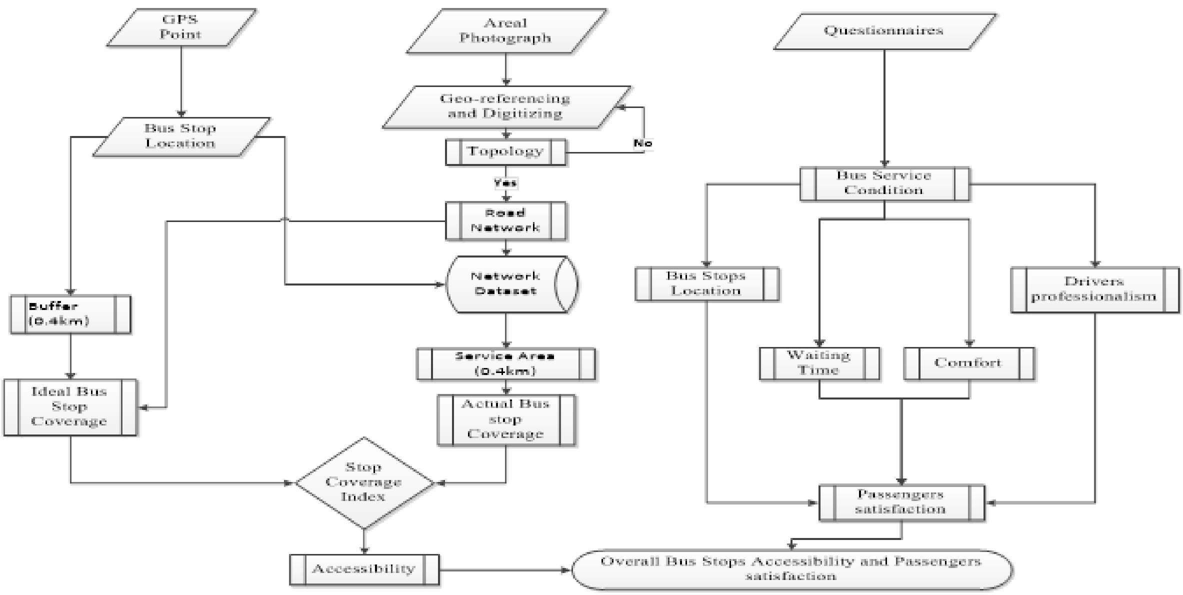

Figure 2. The general workflow of the study

3 Results

3.1 Ideal and Actual Bus Stop Access Index (ASAI and ISAI)

Figure 3a and Figure 3b show the actual service area and ideal service area. A 0.4km buffer was generated around each 11 Bus stop to calculate ASAI. Since the Radius of the buffer is similar, the ideal area coverage is 0.503 km^2. Within this area, the total length of each segment was computed. The total length of access roads across the bus stop is 106.721 km; reachable within the ideal area coverage. The Mazoria station has the highest length of accessible road, which is 12.685 km. On the other hand, the Hospital Bus stop has the lowest length of accessible roads, which is 8.581km compared to other stations. The result of ISAI indicated that Molla Golja station has the lowest index of 15.250 km/km^2 while Mazoria has the highest index (25.219km/km^2).

The Gedeo Zone Higher Court station has the highest actual area coverage (0.427 km^2),whereas the Sunshine bus stop has the lowest area coverage (0.183 km^2). The result of ASAI indicated that Molla Golja station has the lowest index of 15.25 km/km^2 while Mazoria has the highest index (42.401km/km^2). The details of the statistics are found in Table 2.

Table 2. ISAI, ASAI, and SCRI Values for Bus Stops

Station Name	$\sum LI$(km)	IAC(km^2)	ISAI(km/(km^2)	$\sum LI$(km)	AAC(km^2)	ASAI(km/ km^2)	SCRI
Get smart	8.619	0.503	17.135	5.308	0.267	19.843	0.864
Sunshine	10.196	0.503	20.269	5.306	0.183	29.073	0.697
TTC	9.136	0.503	18.164	5.338	0.282	18.928	0.960
Babbo	9.644	0.503	19.172	3.851	0.169	22.730	0.843
Biruk	11.675	0.503	23.211	7.236	0.239	30.229	0.768
Delight	10.042	0.503	19.963	6.120	0.269	22.741	0.878
Hospital	8.581	0.503	17.060	7.579	0.297	25.544	0.668
Gedeo Zone Higher Court	9.857	0.503	19.597	9.360	0.427	21.929	0.894
Lamberet	8.615	0.503	17.128	5.433	0.208	26.181	0.654
Mazoria	12.685	0.503	25.219	11.131	0.263	42.401	0.595
Molla Golja	7.671	0.503	15.250	3.820	0.193	19.776	0.771

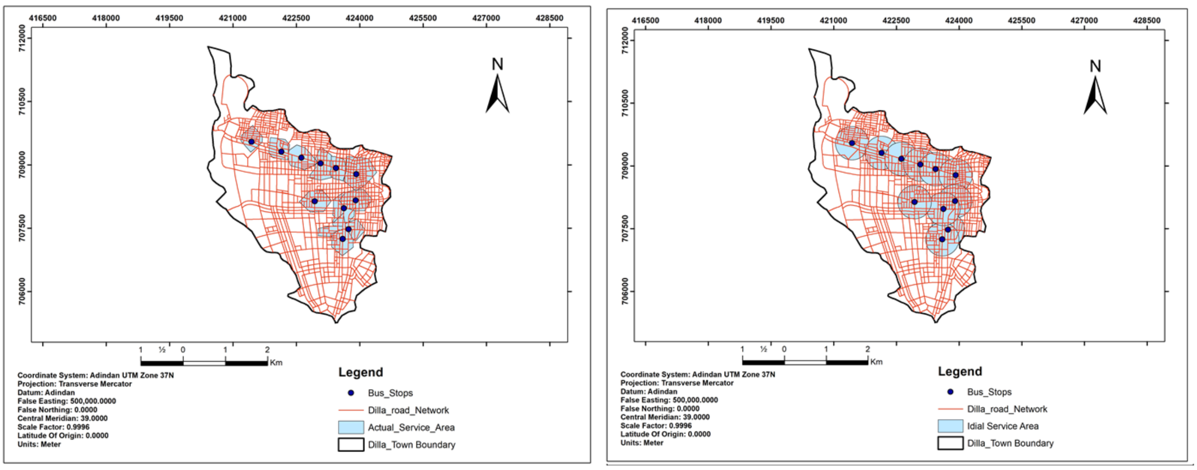

Figure 3. Actual bus stop access (left) and Ideal bus stop access (right)

3.2 Stop Coverage Ratio Index (SCRI)

The SCRI for all 11 stations was calculated by dividing the ISAI by ASAI using the equation [4]. As shown in the (Table 2), the values of SCRI are between 0 and 1. When analyzing the SCRI results for the these stations, it was found that the TTC Bus stop exhibited the highest SCRI value (0.96%). This result indicates that the stationprovides better accessibility to its surrounding area, making it more convenient for transport users to reach their destinations.

The other stations also demonstrated varying levels of access coverage. For example, the station named "Get Smart" had an SCRI value of 0.864%, indicating a relatively high level of accessibility. On the other hand, "Molla Golja" bus stop had the lowest SCRI value of 0.595% (Table 2), suggesting that it provides lower access coverage when compared to other bus stop locations.

3.3 Analysis for Overall Satisfaction Level

In this study, passengers' satisfaction level was measured by how much they were satisfied with the quality of transportation service experienced at Dilla University. The factors examined were the convenience of the location of bus stops, waiting time, denied entry onto buses due to full seats, and the driver's level of professionalism. The majority of respondents (40.95%) reported that the location of bus stops was very convenient, while a small percentage (1.90%) found it inconvenient, suggesting a need for improvements in this area. The largest group of respondents (45.71%) reported waiting for more than 15 minutes for buses, indicating dissatisfaction with the waiting times. On the other hand, 18.10% of the respondents reported waiting less than 5 minutes (Table 3), which suggests a positive experience in terms of waiting time.

The results indicate that 39.05% of the respondents reported frequent cases of being denied entry onto buses due to full seating. A slightly lower percentage (32.38%) reported experiencing this issue somewhat frequently. However, 20.95% of respondents stated that they rarely encountered this problem, indicating a relatively positive experience. The majority of respondents (43.81%) rated the driver's level of professionalism as good, while a similar percentage (42.86%) rated it as average. A smaller group of respondents (13.33%) perceived the driver's professionalism as poor, indicating room for improvement in this area (Table 3).

Table 3. Passenger's satisfaction for service provision of Dilla University, Dilla, Ethiopia, 2023 (n = 384)

Variables	Category	Frequency	Percent %
Convenience of bus stops	Very inconvenient	99	25.7
	Inconvenient	7	1.9
	Neutral	70	18.1
	Convenient	51	13.3
	Very convenient	157	40.9
Waiting time (minutes)	< 5	70	18.1
	5-10	11	2.86
	10-15	128	33.3
	>15	176	45.7
Denied entry onto buses due to full seats	Very frequently	150	39.0
	Somewhat frequently	124	32.3
	Rarely	81	20.9
	Almost never	29	7.62
Driver's level of professionalism	Poor	51	13.3
	Average	165	42.8
	Good	168	43.8

4 Discussion

In this study, the network characteristics of bus stop locations in Dilla Town were analyzed and evaluated the bus service conditions through questionnaires. In this study, the analysis employed a scale of 0 to 1.0 SCRI, where the bus stop's accessibility decreases as the value approaches 0 and increases as the value approaches 1.0 (Daudu *et al.*, 2022). Based on the result of SCRI, the bus stop with the highest value (0.960) is the one named 'Getsmart', indicating a high level of functionality for its surrounding area. On the other hand, the bus stop with the lowest coverage index is 'Molla Golja', with a coverage index of 0.595, less functional to its surrounding area when compared to other stations. The finding of this study is consistent with previous studies conducted in Nigeria, in which the highest SCRI value is 0.972 and the lowest is close to 0.163 (Daudu *et al*., 2022). The bus stops on the main road from Dilla University's main campus and the Odaya campus to Dilla Roundabout are better connected and more accessible to other parts of the network. On the other hand, the outlying areas on the road from Molla Roundabout to Chuchu and residential neighborhoods need additional accessible bus stops.

The convenience of the location of bus stops is a crucial factor for passengers (Chen *et al*., 2015; Nguyen, 2020). While 40.95% of the respondents consider the bus stop locations to be very convenient, 25.71% specifies the need for improvements in this area. This result is supported by studies aimed at assessing passengers' satisfaction and revealed that the locations of the bus stops are crucial factors for stakeholders to prioritize the placement of bus stops to satisfy the needs of customers (Litman, 2008; Liu *et al*., 2017).

The maximum waiting time for the bus transportation service should be in the range of 10-20 minutes (Armstrong-Wright, 1993). However, the majority of the respondents (45.71%) reported waiting for the bus more than 15 minutes. However, there is a positive aspect that 18.10% of respondents reported waiting times of less than 5 minutes, recommending that some individuals have had a satisfactory experience in this regard. The dissatisfaction is consistent with previous research conducted in Oslo, Norway, which specifies that reduced reliability and increased travel time are associated with decreased satisfaction with travel experiences (Lunke, 2020). Another study conducted in Addis Ababa city reported that 32.86% of the respondents wait for more than 20 minutes to get service, which is above the standard (Weldeamanuel, 2019)

Another significant issue identified in the results is denyingentrance into buses due to absence of seats. Several respondents (39.05%) stated experiencing this problem regularly, is a challenge that needs to be addressed. While it is positive that 20.95% encountered this issue rarely, efforts must be made to find solutions that minimize instances of overcrowding and ensure that passengers are not left waiting for the next bus due to capacity constraints.

Regarding the driver's level of professionalism, the majority of respondents (43.81%) rated it as good, while a comparable percentage (42.86%) rated it as average. Although these ratings indicate generally satisfactory performance, it is concerning that a notable portion of respondents (13.33%) perceived the driver's professionalism as poor. This signifies the need for continuous training and monitoring to ensure consistent service quality and professionalism among bus drivers (Shaaban & Kim, 2016).

5 Conclusion

This study analyzed the network characteristics of bus stop locations in Dilla Town using a GIS and evaluated the bus service conditions through questionnaires. The study employed the Service Coverage Ratio Index (SCRI) to assess the functionality and accessibility of bus stops. The study found that bus stops located on the main road between Dilla University's main campus and the Odaya campus and those near Dilla Roundabout, had more accessible bus stops than other parts of the network. In contrast, the outlying areas along the road from Molla Roundabout to Chuchu and residential neighborhoods had no accessible bus stop, indicating a lack of access to bus services. This highlights the need to improve bus service in these areas to enhance connectivity and accessibility. These findings emphasize the importance of addressing the shortcomings in the bus service to meet the needs of the community.

This study contributes significant information to the scientific community by analyzing the spatial distribution of bus stops in Dilla Town and evaluating the conditions of bus services. It not only provides information regarding the accessibility of bus stops throughout the town but also offers valuable information about the distribution of bus services in different areas. These findings can serve as a basis for future research and can guide transportation authorities in similar contexts to optimize bus stop locations and enhance overall bus service quality.

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Conflicts of interests

We disclose no conflicts of interests

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Land use land cover change and expansion of Eucalyptus plantations in Senan District, northwest Ethiopia: analysis of potential factors

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Abstract

In Ethiopia's highlands, farmers are quickly turning their farmland into eucalyptus plantations, which could have an impact on the local economy and environment. In Northwest Ethiopia, more especially in the Senan district, the growth of eucalyptus tree plantations at the expense of other land use practices is being evaluated, along with the reasons that contribute to this phenomenon. 166 houses that planted eucalyptus and 166 households that did not were the subjects of the data collection, which was then subjected to binary logit analysis. Utilizing Landsat satellite imagery from four different time periods (1990, 2000, 2010, and 2021), the research area's land use and land cover changes were examined. Using a supervised classification approach, the land use and land cover classes were split out. The results showed that agriculture decreased from 58.4% in 2010 to 38.1% in 2021, while vegetation cover—which is primarily composed of eucalyptus—increased from 16.8% to 26.5% in the same time frame. The binary logit analysis's findings show that while family size, educational attainment, livestock ownership, and the fertility of farmers' land had a significant negative impact on eucalyptus plantation, the age of the household head, the size of the farmers' land, and savings had a positive and significant impact on the adoption of eucalyptus plantation. In order to evaluate how eucalyptus plantations affect farmers' livelihoods and guarantee that their well-being is enhanced as a result, comparative research is advised.

Keywords/Phrases: Driving factors, Ethiopia, Eucalyptus, GIS, Land-use change

1 Introduction

The most common tree species planted worldwide is eucalyptus (Abebe *et al*., 2019). It has rapidly spread over the world within the past century. It was brought to Africa, more especially Ethiopia, in the 1890s (Jaleta *et al*., 2016).

Zenebe (2016) noted that in terms of livelihoods, eucalyptus plays an important role in addressing food security. Besides, according to Elli *et al*. (2019), the availability of fuelwood is one of the most important contributions of eucalyptus to food security. Cooking, for example, is the most common method of ensuring food utilization through high nutritional absorption from food, and 2.4 billion people use fuelwood to cook.

There is still some criticism of eucalypt plantations despite their many advantages, especially in East Africa where the majority of people rely on wood for fuel and construction. Divergent opinions exist on the economic, social, and environmental sustainability of eucalyptus trees among their users, growers, environmentalists, researchers, and legislators.

The majority of concerns raised are related to the environmental impact, particularly concerning soils, water, and biodiversity (FAO, 2011). On the contrary, according to Sembiring, *et al* (2020) and Silenat and Fikadu (2018), Eucalyptus is a plant that has many positive effects on the environment, such as lowering the risk of forest fires, floods, and erosion; improving water efficiency; restoring degraded or unproductive land; and increasing biodiversity over time. On the other hand, Zenebe (2006) stated that Eucalyptus hurts yield and inhibits undergrowth. However, almost all the firewood, building materials for houses, farm implements, and other materials in the village are made from Eucalyptus. As a result, the benefits outweigh the negative impacts, which can be mitigated by planting Eucalyptus in areas that are unsuitable for agriculture and spacing them widely apart, even in farmlands and borders.

Even though eucalyptus plantations are generally criticized, farmers in Ethiopia, particularly in the northwest highlands, including the Senan district have converted their cropland into eucalyptus plantations (Amare *et al*, 2021). Previous studies have identified various factors associated with the expansion of eucalyptus plantations in Ethiopia. For instance, the age of the household head (Gebreegziabher *et al*., 2010; Tegegne *et al*., 2018), the education level (Kebede, 2017; Asabeneh & Yoseph, 2022), sex of the household head (Zenebe *et al*., 2020), family size (Setiye & Mulatu, 2016), wood demand (Tola, 2010), land degradation (Berihun & Habtemariam, 2017), the need for immediate cash (Tola, 2010), adaptability to wider agro-ecological zones, affordable cost of production (Gashaw *et al*, 2023). and low labor requirements for management (Berihun & Habtemariam, 2017) have all been identified as significant factors influencing land use patterns and the expansion of eucalyptus plantations in Ethiopia. These factors play a significant role in shaping land use patterns and the expansion of eucalyptus plantations in Ethiopia. However, it is important to acknowledge that these factors may vary in different contexts.

While previous studies have provided some insights into the conversion of croplands to eucalyptus plantations in Ethiopia, including the Senan district, there is a lack of adequate research, specifically focusing on the land use and land cover change in this district and the reasons behind the conversion. Amare *et al*. (2022) highlighted that smallholder farmers in the northwestern highlands, including the Senan district, have recently started converting their croplands to eucalyptus plantations. However, their study was conducted across three districts and did not separately analyze the driving factors specific to the Senan district. Therefore, this study assesses the land use land cover change and the factors that motivate farmers to convert their croplands into Eucalyptus plantations in the Senan district.

2 Materials and Methods

2.1 Description of the Study Area

Senan is situated in Ethiopia's East Gojjam Zone, which is between latitudes 10° 25' 13" N and 10° 40' 30" N and longitudes 37° 40' E and 37° 50' 20" E (Lakachew, 2022). There are two urban and seventeen rural kebeles in the district. The district sits between 2300 and 4154 meters above sea level. Notably, this district is home to Mount Choqe, also referred to as the "water tower of Ethiopia." At 4154 meters above sea level, it is the highest point in both the district and the East Gojjam Zone (Senan District Communication Affairs Office, 2021).

Approximately 25% of the land in the district consists of plateau and plain surfaces, while mountains and hills make up around 60%, and valleys account for approximately 15% of the landform. Eucalyptus globules are the dominant vegetation in the study area (Senan District Communication Affairs Office, 2021).

As per 2007 national census, this district is home to 98,939 people overall (CSA, 2007).

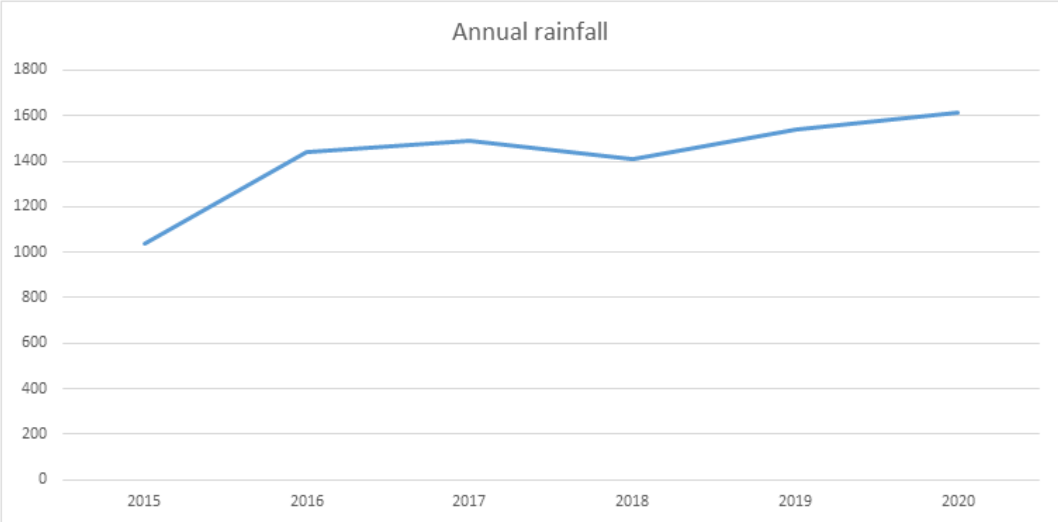

Figure 1. Annual Rainfall of Senan District (2015-2020)(CSA, 2022)

The daily average temperature is 15 degrees Celsius and the annual rainfall in the district is between 900-1500 mm (Central Statistics Agency, 2022).

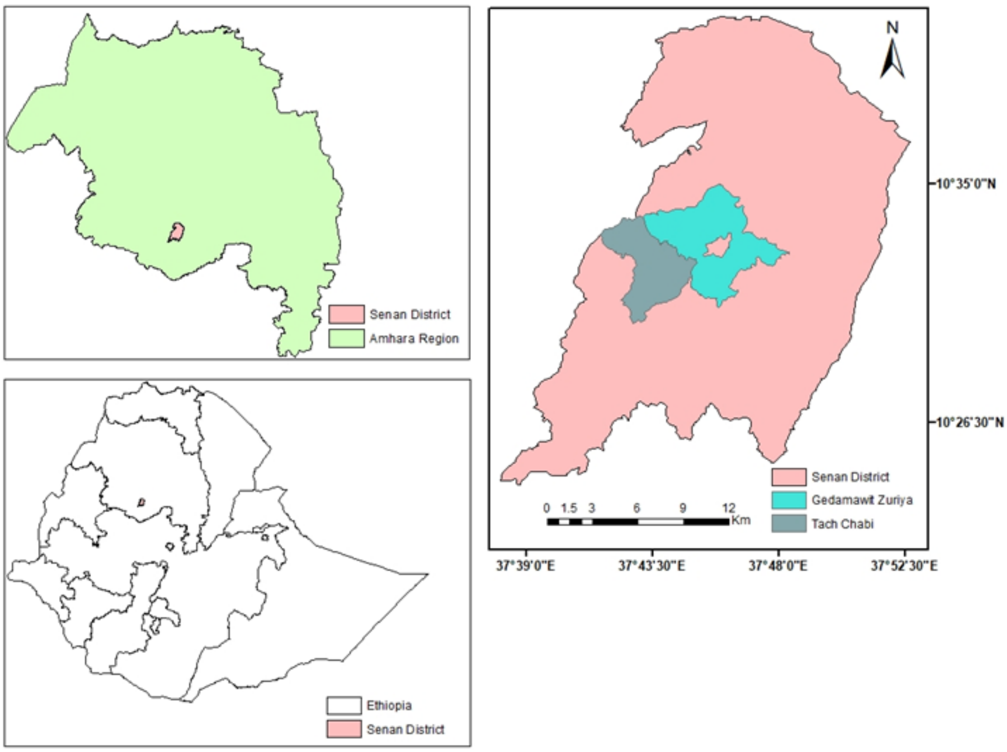

Figure 2. The location map of the study area

2.2 Data Sources and Processes

Both primary and secondary data sources were employed in this investigation. Questionnaires, in-person observations, key informant interviews, focused group discussions, and GPS instrument surveys were used to gather the primary data, while satellite photos and documents and reports from different organizations were utilized to gather the secondary data.

Questionnaire

The researchers collected quantitative data using a questionnaire from 166 households that had planted eucalyptus and 166 households that had not planted eucalyptus. Before undergoing a pilot test, the questionnaire was translated into Amharic, the local language.

Personal Observations

We conducted field observations by walking through the district with agricultural office experts in the area. This method assisted us in comprehending the expansion of eucalyptus plantations. The observation was also carried out at the district's local marketplace, where we asked questions and took notes on what we had seen, further enhancing our understanding of the situation.

Key Informant interviews and focus group discussions

In order to gain insight into the factors influencing eucalyptus plantations based on their perspectives and experiences, four focus groups and thirteen interviews with carefully chosen senior farmers and agricultural bureau officers were conducted. One criterion for determining when to cease gathering qualitative data was saturation.

Satellite Image

The United States Geological Survey (USGS: https://earthexplorer.usgs.gov) provided the study area's Landsat satellite imagery for four different time periods (1990, 2000, 2010, and 2021). The 2021 image was a Landsat 8 Operational Land Image and Thermal Infrared Sensor (OLI/TIRS), while the 1990, 2000, and 2010 images were Landsat 4-5 Thematic Mapper. The images were extracted in Tiff data format during January. This is the time when there is clear sky season in the study area, and important to detect vegetation. Moreover, this time is important to reduce atmospheric and radiometric problems. The detailed feature of the three Landsat satellite images is indicated in table 1.

Ground Control Points

Data collected by satellite sensors should be validated and compared to reality using reliable ground truth data. Therefore, real-world data were gathered using a hand-held GPS instrument for model validation and accuracy evaluation. To generate a land-use land-cover map, training data was collected from the field in order to have the appropriate spectral value for each class. The land use/land cover result was also verified using a Google Earth Pro image.

Table 1. Sources of secondary data

No.	Data Type	Sensor	Date of acquisition	Path/Row	Resolution	Source
1	Landsat image	TM	07/01/1990	169/053	30m by 30m	USGS
2	Landsat image	TM	19/01/2000	169/053	30m by 30m	USGS
3	Landsat image	TM	14/01/2010	169/053	30m by 30m	USGS
4	Landsat image	ETM+	28/01/2021	169/053	30m by 30m	USGS

2.3 Sample Size Determination and Sampling Technique

The choice of the Senan district as the study area was driven by the presence of extensive eucalyptus plantations within the region. Because the research area's population is small, the Cochran modified formula—which is intended for a small population—was applied.

$$n = \frac{n_0}{1+(n_0-1)/N}$$

Here, n_0 is Cochran's sample size recommendation, N is the population size, and n is the new, adjusted sample size. Hence, the sample size will be:

$$n = \frac{385}{1+(385-1)/2392} = 331.89 = 332$$

To ensure representative coverage, a multistage sampling technique was employed. First, the seventeen rural kebeles of the district were categorized into two distinct agro-climatic groups: nine woina dega (subtropical) and eight dega (temperate) dominated kebeles. Then, the kebeles of Gedamawit and Tach Chabi were selected from each group. Households within the selected kebeles were stratified based on ownership of eucalyptus plantations. A proportionate stratified sampling strategy was used to choose 166 planters and 166 non-planters proportionately from each kebele's planters and non-planters. We were able to gather information from homes that plant and do not plant eucalyptus trees with the help of agricultural specialists from the two kebeles.

2.4 Data Analysis

Preparing digital images for human interpretation is known as digital image processing (Bakker *et al*., 2001). Pre-processing procedures have been carried out after downloading and extracting the satellite image. These include atmospheric rectification, layer stacking/merging, gap-filling, image mosaicking, clipping, and other image enhancement pre-processing procedures that were used to enhance the quality and interpretability of the image so that the images are appropriate and prepared for further analysis.

The development of thematic maps involves classifying the satellite image. The subjects could range from general categories to in-depth analyses of specific groups (Schowengerdt, 2007).

The study area's surface features were identified by composing images in various ways. For Landsat 4-5 TM, the classification was done using a true color composite known as RGB 321 (where band 3 reflects red, band 2 reflects green, and band 1 reflects blue), and RGB 432 (for Landsat 8 ETM+).

The land use classifications were conducted by using the maximum likelihood supervised classification. For all spectral classes, 155 training regions were created, making up each information class that the classifier would need to recognize. Based on the researcher's observations (ground truthing) and previous studies conducted in the field (Agenagnew *et al*., 2019; Aramde *et al*., 2014), the following classification schemes were created.

Table 2. LULC classes used for classification

No.	Classes	Description
1	Settlement	Scattered settlements with houses separated from one another.
2	Cropland	This category includes area allotted for annual rain-fed and irrigated cultivation. Lands mostly used for cereal production in subsistence farming. Potato, barley, and beans are the main crops produced in the district. They farm using oxen and horse ploughs in the most traditional way.
3	Grassland	Area predominantly covered by small grasses with a small proportion of shrub and trees.
4	Vegetation	This unit includes a collection of plant species. Eucalyptus is the prominent species in the area.
5	Shrub land	Dominated land with isolated small trees always with a lower range of grass.

One of the main data analysis techniques to determine the shift from farmland to vegetation was to calculate the area in hectares and the percentage of the resulting LULC categories for each research year, then compare the results. ERDAS IMAGIN and ArcGIS 10.8 software were used to make this analysis. The following diagram shows the overall workflow of the land use land cover change.

2.5 The Binary Logit Model

To assess the drivers of eucalyptus plantations in the study area, the dependent variable was categorized into two qualitative parts: whether or not to have eucalyptus plantations. Therefore, a binary logit econometrics model was employed to examine the factors that influence farmers' decisions to plant eucalyptus trees. In binary logistic regression analysis, the dependent variable must be categorical (it can be coded as 0 and 1) (Cokluk, 2010).

The functional form of logit model is specified as follows, according to Gujarati (2003);

$$P_i = E\left(Y = \frac{1}{X_i}\right) = \frac{1}{1+e^{-(\beta_1+\beta_2 X_i)}} \tag{1}$$

For ease of exposition, we write as

$$P_i = \frac{1}{1+e^{-z_i}} = \frac{e^z}{1+e^z} \tag{2}$$

Where, $Z_i = \beta_1 + \beta_2 X_i$.

If P_i, the probability of owning Eucalyptus plantation, is given by (2), then (1 - P_i), the probability of not owning Eucalyptus plantation, is

$$1 - P_i = \frac{1}{1+e^{z_i}} \tag{3}$$

Therefore, we can write

$$\frac{P_i}{1-P_i} = \frac{1+e^{z_i}}{1+e^{z_i}} \tag{4}$$

Now, $\frac{P_i}{1-P_i}$ is simply the odds ratio in favor of owning eucalyptus plantation—the ratio of the probability that a household will own the plantation to the probability that it will not own it. Finally, taking the natural log of equation we obtain:

$$L_i = ln\left(\frac{P_i}{1-P_i}\right) = Z_i = \beta_0 + \beta_1 X_i + \beta_2 X_2 + \ldots + \beta_n X_n \tag{5}$$

$$Z_i = \beta_0 + \beta_1 X_i + \beta_2 X_2 + \ldots + \beta_n X_n \tag{6}$$

β_0 is an intercept; β_1, β_2 ... β_n are slopes of the equation in the model; L_i = is log of the odds ratio, which is not only linear in X_i but also linear in the parameters; X_i = is vector of relevant household characteristics

If the disturbance term (U_i) is introduced, the logit model that has been used to analyze drivers of eucalyptus plantation in this study becomes;

$$Z_i = \beta_0 + \beta_1 X_i + \beta_2 X_2 + \ldots + \beta_n X_n + U_i \tag{7}$$

Table 3. List of independent variables in drivers of Eucalyptus plantations

Independent variables	Description	Expected Effect
Age of household head (years)	Continuous	+
Sex of Household head	Female = 0, Male = 1	-
Marital status of household head	Married= 1, Otherwise = 0	+
Education level of household head (years)	Continuous	+
Family size (number)	Continuous	-
Farm size (Ha)	Continuous	+
Farm fertility (%)	Continuous	-
Livestock ownership (TLU)	Continuous	-
Membership of cooperatives	Not a member = 0, Member = 1	+
Savings	No savings = 0, Have savings= 1	+
Access to savings and credit service	No access = 0, Have access = 1	+

3 Results and Discussions

3.1 Land Use and Land Cover Analysis

The analysis comprises the land use land cover analysis and the factors behind the expansion of eucalyptus plantations. As the classification scheme indicated, cropland, grassland, vegetation settlement, and shrub land area are the major LULC classes of the study periods. The classified images were acquired when crop harvesting had already been completed, farmlands appeared bare, and grasslands looked relatively bright in color.

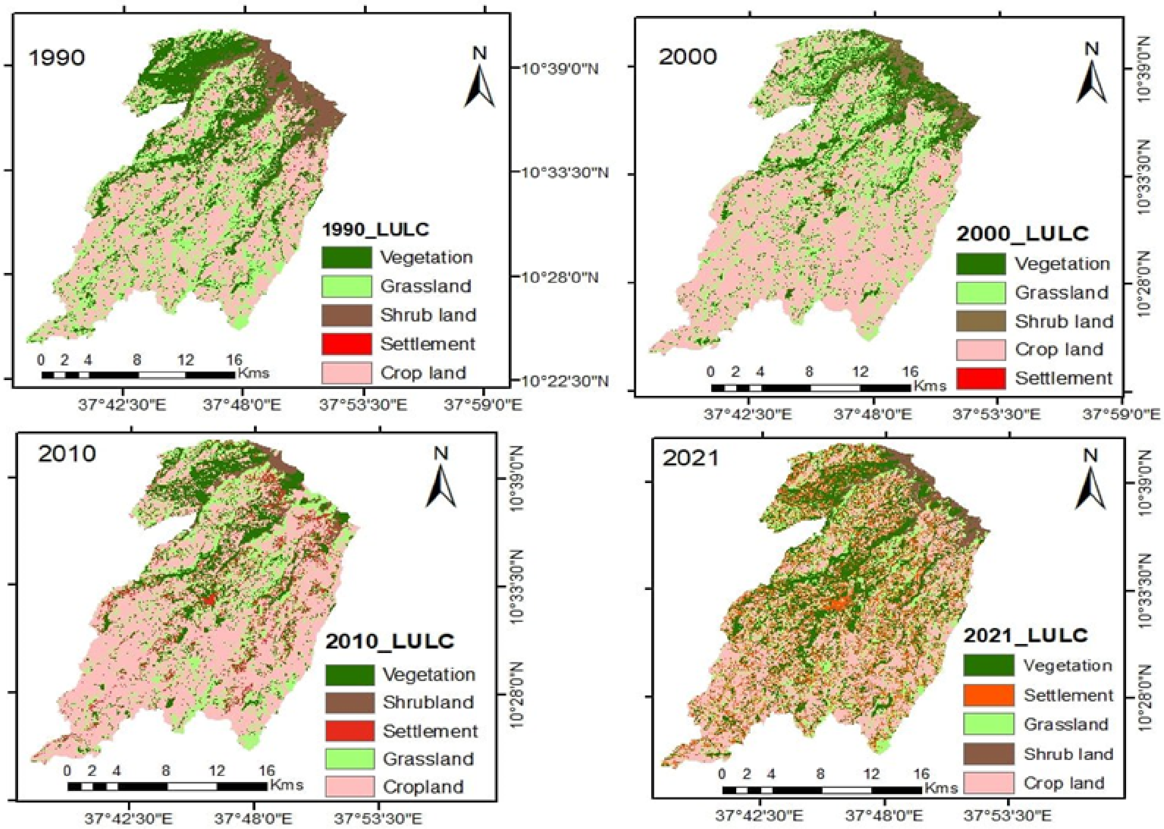

Figure 3. Land use land cover map of Senan district (1990, 2000, 2010, and 2021)

Figure 3 shows the land use land cover classes of the study area in 1990, 2000, 2010, and 2021.

Table 4. LULC classes and their spatial extent with the observed changes over time

LULC classes	1990		2000		2010		2021	
	Area (ha)	Percent	Area (ha)	Percent	Area (ha)	Percent	Area (ha)	Percent
Crop land	19750	45.2	25049	57.4	25500	58.4	16647	38.1
Vegetation	10408.5	23.8	7456	17.1	7294	16.8	11558	26.5
Grassland	10151.6	23.3	9406	21.6	6911	15.8	6297	14.4
Settlement	110.9	0.3	128	0.3	2334	5.4	6996	16.1
Shrub land	3215	7.4	1597	3.6	1597	3.6	2138	4.9
Total	43636	100.0	43636	100.0	43636	100.0	43636	100.0

For 1990, 2000, 2010, and 2021, five major LULC types (cropland, vegetation, settlement, grassland, and shrubland) were classified. The result reveals that there is a recent land-use change, especially in cropland and vegetation cover.

The LULC classification result shows that cropland increased from 45.2 % in 1990 to 57.4 % in 2000 and 58.4 % in 2010, but it decreased to 38.1 % in 2021. On the contrary, the vegetation cover decreased from 23.8 % in 1990 to 17. 1% in 2000 and 16.8% in 2010, but it increased from 16.8% in 2010 to 26.5% in 2021. According to our observation and the focus group discussion result, the highest proportion of the vegetation cover in the Senan district is the eucalyptus plantation, which has been expanded recently.

The focus group discussion result also confirmed that a significant number of farmers has been converted their cropland into eucalyptus plantations during the last 10 years.

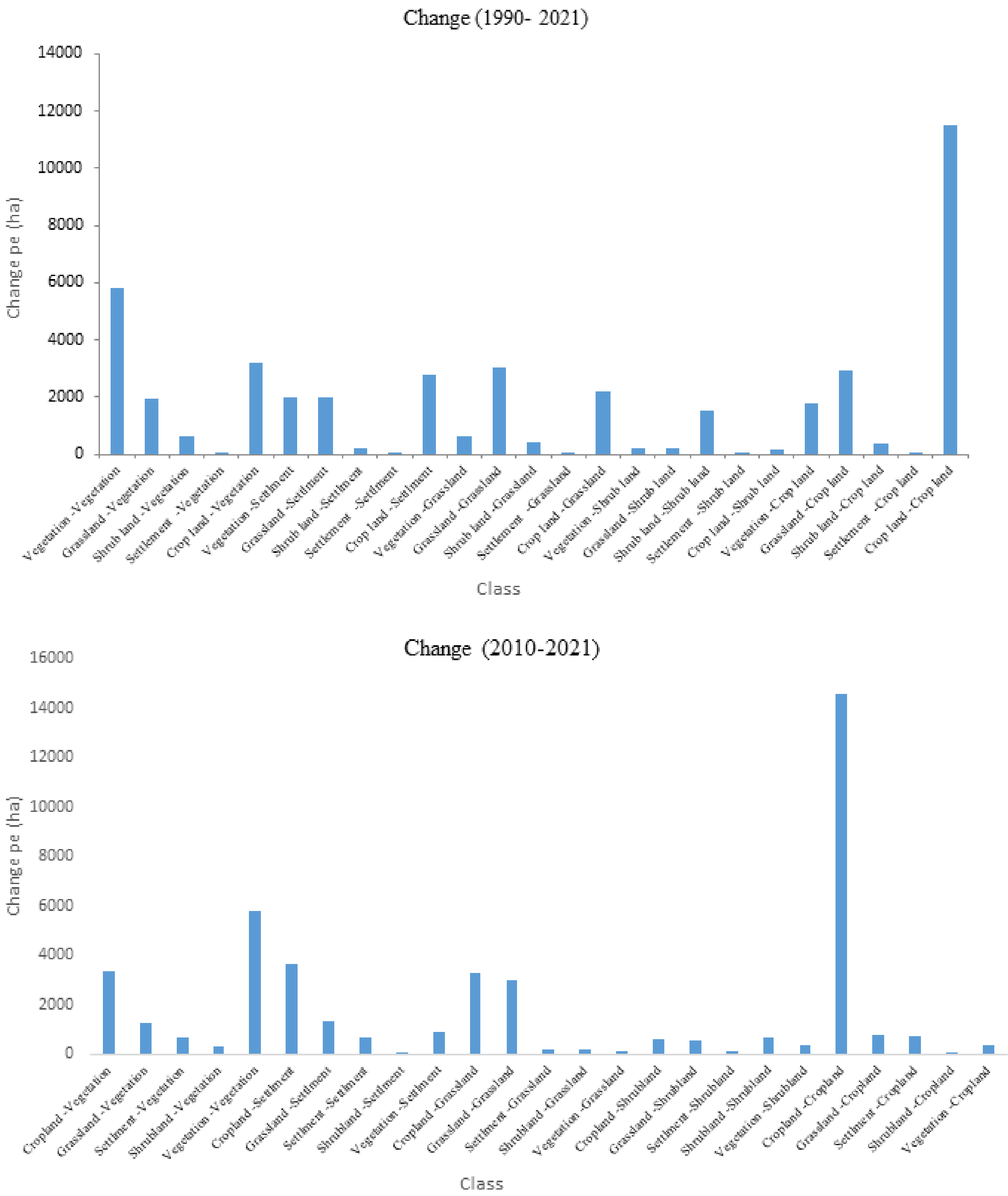

Figure 4. shows the calculated change detection matrix, in percent, covers the change of the whole study period from 1990 to 2021 and from 2010 to 2021

The change matrix (1990-2021) shows that the highest proportion of land was converted from cropland to vegetation. This change is mainly because farmers have changed their farmland into eucalyptus plantations. From 2010 to 2021, the conversion of cropland to vegetation experienced the most significant rate of change, with a total of 3,353 hectares, equivalent to 13% of the initial cropland, transformed into vegetation. Based on personal observation, almost all forests of the area are Eucalyptus. The key informant interview also approved that farmers are aware of the economic advantage of eucalyptus and tried to cover their cropland with this plant.

3.2 Factors Affecting Eucalyptus Tree Plantation

Binary logit model result

Table 5. Llogistic regression results

Explanatory variables	B	S.E.	Wald	Sig.	Exp(B)
Sex of household head	-.185	1.091	.029	.865	.831
Age of household head	.169	.031	29.382	.000***	1.184
Marital status	5.701	6.104	.872	.350	299.189
Educational Status	-1.730	.465	13.833	.000***	.177
Livestock ownership (TLU)	-.385	.140	7.601	.006***	.681
Farm size in hectare	3.039	.548	30.766	.000***	20.883
Family size (adult equivalent)	-.957	.203	22.203	.000***	.384
Farm fertility	-2.204	.497	19.665	.000***	.110
Membership of cooperatives	.363	.604	.362	.548	1.438
Having savings	1.453	.432	11.300	.001***	.234
Access to saving and credit service	.850	.449	3.583	.058	2.340
Constant	-8.738	6.409	1.859	.173	.000

Land Use and Land Cover (LULC) are influenced by a variety of factors, encompassing both natural processes and human activities (Terefe *et al.* 2019). We categorized the driving factors and implications of land use land cover change and expansion of eucalyptus plantations in the Senan district into four broad categories based on the result of the binary logistic regression model, the focus group discussion, and key informant interview result, as described below.

3.3 Socio-demographic Characteristics

Studies by Gebreegziabher *et al.* (2010), Tegegne *et al.* (2018), and Zenebe *et al.* (2020) have all found that age, gender, and education are factors that increase the likelihood and number of trees planted by farmers. However, according to Arragaw and Woldeamlak's (2018) findings, tree-planting activity is negatively influenced by the education level of the household. On the other hand, Tefera and Kassa (2016) noted that household size has a positive and significant influence on the adoption of eucalyptus plantations by farmers. In relation to this, the binary logit results of this study show that the age of the household head positively and significantly affected the eucalyptus plantation, while family size of smallholder and educational status had a significant negative effect on the eucalyptus plantation. This result means that as the age of the household head increases, the likelihood of adopting a eucalyptus plantation also increases by a factor of 1.18. The key informant interview also reveals that farmers' motivation and decision to plant eucalyptus trees increases as their age increases. This is because tree planting does not require much labor force. Therefore, elders prefer to plant eucalyptus trees to practice crop production. Furthermore, since eucalyptus plantations do not demand more labor than crop production, female-headed households in the study area prefer planting eucalyptus to crop production.

According to the binary logistic regression model, the exp (b) value for family size is 0.38, indicating that the odds of adopting the eucalyptus plantation decrease by a factor of 0.38 for every one-unit increase in family size. The focus group discussions also revealed that farmers with large families are less likely to plant eucalyptus trees, which negatively affects their decision-making. In contrast, households with fewer family members tend to use their farmlands to grow eucalyptus because it is less labor-intensive than crop production. However, one of the key informant interviewees noted that even households with large families experience labor constraints due to increasing school enrolment rates in the Senan district, which has led to a shift towards eucalyptus plantations that require less labor. This finding aligns with previous studies, such as Asabneh *et al*. (2023), which found that family size has a detrimental impact on adopting eucalyptus tree plantations.

Based on the results of the focus group discussions and key informant interviews, it was found that female-headed households with smaller family sizes tended to choose eucalyptus planting over other crops due to its low labor requirements. A widow female-headed household also stated 'My husband was a hard-working farmer who was capable of working day and night. But after I lost him, I turned the cropland into the eucalyptus plantation because no one can help me on the farm.

3.4 Economic Drivers

The decision-making process of farmers regarding eucalyptus tree planting is influenced by resource ownership, including access to land, labor, livestock, agricultural inputs, and market opportunities. Asabeneh and Yoseph (2022) stated that planting eucalyptus trees offers a considerably better return on investment than growing crops and raising animals.

Other previous studies, (Kebede, 2017; Setiye & Mulatu, 2016; Zenebe *et al*., 2020; Dereje *et al*., 2011), However, it was underlined that a farmers' decision to grow eucalyptus trees is largely influenced by the area of their farmland. The number of cattle that households possessed significantly decreased their likelihood of working in eucalyptus plantations, according to Gebreegziabher *et al*. (2010). Eucalyptus plantations were positively and significantly impacted by total land size and savings, whereas livestock ownership had a negative impact, according to the results of the binary logistic regression model in the research region.

According to the odds ratio between livestock ownership and farm size, smallholder farmers' decision to adopt a eucalyptus plantation decreases by a factor of 0.68 as livestock ownership increases by one, while the likelihood of eucalyptus plantation increases by a factor of 20.8 as household farm size increases by one, all other things being equal.

Interviewees also reported that farmers with a large number of cattle do not have eucalyptus plantations because eucalyptus trees are not used for animal grazing, unlike crop residues. As Setiye and Mulatu (2016) described the farmers who have small landholdings prefer to produce crops and other purposes like growing fruits and vegetables than growing eucalyptus trees. The family who has a large landholding uses their land for diversifying the source of income like growing crops, fruit, tree planting, vegetables, and animal rearing.

Farmers may choose to plant eucalyptus on marginal land that has limited potential for crop production. The binary logistic regression model and focus group discussions indicate that farmers are less likely to adopt eucalyptus plantations on highly fertile land. Moreover, one of the interviewees said that

"*I do have four temad (one hectar) land. The two temad are very fertile but the remaining two temad are not suitable for crop production. That's why I planted eucalyptus trees on the plot of land which is not fertile*."

The findings of the focus group discussion revealed that farmers plant eucalyptus to make a lot of money at a time so that they will be able to either construct a house, pay school fees to their children, or move to urban areas.

Moreover, Belay *et al*. (2021) also revealed that the growing need for fuelwood, construction, and cash for various purposes are the primary economic drivers behind the planting of eucalyptus plantations.

3.5 Environmental Drivers

In Ethiopia's Amhara Region, Senan is one of the areas that is primarily Dega and unsuitable for growing valuable commodities like teff. Therefore, the farmers preferred to plant eucalyptus than to produce low-value products like potatoes.

Moreover, according to Yusuf (2016), Tola (2010), and Dereje *et al*. (2011) land degradation and depletion of natural vegetation are also the driving factors of eucalyptus plantations. The key informant interviewees described that land degradation is the most common problem in the district, which is usually related to soil acidity. Concerning this, Hailu and Getachew (2011) stated that Ethiopia's highland areas are experiencing an increase in soil acidity. These issues are the result of continuous cropping and the use of acidifying fertilizers. The logit result reveals that farm fertility level and eucalyptus plantation have a negative and significant relationship. According to the interview and focus group discussion, reduced crop yield because of declining soil fertility made farmers convert their cropland into eucalyptus plantations.

3.6 Properties of the Eucalyptus Species

According to Tefera and Kassa (2017), coppicing ability, straight pole growth, quick growth and thus shorter maturity period, multiple uses of the wood, low labor required for management, and drought, disease, and pest resistance are important characteristics of the species. These characteristics are also one of the farmers' driving factors in planting eucalyptus in the Senan district. One of the interviewees stated that

"*Eucalyptus is a good species because it saves my time and labor; it teaches me to save a lot of money; it is free from natural hazards; unlike crops, it is not consumed by animals which make it easy to have the plantation*."

The focus group discussion participants also stated that shorter growing seasons and higher biomass, increasing price of farm input such as fertilizer and improved seed, the negative effects of nearby eucalyptus plantation shades on a crop, and other farmers' successful experiences are some of the factors related to the properties of the species.

In relation to this, an interviewee emphasized that "*the shade of my neighbors' eucalyptus plantation on my cropland affects its productivity. Hence, I was obligated to convert my cropland into a eucalyptus plantation even though I did not want to do that*."

Silenat and Fikadu (2018) also stated that eucalyptus plants are typically taller than other plants of equal age due to their rapid growth, and their shade may affect nearby crops by reducing the sunlight required for growth. Moreover, Gashaw *et al* (2023) described that the detrimental effects that eucalyptus plantations have on nearby cropland made farmers convert their cropland into eucalyptus tree plantations.

4 Conclusion

The results indicated a decline in cropland area from 58.4% in 2010 to 38.1% in 2021, while there was an increase in vegetation cover, primarily eucalyptus, from 16.8% to 26.5% over the same time frame. This is mainly caused by socio-demographic characteristics of the household, economic factors, environmental factors, and the characteristics of the eucalyptus species, such as the availability of large plots of land for ownership, infertile agricultural land, a small labor force, a shorter growing period, the species' shading impacts, and easily accessible market opportunities are responsible for the rapid expansion of eucalyptus plantation in the study area. As a result, agricultural experts should provide support to farmers through various land-use planning strategies that take into account their socio-demographic, economic, and environmental elements and the country's land-use policy. Moreover, comparative studies should be conducted to make sure the livelihood of farmers is improved due to eucalyptus plantations.

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Conflict of Interest

No conflicts of interest are disclosed by the authors.

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Economic efficiency in maize (*Zea mays* L.) production of small holder farmers in Amhara Regional State, Ethiopia

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Abstract

Ethiopian agriculture's low production can be attributed to a number of issues, including legislative limitations, drought, conflict, a lack of basic infrastructure, and demographic and economic factors. Many researchers are just concentrating on technical efficiency in an attempt to solve this issue. Allocative and technical efficiency are therefore crucial for enhancing the productivity gains from current technologies. To assess this cross-sectional research was carried out. Multistage sampling method was used and 366 households randomly selected. While determinants influencing efficiency level were identified using the Tobit model, technical efficiency (TE), allocative efficiency (AE), and economic efficiency (EE) levels were estimated using the stochastic frontier function. The result revealed that the mean TE, AE, and EE were 90.3%, 59.9%, and 76.4% respectively. As per Tobit model findings, TE was significantly impacted positively by gender, group membership, training, extension services, seed variety, and distance to market, whereas TE was significantly impacted negatively by household size and educational attainment. While household size had a substantial negative impact on AE, other factors including age, gender, group membership, training, extension services, and seed type showed favorable significant effects. The following factors also significantly improved EE: age, gender, group membership, training, extension service, and seed variety. Nonetheless, EE was significantly impacted negatively by household size, experience, and market proximity. The findings indicated that, by improving seed, there is a chance to boost the productivity of maize production in the research region. In order to improve the efficiency level of maize producer farmers, policies and research initiatives may influence these variables.

Keywords/Phrases: Cobb-Douglas, Efficiency, Maize, Production, Stochastic frontier, Tobit model

1 Introduction

Ethiopia's primary economic activity is agriculture. Two-thirds of people in developing nations reside in rural areas, according to the United Nations Development Program (UNDP, 2015). Most rural residents, many of whom are small-scale farmers, rely on agriculture as their primary source of income and subsistence. A hand-to-mouth lifestyle is the norm for farmers in underdeveloped nations that rely on farm income. This is a result of low livestock output, fast population expansion, and technological backwardness (FAO, 2014).

In Ethiopia, agriculture is the main industry, supporting the livelihoods of over 85% of the workforce, and this employment contributes roughly 45% of the country's GDP and 86% of its foreign exchange earnings (FDRE, 2016). As a result, the Ethiopian government has implemented measures aimed at promoting success, which can be guaranteed by increasing market performance and efficiency through lowering losses. Low productivity in Ethiopian agriculture is a result of both technical and socioeconomic issues. Due to ineffective management, a lack of use of contemporary agricultural technologies, outdated farming methods, inadequate supplementary services like extension, credit, marketing, and infrastructure, and biased agricultural policies, farmers with identical resources typically produce different amounts of output per hectare (WFP, 2012).

Cereals make up 65 percent of agricultural value added, or roughly 30 percent of the national GDP, and maize is the most important crop in terms of both crop output and the number of farmers involved in cultivation (Shahidur *et al*., 2010). The main producers and consumers of maize in Ethiopia are smallholder farmers, who make up almost 80% of the country's population (Dawit *et al*., 2008). As a key staple item for food security and the general growth of the agricultural industry, maize plays a crucial role in agricultural policy decisions.

Since agriculture is the main economic sector in Ethiopia, the government has worked hard to increase smallholder farmers' agricultural productivity and efficiency (Jema, 2008). Modern technology can be introduced to increase maize production, or current technologies can be improved to increase input efficiency. Since the introduction of new technology cannot bring about the anticipated shift of the production frontier if the current level of efficiency is low, these two are not mutually incompatible. This finding suggests that integrating contemporary technologies with higher levels of efficiency is necessary (Kinde, 2005).

According to this study, economic efficiency is the capacity of a farmer to use their existing resources as efficiently as possible in order to generate the greatest amount of output at the lowest practical cost. It includes both technological and allocative efficiency. Both technical and allocative efficiencies must be estimated in order to properly analyze farmers' economic efficiency. Thus, this study examined the economic efficiency of smallholder farmers' maize production; increased efficiency would support sustainable farming and better well-being for a sizable portion of Dega Damot Woreda, West Gojjam Zone, Amhara Region.

According to earlier studies conducted in Ethiopia, there is a significant disparity in grain yields across farmers, which may be caused by a variety of variables, including inadequate management, climate-related issues, and a lack of expertise and information about new crop technology (Sisay *et al*., 2015).

Many researchers only look at technical efficiency, ignoring the potential benefits for producers from the overall performance of how farmers allocate their resources in response to price incentives, which is a key factor in determining the farming enterprise's profitability. Thus, enhancing the productivity gains from current technology requires both technical and allocative efficiency. To the best of the researcher's knowledge, however, no research has been done on the economic efficiency of smallholder maize growers in the study region.

Therefore, by addressing technical, allocative, and economic efficiencies of smallholder farmers' maize production in the research area and offering empirical information on smallholder resource use efficiency, it is necessary to close the current knowledge gap. With the goals of assessing the degree of technical, allocative, and economic efficiencies of maize production and determining the factors influencing them in the study area, the current study is helpful in developing suitable policies and research data for lowering the degree of economic inefficiency.

Thus, this research addresses the following goals.

1. To assess the economic, technical, and distributive efficiency of smallholder farmers' maize production in the Dega Damot woreda, West Gojjam zone.

2. To determine the primary factors influencing maize production efficiencies in the research region.

2 Materials and Methods

2.1 Description of the Study Area

Dega Damot is a woreda in Ethiopia's Amhara Region's West Gojjam zone. Part of the Mirab Gojjam Zone, it is 399 kilometers from Addis Ababa, Ethiopia's capital. Dega Damot shares borders with Dembecha to the south, Jabi Tehnan to the southwest, Kuarit to the west, and the Misraq Gojjam Zone to the north and east. The population density of 183.27 people per square kilometer in Dega Damot is higher than the Zone average. In this Woreda, 33,336 households were counted, meaning that there were 32,497 dwelling units and an average of 4.57 people per household.

In Dega Damot, Amhara people make up the main ethnic group (99.95%). Of the population, 99.97% speak Amharic as their first language. With an average rainfall of between 900 and 1200 milliliters, the woreda is also known for its pleasant climate for the majority of the year (CSA, 2007). In Ethiopia's poorest and most food-insecure areas, such as Dega Damot woreda, maize is one of the main staple crops. The crop is grown in unfavorable circumstances, like marginal lands and low input utilization. The Dega Damot woreda's environment is ideal for growing a wide range of crops, including oil seeds (fruit and vegetable), teff, wheat, barley, beans, peas, sorghum, and maize.

Figure 1. Map of the study area (Source: Ethio-GIS, 2018)

2.2 Method of Data Collection

For this investigation, both primary and secondary data were employed. Questionnaires were manually distributed during the 2017–18 farming season in order to gather primary data. 366 respondents participated in the study in order to gather primary data using structural questionnaires. In-depth qualitative data was gathered through interviews. Four extension agents—one from each kebele—were interviewed in a structured manner. Focus Group Discussions (FGD) were used to gather people's opinions and worries regarding the production of maize. Interactions between participants and the researcher are made possible through focus groups. Four farmers from each kebele made up the group.

2.3 Sample Size Determination and Sampling Technique

To examine the economic efficiency of smallholder maize growers, a multi-stage sampling technique was used. Due to the huge number of families that produce maize and the volume of maize produced in the study area, Dega Damot Woreda was purposefully chosen for the study in the first stage. 32 kebeles make up the Dega Damot woreda in the second stage. Of them, 27 rural kebeles are important producers of maize. The primary target locations for the sample selection are maize producer kebeles, as the research primarily focuses on maize production. Due to the uniformity of maize production across all kebeles, four of the 27 kebeles are chosen at random in the third stage. Lastly, using the systematic random sampling (SRS) technique based on probability proportional to size (PPS), 366 sample farm households were chosen from the total households of four kebeles based on the list of households of the kebeles that produced maize during the 2017–18 production year.

2.3.1 Sampling Size Determination

The agriculture and rural development office of Dega Damot woredas reports that there are 4370 households spread over the four rural kebeles. The researchers used a formula developed by Yamane (1967) with a precision level of, ±5 (because the target population is homogenous).

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

Where, N = designates total number of households in four *Kebeles* n = the sample size whom the researcher used e = designates maximum variability or margin of error 5% (0.05).

Thus, $N = 4370$, $e = 0.05$

Therefore, $n = 366$

In accordance with the size sampling procedure, 366 farmers in total were chosen from the four kebeles based on this methodology. Four rural kebeles out of the 27 were chosen at random, and the respondents from these kebeles were used as a sample using the methods outlined below.

Table 1. Summarize on Sample size per *Kebele*

Kebele	**Maize producing households**	**Sample size (n)**
Geshet Slassie	1290	108
Arefa Debtera	1242	104
Damot Tsion	1015	85
Feresbet Mikael	823	69
Total	4370	366

2.4 Method of Data Analysis and Interpretation

Descriptive statistics and econometric techniques were used to assess the data gathered from various sources. Some significant features of the sample households were compiled using the descriptive analysis. Tables, basic ratios, percentages, frequencies, standard deviations, and more are all part of the descriptive technique.

A two-limit Tobit regression model and a stochastic frontier model (SFM) were employed in the econometric analyses. Estimating the effects of inputs on maize output, measuring the economic efficiency of maize production using the stochastic frontier production model with maximum likelihood estimation, and identifying factors influencing the economic efficiency of smallholder maize producers using the two-limit Tobit model in Dega Damot Woreda were the goals of the econometric approach. To support the findings of the quantitative analysis, a summary and presentation of the qualitative data were also made. STATA software and the Frontier 4.1c program were used to examine the data.

Model Specification and Estimation Procedures

The original models for Aigner *et al.* (1977) and Meesuen and van den Broeck (1977) proposed a stochastic frontier production model, which Battese and Coelli (1995) applied to cross-sectional data in order to assess the impacts of input on maize output using maximum likelihood estimation. The stochastic production function was employed in this study because to its two main characteristics: a one-sided component and a two-sided, symmetric term that make up the disturbance term.

Cobb-Douglas stochastic frontier production function Model

One of the two functional forms for the production functions is either Translog (TL) or Cobb-Douglas (CD). The sole model stated in this study was the CD model, and log-likelihood ratio tests were used to determine which model was best.

For Cobb-Douglas production function defined over N inputs,

$$Y = AX_1^{\beta_1} X_2^{\beta_2} ......XN^{\beta_N}$$

Where, Y = yield of maize and X_i = different variable of inputs (i = 1, 2, 3, ..., N)

Estimated as the sum of output elasticities for all inputs, RTS is a measure of returns to scale that shows the percentage change in output as a result of a proportionate change in the utilization of all inputs.

The specific Cobb-Douglas production model estimated is given.

$$Y_i = \beta_0 * \prod_{i=1}^{n} X_i \beta_i * e^{(v_i - u_i)}$$

By transforming it into double log-linear form

$$lnY_i = ln\beta_0 + \sum_{i=1}^{5} lnX_i + (V_i - U_i)$$

Where, Y_i represents maize yield harvested and X_i represents maize inputs by i^{th} farmer (Land, Oxen, Seed and Fertilizer). Whereas β_0, β_1, β_2, β_3, β_4, and β_5 the regression parameters to be estimated and ln= natural logarithm.

From the error term component ($V_i - U_i$), V_i is a two sided ($-\infty < V < \infty$) normally distributed random error ($v \sim N$ [0, $\sigma^2 v$]) that represents the stochastic effects outside the farmer's control (e.g., weather, natural disasters, and luck), measurement errors, and other statistical noise while Ui is a one-sided ($u_i \geq 0$) efficiency component which is independent of vi and is normally distributed with zero mean and a constant variance ($\sigma^2 u$) allowing the actual production to fall below the frontier but without attributing all short falls in output from the frontier as inefficiency.

Stochastic frontier Cobb-Douglas cost function

In order to estimate farm level overall economic efficiency, the stochastic frontier cost functions model is specified as follows:

$$C_i = h\ (Y_i, P_i, \alpha_i) + \varepsilon_i$$

Where, C_i is the total production cost, Y_i stands for output produced, P_i is price of input, α_i represents the parameters of the cost function to be estimated and ε_i is the error term. Since, inefficiencies are assumed to add to costs, error components, therefore, have positive signs.

Tobit Model with Maximum Likelihood Estimation

To honor Tobin (1958), who was the first to introduce censoring in economics, the Tobit Model is estimated using the censored regression model, often known as the Tobit model. The Tobit model, the most used censored regression model, uses an underlying latent variable to reflect the observed level. A Tobit is a type of censored regression model where the dependent variable is only tracked if it falls or rises above a predetermined threshold.

The dependent variable in the Tobit model, a censored normal regression model, is continuous, and its range is limited by a cut-off point from both above and below. Between zero and one, or inside a double-bounded range, is where the dependent variable is located. It makes sense to employ the Tobit model as using OLS results in skewed and inconsistent parameter estimates (Gujarati, 2004). Economic efficiency (technical and allocative efficiency) scores are the dependent variables in the model. These scores will be regressed against the common independent variables, which include the household head's age, education, gender, experience in maize production, extension services, group membership, distance to market, family income training, and seed varieties. It was anticipated that several explanatory factors will either directly or indirectly affect the economic efficiency (technical and allocative efficiencies).

Using a two-limit Tobit regression model, the factors influencing economic efficiency levels were measured. A set of socioeconomic, institutional, demographic, and other characteristics that were thought to be significant predictors of efficiency were used to regress the predicted efficiency scores. Given that the values of the dependent variables (efficiency scores) were within a specific range (0, 1), the Tobit regression model was thought to be more suitable.

A two-limit Tobit model was used to estimate three distinct equations for the determinants of technical, allocative, and economic efficiency, with the technical, allocative, and economic efficiency indices, respectively, serving as the dependent variable. The two-limit tobit model was defined as follows in accordance with Amemiya (1981), Waluse (2011), Essa *et al.* (2011), and Endrias *et al.* (2013):

$$Y_i\text{*EE, TE, AE} = \beta_0 + \sum_{j=1}^{12} \beta_i Z_{ij} + U_i$$

Where $Yi*$ is the latent variable representing the efficiency scores, β_0, β_1, ..., β_{12} are parameters to be estimated, and EE, TE, and AE are economic, technical and allocative efficiency of the i^{th} farmer, respectively. Z_i is demographic, socioeconomic and institutional factors that affect efficiency level. And, μ_i is an error term that is independently and normally distributed with mean zero and variance σ^2 ($\mu_i \sim$ IN 0, σ^2).

2.5 Diagnostic Tests

2.6.1. Test for Heteroskedasticity

When the conventional linear regression model's assumption of equal variance of residuals is broken, it is known as the heteroscedasticity test. In this case, the estimates of the variances are biased and the estimators are impartial but ineffective, which leads in invalid tests of significance (Maddala, 1992). Determining whether heteroscedasticity exists is the first step in solving the heteroscedasticity problem. Gujarati (2004) lists a number of tests for detecting heteroscedasticity, including the Breusch-Pagan, White's, PBPG, and Koeker Basset tests.

To confirm that the variance was constant, a heteroskedasticity test was conducted. For heteroscedasticity, the Breusch-Pagan/Cook-Weisberg test was applied. For both models, the robust option was used in the MLE regressions to account for heteroscedasticity (Baum, 2006).

2.6.2 Multicollinearity

Multicollinearity tests were also performed on the data. To check if the models have multicollinearity, the Variance Inflation Factor (VIF) was used. A scenario known as multicollinearity occurs when there is a significant degree of correlation between the independent variables.

A VIF value more than 10 is typically seen as a sign of significant multicollinearity and ought to be removed from the model, according to Gujarati (2004). The Variance Inflation Factor (VIF) was used to test for multicollinearity across all of the variables that were entered into the model, simultaneously for both continuous and dummy variables. Additionally, the contingency coefficient and variance inflation factors were used to verify the multicollinearity tests of dummy and continuous variables, respectively.

3 Result and Discussion

3.1 Estimating the Result of the Production and Cost Function

Table 2 shows maize farmers' maximum likelihood estimates (MLE) for the parameters of the stochastic frontier production function. The output values with the exception of labor, all input variables exhibit positive elasticity and significantly impact the growth of maize output. This implies that maize productivity falls as labor rises. According to this outcome, employing additional workers on a given amount of land may result in labor redundancy and a labor surplus, whose removal would essentially leave output unaltered.

Fertilizer: One important land-augmentation input that raises the productivity of existing land by raising yield per unit area is fertilizer, both chemical and organic. At the 1% level, the farmer's fertilizer coefficient is substantial and positively correlated with maize yield. Research suggests that a 1% increase in fertilizer quantity in kilograms will result in an 11.1% increase in maize production. The other input doesn't change. However, in order to prevent a declining return on fertilizer, this kind of relationship is predicted when the available fertilizer is used effectively in terms of rate in conjunction with other inputs. This outcome is in line with what Netabirabose (2017) found. Fertilizer was statistically significant at the 1% and 5% levels and had a favorable effect on production.

Land: The size of the farm, or land, is another important factor. Additionally, it was discovered that the coefficient of land was positive and significant at the 1% level. The largest output to land coefficient (24.4%) suggested that the primary factor influencing maize productivity in the research region is land. Land has a pretty big impact on maize output. In other words, if all other inputs stay the same, a 1% increase in farm size measured in hectares results in a 0.244% increase in maize production. The 1% statistical significance level for farm size suggests that changes in farm size had a significant impact on production efficiency.

Table 2. The Maximum Likelihood Estimates of the Cobb-Douglas Stochastic Frontier Production Function

Variable	**Parameter**	**Coefficients**	**Std. Error**	**Z**	***p*-value**
Constant	β_0	5.45	0.187	29.19	0.000
ln(land)	β_1	.244	0.0858	2.84	0.005
ln(labor)	β_2	0.0163	0.0684	-0.24	0.811
ln(seed)	β_3	0.103	0.046	2.27	0.023
ln(oxen)	β_4	0.219	0.086	2.55	0.011
ln(fertilizer)	β_5	0.111	0.036	3.09	0.002
$\ln\sigma^2 v$		-3.737	0.211	-17.83	0.000
$\ln\sigma^2 u$		-4.086	0.784	-5.21	0.000
σv		0.153	0.016		
σu		0.130	0.051		
σ^2		0.040	0.009		
λ (lambda)		0.848	0.066		
γ (gamma)		0.522			

Note: *, **, *** significant at 10%, 5% and 1% level of significance, respectively

This indicates that there is room to grow the farm in order to increase output. This outcome is comparable to Tarekegn's (2017) findings, which showed a substantial relationship between cumin output and farm size.

Oxen: The primary source of draft power for tasks like plowing and agricultural planting in the majority of developing nations, including Ethiopia, is oxen. At the five-level, the predicted coefficient of oxen days—one oxen-day is equal to eight working hours—was identified as positive and significant. The positive indicator suggests that maize production can be increased by employing more ploughs. Therefore, if all other inputs remain the same, a 1 percent increase in the daily number of oxen will result in a 21.9% increase in the output of maize. This result aligns with the research conducted by Getachew (2017) and Bealu *et al.* (2013).

Seed: The results also indicated that seed had a positive impact on maize productivity, with significance at the 5% level. Therefore, with everything else being equal, a 1% increase in seed quantity in kilograms will result in a 10.3% increase in maize production. To boost their maize production, it could be preferable to use certified and improved maize seeds. Seed is the most important input for crop yield, according to research by Bealu *et al.* (2013) and Tarekegn (2017).

Given that the Wald $Chi-square$ statistic is significant at the 1% level (Wald $Chi-square$ statistic = 752.41 and probability = 0.000), we reject the null hypothesis that inefficiency does not exist in favor of the presence of inefficiency. The important test can be used to determine whether technical inefficiency effects are absent. In the half-normal model, the important log-likelihood value is $\lambda=\sigma u/\sigma v$. If λ is equal to zero, then all deviations from the frontier are caused by noise and there are no technical inefficiency effects (Aigner, Lovell, & Schmidt, 1977). Since the estimated value of $\lambda = 0.848$ differs considerably from 0, the null hypothesis—that there are no inefficiency effects—is rejected at the 1% significance level.

The variance parameter gamma (γ), which ranges from zero to one, is the ratio of the variance of technical efficiency particular to a farm to the overall variance of production, according to the results of Maximum Likelihood estimations of variance parameters.

$$\gamma = \frac{\sigma^2 u}{\sigma^2 u + \sigma^2 v} = 0.522$$

Thus, it is possible to draw the conclusion that maize production is inefficient. Technical inefficiency accounted for almost 52% of the overall variation in maize farm output, according to the calculated γ value of 0.52. Therefore, the inefficiency component accounted for 52% of the variation in the composite error term. This finding also implies that random shocks beyond the farmer's control accounted for roughly 48% of the variation. For example, the temperature and weather during the cultivation of corn. The yield of maize can be optimized if technological inefficiencies among producers are reduced.

3.2 Efficiency Scores

Technical efficiency (TE) and cost efficiency (CE) were estimated using the Frontier version 4.1c computer program. The ratio of the actual cost to the ideal cost is known as cost efficiency.

Table 3. Summary Statistics of Efficiency Measures

Types of efficiency	Min	Max	Mean	Std. deviation
TE	0.755	0.963	0.903	0.342
AE	0.309	0.826	0.599	0.865
EE	0.526	0.909	0.764	0.120

TE (Technical efficiency), AE (Allocative efficiency), and EE (Economic efficiency)

Consequently, technical, allocative, and economic efficiency will always be limited between 0 and 1, whereas cost efficiency will always fall between 1 and infinite. Calculate economic efficiency to take the inverse of cost efficiency, however, to keep the conversation focused on technical efficiency from the production function and cost efficiency from the cost function. The following is an estimate of the allocative efficiency derived from technological and economic efficiencies: AE is equal to EE/TE. After the estimation of the cost function and the stochastic frontier production function, respectively. The sample farm of Dega Damot Woreda has mean scores of 90.3%, 76.4%, and 59.9% for technical, economic, and allocative efficiency, respectively. The farms that were sampled had the following minimal technical, allocative, and economic efficiency scores: 0.755%, 0.309%, and 0.526%, respectively. The sampled farms had maximum allocative technical and economic efficiency scores of 90.9%, 82.6%, and 96.3%, respectively.

3.3 Determinants of Efficiency among Maize Producers in the *Woreda*

The parameters influencing economic efficiency levels were measured using a two-limit Tobit regression model. A set of socioeconomic, institutional demographic, and other characteristics that were thought to be significant predictors of efficiency were used to regress the predicted efficiency scores. The main goal of assessing TE, AE, and EE levels is to identify the variables that affect each farm household's efficiency level and to develop and implement policies that increase that efficiency. The Tobit regression model was used to regress the model's TE, AE, and EE scores on institutional, socioeconomic, and demographic factors that account for differences in inefficiency among farm households.

3.3.1. Determinants of Technical Efficiency

The results of a tobit regression of the socioeconomic, demographic, and institutional factors that affect technical efficiency scores in the research area are displayed in Table 4. The variables that were identified were: family income, seed variety, distance to market, extension service, gender, education level, experience, household size, group participation, training, and family income.

Table 4. Two–limit Tobit model technical efficiency result

		Robust		
Technical efficiency	**Coefficient**	**Standard error**	*t*	*P* >|t|
Constant	0.866	0.0103	83.67	0.000
age	0.00014	0.0003	0.49	0.625
gender	0 .0121	0.0037	3.25	0.001
education	-0.0046	0.0016	-2.90	0.004
hhsize	-0.0014	0.00080	-1.71	0.088
famincome	3.98e-07	3.61e-07	1.10	0.271
experience	-0.00035	0.00040	-0.87	0.387
dismarket	0.00045	0.00015	2.99	0.003
acccredit	0.0229	0.0030	7.53	0.000
groupmm	0.0106	0.0030	3.51	0.001
training	0.0079	0.0030	2.63	0.009
extsservice	0.008	0.0029	2.56	0.011
seedvariety	0.009	0.0036	2.57	0.011
Number of obs =	366			
LR Chi^2 (12) =	242.49			
Prob > Chi^2 =	0.0000			
Log likelihood =	833.19002			
Pseudo R^2 =	-0.1703			

Note: significant at 10%, 5% and 1% level significance, respectively

The findings of this study's Tobit model are examined for each important variable in the following manner.

At the 1% level, the gender of the head of the family was found to have a considerable beneficial impact on the technical efficiency (TE) of the maize fields. According to the marginal effect result, the sex of the household head from (0=F, 1=M) raises the likelihood that farmers will be technically efficient by roughly 1.2 percent. Another implication is that households headed by men are technically more efficient than those headed by women. Male family heads may have more practical farming expertise, which could be the explanation.

Furthermore, it might be argued that poor technical efficiency levels result from female family heads being overly preoccupied with home chores and lacking the time necessary to manage their maize plots. This outcome aligns with Muluken's (2014) findings.

A Group membership: A maize farmer who was a member of a producer cooperative or group also had an impact on technical efficiency. As a result, the technical efficiency (TE) of the maize fields was found to be positively impacted by the household head's group membership, which was significant at the 1% level. An rise in group membership in farmers' cooperatives also raises the likelihood of technical efficiency, according to the marginal impact result. Assuming all other factors remain unchanged, farmers who joined farmers' cooperatives increased their technical efficiency levels by 1.057 percent more than those who did not join farmer organizations. This outcome is in line with Bealu *et al*. (2013)'s findings.

Theoretical distance to market: It is postulated that technological efficiency was inversely correlated with the distance of maize production to the market. Technical efficiency was higher in households closer to the factor markets than in households farther away.

The surprise discovery, however, was that the technical efficiency (TE) of the maize fields was positively impacted by the household head's distance to the market, and this effect was significant at the 1% level.

According to the marginal effect result, if all other factors remain constant, a one-kilometer increase in the farmer's distance to the market results in a 0.045 percent rise in the farmer's chance of technical efficiency. Therefore, in order to achieve a higher degree of technological efficiency, farmers must have easy access to inputs and enhanced communication channels. This results contradicts the findings of Ntabakirabose (2017) and Bealu *et al.* (2013), who found a negative correlation and a significant impact on technical efficiency.

Access to credit: One crucial component of agricultural production systems is finance availability. It enables the manufacturer to meet the financial demands brought on by the production cycle. Because it temporarily addresses the need of operating capital and liquidity, the quantity of credit boosts farmers' productivity. The amount of credit was postulated in this study so that farmers who receive more credit from formal or informal sources during a given production season should be more productive than those who receive less credit. The technical efficiency (TE) of the maize farms was found to be positively impacted by the household head's access to finance, and this effect was significant at the 1% level. According to the results of the marginal effect, the likelihood of technical efficiency is increased by roughly 0.75% for a household head who has access to credit. This outcome aligns with the research conducted by Musa *et al.* (2014) and Netabirbose (2017).

Training: Developing the managerial skills of the head of the home requires training. It is predicted that household heads who acquire instruction in crop production and marketing, or any other associated agricultural training, are more productive than those who do not. It was crucial to train farmers on maize crops since it may enhance their knowledge of production methods and other topics. For a few days, a number of farmers in the study areas received instruction on maize, mostly on enhanced packaging and production techniques.

The results indicated that household head training had a significant positive impact on the technical efficiency (TE) of the maize fields at the 1% level. According to the marginal effect result, the likelihood of farmers becoming technically efficient is increased by around 0.79 percent for every farmer who attended training in maize production. According to this finding, farmers who received instruction were theoretically more productive than those who did not. This outcome aligns with the research conducted by Bealu *et al.* (2013) and Netabirbose (2017).

Seed variety: At the 1% level, the household head's seed variety had a considerable beneficial impact on the technical efficiency (TE) of the maize farms. According to the marginal effect result, farmers who used better household head seed varieties had a roughly 0.91% higher chance of being technically efficient; all other factors remained unchanged. In theory, farmers are more efficient than others if they have at least one plot of enhanced seed. A dummy variable called "seed variety" indicates whether or not the farmer used better seeding techniques.

It was predicted that farmers who used seed variety would be more productive than their counterparts since it reduces expenses and improves the quality of the seeds needed to produce maize. The results of Bealu *et al.* (2013) are in line with this outcome.

The technical efficiency (TE) of the maize farms in the study area was negatively impacted by the household head's educational attainment, and this effect was significant at the 1% level. According to the marginal effect result, farmers' chances of being technically efficient dropped by 0.45% as their years of education increased, while all other factors stayed the same. This outcome is in line with Getachew *et al.* (2017)'s findings. The findings of Alemu *et al.* (2009) indicate that efficiency is reduced by schooling.

It is argued that a farmer may have better prospects outside of farming as their level of schooling rises. In the end, this lowers efficiency by reducing the amount of labor available for maize production in the home. Additionally, Adesina and Djato (1996) have opinions about how education affects productivity. They argue that although uneducated farmers may have more farming experience and expertise than their educated counterparts and may be technically more effective, educated farmers may not always be more efficient than uneducated farmers.

Evidence from Battesse and Coelli (1995) refutes these claims, demonstrating that education improves farmers' efficiency and their capacity to use current technology. Unexpectedly, these research show a negative correlation between schooling and technological efficiency. This outcome contradicts the conclusions of Bealu *et al.* (2013), Mustefa *et al.* (2014), and Muluken (2014). This study demonstrated that education significantly and favorably affects all kinds of efficiency. It reaffirmed how crucial education is to raising manufacturing efficiency. It is a variable that is anticipated to improve managerial skills and result in wise farming judgments. Literate farmers are better equipped to manage their farm resources and agricultural activities than illiterate ones due to their superior abilities, information availability, and sound farm planning. They are also more likely to adopt enhanced production methods.

Household size (family size): The technical efficiency (TE) of the maize farms in the study area was negatively impacted by the household size (family size) of the household head, and this effect was significant at the 10% level. With all other factors held constant, the marginal effect result indicates that a one-person increase in household size would result in a 0.14 percent decrease in the likelihood of farmers being technically efficient. Due to a lack of funds, homes with a significant number of family members were unable to employ the proper input combinations.

Similar results were found by Musa *et al.* (2014), Essilfie *et al.* (2011), and Belete *et al.* (2014). Their reasoning was predicated on the idea that a big household size puts more strain on the farmer's limited resources because of rising household spending.

Extension service technical efficiency level was positively and considerably impacted by extension service at the 1% level. The marginal effect result showed that maize farmers who used extension services had a 0.75% greater level of technical efficiency than those who did not. There are no changes made to other variables. Efficiency rises as extension workers visit the farm household more frequently, according to the positive predicted coefficient for interaction with extension workers. The implementation of crop diversification has been comparatively more prevalent among farmers who have access to extension services than among those who do not.

Extension agents can help farmers carry out their crop diversification decisions since they possess technical expertise in crop production and enhanced production management techniques. As a result, suitable and sufficient extension services ought to be offered. The findings of Ahmed *et al.* (2013), Netabirbose (2017), Desale (2017), Daniel (2016), and Bealu *et al.* (2013) are all in agreement with this outcome.

3.4 Determinants of Allocative Efficiency

The results of a tobit regression of socioeconomic, demographic, and institutional factors on the effects of allocative efficiency scores in the research area are shown in Table 5.

The findings showed that allocative efficiency was significantly influenced by nine out of twelve variables. As was already mentioned, allocation efficiency plays a significant role in farms' overall productivity. One factor that might raise farms' overall production is the efficient use and distribution of resources.

The allocative efficiency (AE) of the maize farms was found to be positively impacted by the gender of the household head, and this effect was significant at the 1% level. When all other parameters were held constant, the marginal effect finding indicates that the sex of the household head from (0=F, 1=M) enhanced the chance of farmers' allocative efficiency by almost 3.57 percent. Additionally, it suggests that households led by men are more allocatively efficient than those headed by women. This might be the case because allocative efficiency necessitates a higher level of knowledge and expertise acquired with time, which boosts farmers' ability to allocate resources and technologies in the most efficient manner.

Table 5. Two–limit Tobit model Allocative efficiency result

Allocative efficiency	Coefficient	Robust Standard error	t	P >|t|
Constant	0. 4245	0.0410	10.34	0.000
age	0.00295	0.00112	2.63	0.009
gender	0.03578	0.0146	2.45	0.015
education	-0.01065	0.00709	-1.50	0.134
hhsize	-0.0061	0.0030	-2.06	0.040
famincome	2.90e-06	1.22e-06	2.38	0.018
experience	-0.0035	0.0016	-2.22	0.027
dismarket	-0.00102	0.00073	-1.41	0.159
acccredit	-0.01145	0.013	-0.88	0.379
groupmm	0.0517	0.013	3.84	0.000
training	0.0553	0.012	4.49	0.000
extservice	0.03108	0.013	2.45	0.015
seedvariety	0.0463	0.014	3.35	0.001
Number of obs =	366			
R Chi^2 (12) =	153.53			
Prob > Chi^2 =	0.0000			
Log likelihood =	326.92949			
Pseudo R^2 =	-0.3068			

The allocative efficiency (AE) of the maize farms was positively impacted by the age of the household head, and this effect was significant at the 5% level. When all other factors were held constant, the marginal effect result showed that the probability of allocative efficiency increased by 0.30% for every year that the household head's age increased. This suggests that older farmers are more productive than their younger counterparts. This might be the case because allocative efficiency necessitates the accumulation of knowledge and expertise over time, which enhances farmers' ability to allocate resources and technologies in the most efficient manner. This implied that elderly farmers were more productive than younger ones. The reason for this could be that as farmers age, their combined farming experience makes them more skilled. This is in line with Daniel's (2016) findings.

Allocative efficiency (AE) of the maize farms was positively impacted by the household head's family income, and this effect was significant at the 5% level. Based on the marginal effect result, when all other factors were held constant, the chance of allocative efficiency rose by roughly 0.00029 percent for every unit rise in a household's family income. Farmers become more efficient as these family incomes rise. The reason for this is that having family money allows farmers to timely buy inputs that they are unable to supply with their on-farm income, shifting the financial restriction outward.

Therefore, by allocating effectively at an efficient cost of production, it allows farmers to optimize their output. The outcome is consistent with the research conducted by Mustefa (2014), Abebayehu (2011), and Hasen (2011).

The research area's maize farms' allocative efficiency (AE) was negatively impacted by the household head's family size, and this effect was significant at the 5% level. The marginal effect result indicates that, when all other factors are held constant, a one-person increase in household size would result in a 0.61 percent decrease in the likelihood of farmers being allocatively efficient. The reason for this could be that farmers with large families were less able to allocate resources optimally. The findings of Daniel (2016) and Hika (2016) are in line with this outcome.

The allocative efficiency (AE) of the maize farms in the study area was positively impacted by the household head's group membership, and this effect was significant at the 1% level. Assuming all other factors remain unchanged, the marginal effect analysis showed that farmers who belonged to farmers' cooperatives had higher levels of allocative efficiency than those who did not join farmer organizations by 5.16 percent. In theory, being a member of social groups aids producers in becoming more efficient. This outcome is in line with what Waluse (2012) and Bealu (2013) found.

At the 5% level, it was also discovered that extension services had a favorable and significant impact on allocative efficiency (AE) level. According to the results of the marginal impact, maize farmers who used extension services reported a 3.11% greater degree of probability of allocative efficiency than those who did not. Additionally, one significant factor influencing the allocative efficiency of farmers in the research area was the frequency of extension interaction. Farmers gained new knowledge and abilities from development agents, which led to this outcome. The findings of Mustefa (2014), Tarekegn (2017), Desale (2017), Daniel (2016), and Bealu (2013) are all in agreement with this outcome. The likelihood of maize market involvement increases by 0.47% when extension contact is increased by one day, according to the marginal effect result.

Experience: One of the socioeconomic elements that has received more attention in many stochastic production function studies is the impact of farming experience, which is typically expressed as the number of years the farmer has been engaged in maize farming. At the 5% level of significance, experience had a substantial impact on the sampled households' AE. According to the marginal effect result, when all other parameters were held constant, farmers' chances of being allocatively efficient dropped by 0.34 for every year of farming experience. Allocative efficiency's coefficient, on the other hand, has a negative sign, which goes against expectations. Its drawback could be that farmers with more farming expertise might not be receptive to cutting-edge input combinations that reduce expenses.

More capital has been accumulated by farmers with many years of productive experience than by those with less. As a result, the farmer may lose interest in farming after he has accumulated wealth and turn to other commercial endeavors. Therefore, this could result in smallholder farmers producing maize less efficiently. This outcome is consistent with previous research findings by Gosa (2014), Hika (2016), Getachew (2017), and Musemwa *et al* (2013).

At the 1% level, training the head of the household had a considerable favorable impact on the maize fields' allocative efficiency (AE). The probability of allocative efficiency among farmers is increased by approximately 5.53 percent compared to those who did not attend training in maize production, according to the marginal effect finding. They were able to use inputs in a cost-minimizing input ratio as a result of training. This outcome supports Nejuma's (2012) findings. Allocative efficiency (AE) of the maize farms was positively impacted by the household head's seed variety, and this effect was significant at the 1% level. Using the household head's enhanced seed variety increases the likelihood of the farmers' allocative efficiency by approximately 4.63% when all other factors stay the same, according to the marginal impact result. This outcome aligns with the research conducted by Bealu *et al*. (2013). Additionally, efficiency will rise with the usage of better seeds.

3.5 Determinants of Economic Efficiency

The findings showed that 10 out of twelve variables significantly contributed to economic efficiency.

At the 1% level, the family head's gender had a considerable favorable impact on the maize farms' economic efficiency (EE). According to the marginal effect result, the sex of the household head from (0=F, 1=M) raises the likelihood that farmers will be economically efficient by roughly 4.36 percent. Farm households led by men were more inclined than those headed by women to make decisions based on the market. Due to resource limitations for crop production, households led by women had this outcome.

Table 6. Two–limit Tobit model economic efficiency result

Economic efficiency	Coefficient	Robust Standard error	t	P >|t|
Constant	0.6345	0.0279	22.70	0.000
age	0.00224	0.00081	2.75	0.006
gender	0.0437	0.1028	4.26	0.000
education	-0.00625	0.0048	-1.31	0.192
hhsize	-0.0043	0.0021	-2.09	0.037
famincome	1.89e-06	8.50e-07	2.23	0.027
experience	-0.00338	0.00108	-3.11	0.002
dismarket	-0.0011	0.00049	-2.22	0.027
acccredit	-0.0118	0.0087	-1.35	0.177
groupmm	0.0385	0.0090	4.23	0.000
training	0.0433	0.0084	5.13	0.000
extservice	0.0285	0.0086	3.32	0.001
seedvariety	0.03079	0.0092	3.32	0.001
Number of obs =	366			
LR Chi^2 (12) =	196.34			
Prob > Chi^2 =	0.0000			
Log likelihood =	450.24502			
Pseudo R^2 =	-0.2788			

At the 1% level of significance, the age of the family head had a beneficial impact on the maize farms' economic efficiency (EE). When all other factors are held constant, the marginal effect finding shows that a one-year increase in the farmer's age raises the level of likelihood of economic efficiency by 0.22%. Older farmers are therefore more economically efficient. The elderly head of the home is more productive and efficient, according to the data. Because of this outcome, older households are more experienced and can effectively employ their prior knowledge to produce more with a given amount of inputs. This outcome aligns with the research conducted by Tarekegn (2017) and Nejuma (2012).

The economic efficiency (EE) of the maize farms was positively impacted by the household head's family income, and this effect was significant at the 5% level. According to the marginal effect result, when all other factors were held constant, a household's chance of economic efficiency rose by roughly 0.0002 percent for every unit rise in family income. The outcome agreed with Solomon (2014).

At the 5% level, the household head's family size had a substantial negative impact on the economic efficiency (EE) of the maize farms in the research area. When all other factors are held constant, one person reduces the likelihood of economic efficiency by approximately 0.43 percent and increases the size of the home headed by the householder, according to the marginal effect result. Household size is a surprising indicator of economic efficiency; one explanation for this could be that a bigger household size ensures family labor is available to complete farm tasks on schedule.

Because there is a labor shortage during peak seasons, households with larger family sizes are more efficient in producing maize because they assign more workers to complete essential farming tasks like plowing, weeding, and harvesting on time.

The economic efficiency (EE) of the maize farms in the study area was positively impacted by the household head's group membership, and this effect was significant at the 1% level. According to the marginal effect result, farmers who joined cooperatives had a roughly 3.84 percent higher chance of being economically efficient than farmers who did not join, when all other factors were held constant.

The participation of farmers in farmer cooperatives serves as a stand-in for gauging the contribution of social organization to productivity. Compared to non-members, farmers who are part of farmer cooperatives are given access to more useful knowledge about production technologies. They experiment with and implement new production technology as a result, making them more productive in the production of maize. This outcome aligns with the research conducted by Waluse (2012) and Bealu (2013).

Economic efficiency (EE) level was also found to be positively and considerably impacted by extension service at the 1% level. The results of the marginal effect showed that, when all other factors were held constant, maize farmers who used extension services had a 2.85% better chance of economic efficiency than those who did not do so. This outcome may have resulted from the knowledge that extension agents provided, which had the ability to lessen farmers' inefficiency and resource waste by raising farmers' understanding of technology and the effective use of already-existing resources.

At the 1% level, it was also discovered that extension services had a favorable and considerable impact on economic efficiency (EE) levels. The results of the marginal effect showed that, when all other factors were held constant, maize farmers who used extension services had a 2.85% better chance of economic efficiency than those who did not. This outcome may be the consequence of information gathered from extension agents, who had the ability to raise farmers' awareness of technology and the effective use of their current resources in order to reduce their inefficiency and resource waste.

Agricultural experience: Surprisingly, at a 1% level of probability, the correlation between farmers' farming experience and maize production had a negative impact on farmers' economic efficiency (EE). When all other parameters were held constant, the marginal effect finding showed that farmers' chances of being economically efficient dropped by 0.34 for every year of increasing farming experience. Its negative sign could be the result of more seasoned farmers not being receptive to the mix of contemporary inputs that reduces their expenses. They might have greater experience with their more expensive and time-consuming traditional technology. Our expectations are not met, though, as the coefficient for economic efficiency has a negative sign.

More capital has been accumulated by farmers with many years of productive experience than by those with less. As a result, the farmer may become less motivated to farm after he has accumulated wealth and turn to other commercial endeavors.

The economic efficiency (TE) of the maize fields was negatively impacted by the household head's distance to the market, and this effect was significant at the 5% level. When all other factors were held constant, the marginal effect finding showed that a one-kilometer increase in the distance to the market decreased the level of probability of economic efficiency by roughly 0.11 percent. This suggests that farmers who live distant from the market are more inefficient since it costs more to transport inputs and outputs, conduct transactions, and obtain market information. This outcome aligns with the research conducted by Essa (2011), Hassen (2011), and Musa *et al*. (2015).

The economic efficiency (EE) of the maize farms was positively impacted by family head training, and this effect was significant at the 1% level. According to the marginal effect result, farmers who participated in more training in maize production are more likely to be economically efficient than those who did not, by roughly 4.32%. The findings of this study contradict the notion that farmers who participated in training related to maize production should be more productive than those who did not. Additionally, this research showed that farmers who participated in training in the study area were more productive than those who did not.

The household head's seed variety had a significant, 1%-level beneficial impact on the maize fields' economic efficiency (EE). Based on the marginal effect result, farmers who utilize the household head's enhanced seed variety have a 3.07 percent higher chance of being economically efficient when all other factors are held constant. The findings of Bealu *et al.* (2013), Nejuma (2012), and Essa (2011) are all in agreement with this outcome. Improved maize cultivars have a significant effect on economic effectiveness. In comparison to traditional types, the majority of enhanced cultivars issued by agricultural research organizations around the world have demonstrated exceptionally high yields.

4 Conclusion and Recommendations

The purpose of this study was to determine the factors influencing economic efficiency among households that produce maize in the Dega Damot woreda of the Amhara National Regional State of Ethiopia, as well as to estimate technical, allocation, and economic efficiency. Improved input efficiency or the use of contemporary technologies could both boost agricultural productivity. This suggests that current technologies must be integrated with increased efficiency.

The technical efficiency of farmers in emerging nations has been the subject of numerous studies. But a large number of the studies solely looked at technical efficiency. Consequently, increasing the productivity advantages from current technology requires both technical and allocative efficiency. Furthermore, the research area's smallholder maize growers' economic efficiency was not examined.

The Tobit regression model's estimates also revealed that, of the total variables, nine (household head age, family income, gender, household size, experience, group membership, training, seed variety, and extension service) significantly influence the allocative efficiency of maize production, while nine (household sex, education level, distance to market, access to credit, household size, extension service, group membership, training, and seed variety) were statistically significant in affecting the level of technical efficiency.

Additionally, the model's outcome showed that 10 factors—geography, age, gender, group participation, training, extension services, market distance, experience, household size, family income, and seed variety—were significant in affecting the economic efficiency of families in the research area. The study's findings also showed a significant degree of variation in the sample homes' overall efficiency scores for maize production in the study area. Thus, by following the methods of the more productive farmers in the region, less productive farmers raise their level of efficiency. In light of the findings, recommendations are given to boost maize production's efficiency and productivity. In order to improve resource use efficiency and raise maize yield in the study area, policy implications are therefore made based on the study's findings.

The acquisition of inputs required for maize production and the expansion of extension services for simple technology adoption and input implementation should be made possible by a high degree of financial support. The main policy consequence is that suitable policies should be created to offer sufficient and efficient basic educational opportunities for farmers in the research area, as attainment level is a significant influence in TE, AE, and EE. To address issues related to credit consumption, the government ought to make investments in and promote the satisfaction of credit service providers.

The efficiency of maize production could be increased with the support of policies and initiatives that enhance extension services. Therefore, through further training programs, the number of visits from families to extension agents should be increased.

Additionally, considering the complementary nature of extension services, expanding basic and functional educational options in rural regions need to be a top priority in order to boost the agricultural production of smallholder households.

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Conflict of Interest

The authors affirm that none of the work described in this publication may have been influenced by any known competing financial interest or personal relationship.

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Ethnobotanical survey of traditional medicinal plants used to treat human ailments in Arero District, Borena Zone, Ethiopia

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Abstract

Pastoralist communities have traditionally possessed extensive knowledge regarding the plants and grazing areas in their vicinity, acquired through continuous practice and meticulous observation. As members of the Borana pastoralist communities, the people residing in the Arereo District utilize a variety of plant resources found in their rangelands. To assess the traditional application of medicinal plants for treating human health issues in the Arero District of Borena Zone, an ethnobotanical study was carried out. The main aim of this research was to document the medicinal plants utilized by the local populace. A total of fifty-one key informants were intentionally chosen to take part in the study. Data collection was achieved through questionnaires, focus group discussions, and field observations. In the area under study, forty-four species of medicinal plants from thirty-six genera and twenty-four plant families were identified and recorded. These plants were reported to be used for the treatment of thirty-five distinct human ailments. Among the various plant parts utilized for medicinal purposes, roots emerged as the primary source of remedies (47.7%), followed by leaves (13.6%). Of the documented remedies, 59.7% were prepared for internal use, with oral consumption being the most prevalent method (53.73%). Furthermore, 40.3% of the remedies were designed for external applications. The decoction method was the most common approach to remedy preparation, representing 41.8% of the remedies identified in the study area. The results revealed that the local community held significant knowledge regarding the use, preparation, and application of medicinal plants for addressing human ailments. Nonetheless, it was also observed that certain medicinal plants in the area, such as Vachellia nilotica and Vachellia tortilis, were reported to be at risk locally. It is essential to give proper attention to mitigate further threats to these medicinal plants and to conserve them, along with the related local knowledge. Initiatives should be undertaken to protect the medicinal plant resources in the study area, ensuring their sustainable use and preservation for future generations.

Keywords/Phrases: Borena, Human ailments, Indigenous knowledge, Medicinal plant, Traditional healers

1 Introduction

Plants play a crucial role in the lives of human beings, providing essential resources for their well-being and fulfilling their basic needs. The utilization of plants by humans can be traced back to the process of domestication, which originated about 10,000 years ago (Martin, 1995). Over time, indigenous communities have developed their own specific knowledge regarding the use, management, and conservation of plants in their local environments. This indigenous knowledge (IK) is continuously adapted to changing circumstances, passed down through generations, and deeply intertwined with cultural values (Cotton, 1996).

Ethiopia is recognized for its rich plant biodiversity, boasting approximately 6,000 species of higher plants (Hedberg *et al*., 2009). Throughout various regions of the country, people have long relied on medicinal plants to treat human and animal ailments. Traditional Ethiopian medicine has depended significantly on plant usage for centuries (Debela *et al*., 1999; Fullas, 2007), establishing itself as a vital component of Ethiopian culture due to its enduring practice (Kaba, 1998). Indeed, it is estimated that approximately 80% of the Ethiopian population depends on traditional herbal treatments (Abebe, 1996). The widespread use and interest in medicinal plants in Ethiopia can be ascribed to their acceptability, availability, and biomedical advantages (Abebe, 2001). The southern and southwestern regions of the country, known for their biological and cultural diversity, exhibit a particularly rich diversity of medicinal plants (Tadesse & Demissew, 1992).

Knowledge and services related to traditional medicinal plants are passed down to other family members, neighbors, and communities, ensuring their continuity across generations (Yirga, 2020). Traditional healers and those who have benefited from these practices have been the primary disseminators of information regarding medicinal plants and their applications (Punjani, 2010). However, the restricted availability of this knowledge to the wider public has led to its concealment, making traditional medicinal plant knowledge and skills more hidden (Abbink, 1995). Consequently, the potential loss of this valuable knowledge looms as traditional healers and elderly community members passes away.

In Ethiopia, the documentation of local knowledge concerning traditional medicinal plants and their uses remains incomplete (Abbink, 1995; Getahun, 1974). As much of this knowledge is transmitted orally from one generation to the next, the disapproval of traditional medicine practitioners jeopardizes the future preservation of the country's cultural heritage (Kibebew, 2001). The Borana pastoralists, with their diverse cultures, unique traditional practices, and distinct livelihood systems, utilize a variety of plants for traditional medicines, food, forage, construction materials, household implements and utensils, firewood, and more, much like other ethnic groups in Ethiopia. Additionally, certain plant species hold ritual and commercial significance and provide shade. The Arero District, situated within the pastoralist areas of Borana, boasts a wealth of indigenous medicinal plant knowledge. Community members frequently depend on herbal remedies sourced from medicinal plants to treat various human ailments. Nevertheless, the expertise possessed by the community has been significantly neglected by researchers. The indigenous knowledge related to the use and practices of medicinal plants in this area is inadequately recorded, confined to traditional healers and a limited number of community members. This scenario presents a considerable threat to the future conservation of medicinal plants, traditional knowledge, and their application. Consequently, the aim of this study was to evaluate and document the medicinal plants employed in the treatment of human diseases and the related practices in the Arero District.

2 Research Methodology

2.1 Description of the Study Area

The study was carried out in Arero District, Borana Zone, Southern Ethiopia, as described by the author (Year). Arero District is situated approximately 660 km south of Addis Ababa. Geographically, the district is located between 38°15' - 39°30' East Longitude and 3°45' - 5°15' North Latitude (Figure 1). It covers a total area of 3660 km^2 and exhibits a diverse landscape characterized by plains, undulating topography, hills, and gorges. The elevation of Arero District ranges from 700 to 1,600 meters above sea level.

The study area, as mentioned by the author (Year), is primarily recognized for its semi-arid agroclimatic conditions. It experiences a bimodal rainfall pattern. Based on data obtained from the National Meteorological Agency (NMA, 2021) for the Yaballo Meteorology Station, the mean annual rainfall and temperature in the area are recorded as 603 mm and 20°C, respectively.

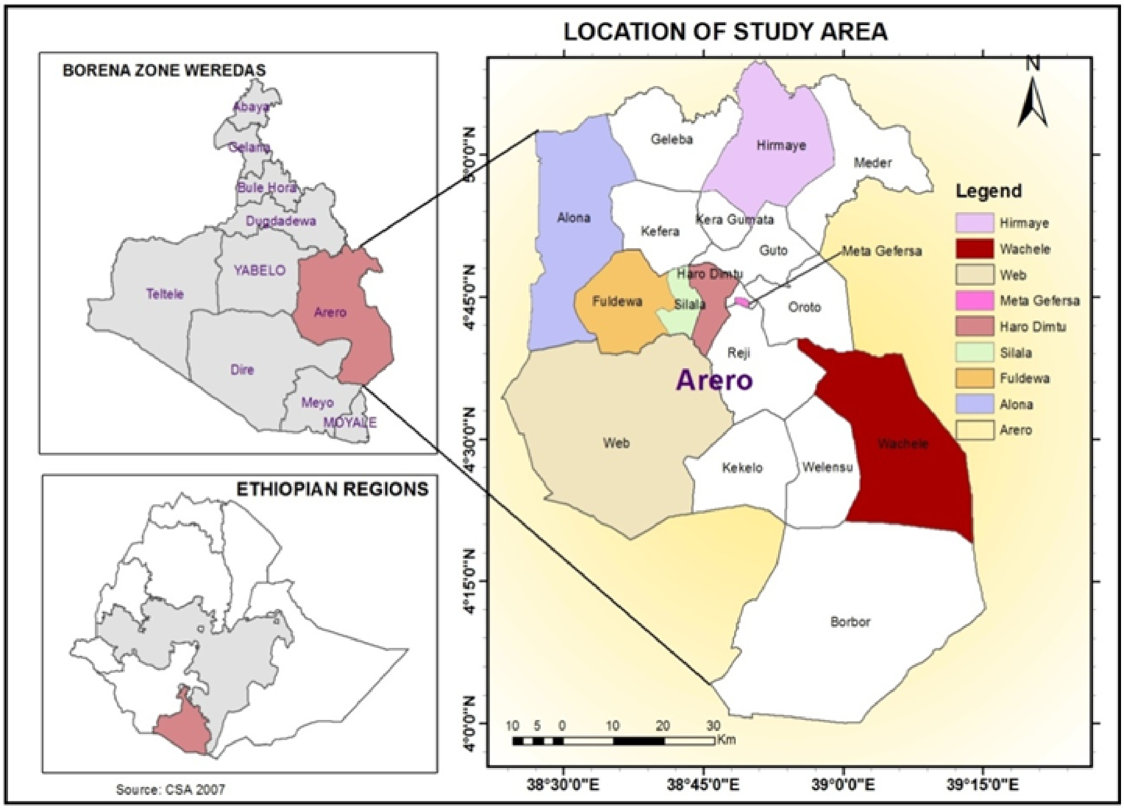

Figure 1. Map of the study area (right), Ethiopia (bottom left), Borena Zone (top left)

2.2 Sampling

For the sampling process, a total of fifty-one traditional healers (37 male and 14 female) residing in eight Kebeles within Arero District were purposefully selected, following the approach outlined by Martin (1995). The selection of traditional healers was based on information acquired from the elderly and local community leaders in the respective Kebeles. In accordance with the "Rule of Thumb" for purposive sampling, which suggests a sample size of at least 10% of the population or 30 for smaller populations, a sample size of 30% of the total traditional healers (170) in the study area was deemed appropriate. Consequently, a proportional number of traditional healers from each Kebele were included in the sample (Table 1). The selection of key informants was based on their profile, experience, and history of practice.

Table 1. Number of traditional healers in the study area and sampled

Name of the *Kebeles*	Number of traditional healers in the *Kebele*	Number of traditional healers sampled
Alona	20	6
Fuldowa	16	5
Silala	23	7
Haro-dimtu	21	6
Mata-Gafarsa	24	7
Wachile	24	7
Web	19	6
Hirmaye	24	7
Total	171	51

2.3 Ethnobotanical Data Collection

To collect ethnobotanical data, standard methods of ethnobotanical techniques and herbarium preparation, as described by the author (Year) and Alexiades (1996), were employed.

The techniques used included focus group discussions with various groups of people, including traditional healers, Kebele authorities, and elderly community members (both male and female). Semi-structured interviews with traditional healers and field observations were also conducted. The primary source of ethnobotanical data was the interviews conducted with the traditional healers.

During the interviews, the following information was collected from the informants: human ailments addressed by traditional healers through the use of medicinal plants, local names of these plants associated with specific ailments, the parts of the plants utilized in remedy preparation, the methods of preparing and administering these remedies, the transfer of knowledge regarding medicinal plants, and the threats faced by these plants.

In addition to the interviews, a focus group discussion was held to assess the preference for medicinal plants used in treating snake bites, a common occurrence in the region. The discussion also encompassed topics such as knowledge transfer and the threats to medicinal plants.

2.4 Data Synthesis or Analysis

Descriptive statistics were utilized to summarize and describe the collected ethnobotanical data, with percentages and frequencies used for data presentation. Microsoft Excel 2016 was employed to organize quantitative data, calculate proportions, and create tables and graphs. For the analysis of qualitative data obtained through interviews and focus group discussions, NVIVO 12, a software for qualitative data analysis, was utilized.

According to the traditional healers, snake bites were reported as the most prevalent incidence among community members seeking traditional medication. The preference ranking of five medicinal plants used for preparing remedies for snake bites was conducted by seven key informants, following the methodology outlined by Martin (1995). During the focus group discussion, the informants compared the given medicinal plants based on their knowledge of their effectiveness in treating the illness and assigned scores ranging from 1 to 5, with 5 indicating the most effective and 1 indicating the least effective. The scores assigned to each medicinal plant species were then totaled to determine the overall rank of preference.

Furthermore, a direct matrix ranking, a more complex version of preference ranking (Martin, 1995; Cotton, 1996), was performed to assign scores to seven medicinal plants reported to have multiple uses in addition to their medicinal value. The seven multipurpose plant species included *Boscia mossambicensis*, *Grewia tembensis*, *Grewia villosa*, *Lanea rivae*, *Pappea capensis*, *Vachellia nilotica*, and *Vachellia tortilis*. These plants were reported to be used for various purposes in the study area, such as forage, medicine, traditional cleansing, construction of houses or corrals, firewood, charcoal, farm and household implements, shade, rituals, and wild edible food. Seven randomly selected key informants (traditional healers) were asked to score each multipurpose plant based on its uses. The attributes considered were medicinal use, firewood, charcoal, construction, live fence, and fodder. Each key informant independently assigned scores ranging from 0 to 5 (where 0 = not used, 1 = less used, 2 = moderate, 3 = good, 4 = very good, and 5 = the best) for each medicinal plant in relation to its preferred uses. The scores given for each attribute and corresponding multipurpose plant species were summed up to obtain a total score for each plant. The seven multipurpose plant species were then ranked based on their respective total scores.

3 Results and Discussion

3.1 Demographic Feature of Informants

In this study, a total of informants participated. Among them, 72.54% were male, while 27.45% were female. The informants were categorized into three age groups for the collection of basic ethnobotanical data. Specifically, 7.84% were between 20 and 35 years old, 31.37% were between 36 and 55 years old, and 60.78% were above 55 years old (Table 2).

Table 2. Demographic profile of the informants

Demographic Attributes	Characteristics	Male	Female	Total	Percentage (%)
Sex:	Female	-	14	-	27.45
Sex:	Male	37		-	72.54
Age group:	20-35 years	4	-	4	7.84
	36-55 years	7	9	16	31.37
	Above 55 years	26	5	31	60.78
Literacy:	Illiterate	30	12	42	82.35
	Literate	7	2	9	17.64
Livelihood category:	Agropastoralist	4	2	6	11.76
	Pastoralist	33	12	45	88.24

3.2 Species Composition of Medicinal Plants

The family of plants that contains the greatest number of medicinal species in this research is Fabaceae, comprising eleven species. Following this, Solanaceae has four species, Euphorbiaceae has three species, and Anacardiaceae, Apocynaceae, Capparidaceae, Cucurbitaceae, and Tiliaceae each have two species. Furthermore, sixteen additional families are represented by a single species each (Table 3).

The ecological success of the Fabaceae family can potentially be attributed to its ability to form root nodules containing nitrogen-fixing bacteria, although it is important to note that not all Fabaceae species fix nitrogen. This finding aligns with the results of previous studies conducted by Hunde (2001), Teklehymanot & Gidey (2007), Amenu (2007), Tolosa (2007), Yineger & Yewhalaw (2007), and Tamene (2011), where the family Fabaceae also emerged as the predominant family of medicinal plants in their respective study areas.

Table 3. Plant families, number of medicinal plant species and proportions

Plant family	Species richness	Percentage	Plant family	Species richness	Percentage
Fabaceae	11	25.0	Ascelpiadaceae	1	2.3
Solanaceae	4	9.1	Asparagaceae	1	2.3
Euphorbiaceae	3	6.8	Asteraceae	1	2.3
Anacardiaceae	2	4.5	Balantaceae	1	2.3
Apocynaceae	2	4.5	Boraginaceae	1	2.3
Capparidaceae	2	4.5	Ebenaceae	1	2.3
Cucurbitaceae	2	4.5	Lamiaceae	1	2.3
Tiliaceae	2	4.5	Plumbaginaceae	1	2.3
Acanthaceae	1	2.3	Rutaceae	1	2.3
Aloaceae	1	2.3	Sapindaceae	1	2.3
Amaryllidaceae	1	2.3	Sapindaceae	1	2.3
Apiaceae	1	2.3	Vitaceae	1	2.3
Total	44	100.0	Total	44	100.0

Due to the remote characteristics of the study area and the limited availability of medical facilities, the pastoralists in this region significantly depend on traditional remedies (Dale *et al*., 2005). The medicinal plants identified in this study were used to treat 35 distinct human ailments (refer to Appendix). Since the community in the study area is composed of pastoralists, they do not grow medicinal plants in gardens. Rather, these medicinal plants are gathered from the wild. Given the nomadic lifestyle of the pastoralists, who migrate with their cattle in search of pasture and water, there is no tradition of cultivating medicinal plants in proximity to residential areas.

In the study area, of all the documented medicinal plant species, 47.7% were classified as shrubs, 29.6% as trees, 13.6% as herbs, and 9.1% as lianas (refer to Figure 2).

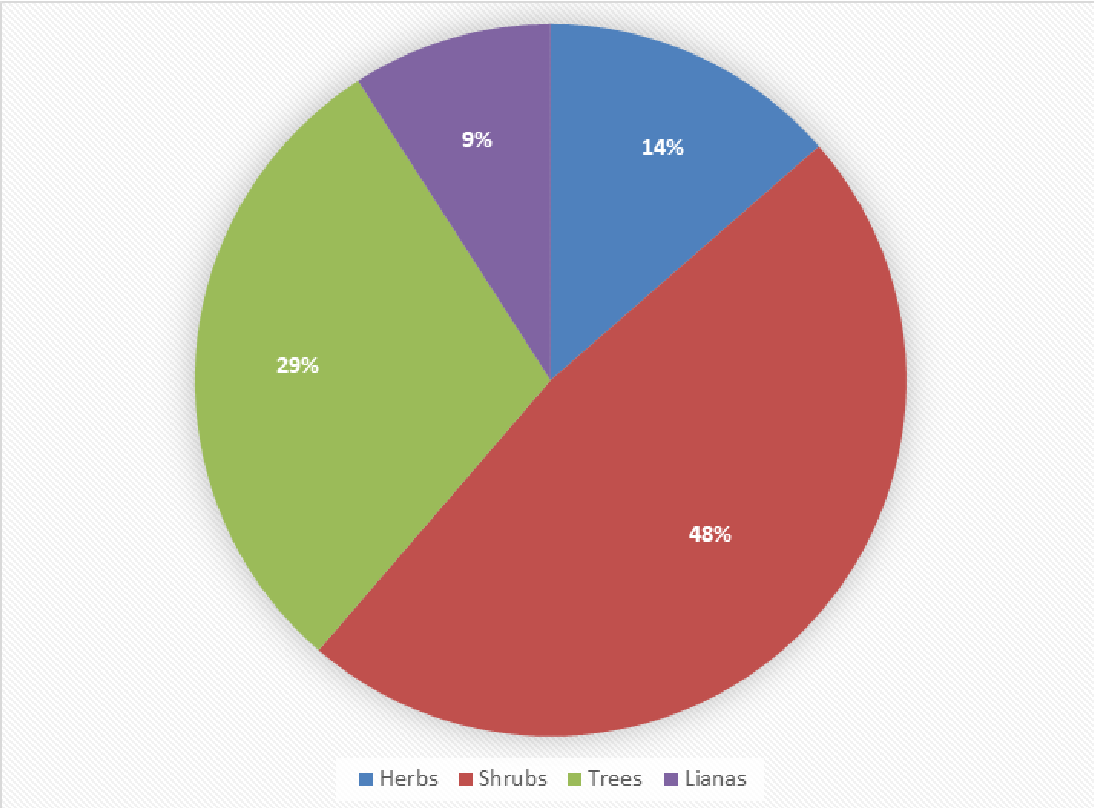

Figure 2. Proportion of growth forms of medicinal plants documented in the study area

Shrubby medicinal plant species were found to be prevalent in the study area and were frequently used due to their year-round availability. This finding is consistent with a study conducted by Hunde (2001) in Boosat District, where shrubs ranked first (at 59%), followed by herbs (14%). Similar findings were reported by Tamene (2000) in semi-wet lands of Cheffa area in South Wello, Tolasa (2007) in Gimbi District of western Wellega, Yineger & Yewhalaw (2007) in Sekoru District, and Tamene (2011) in Wondo-Genet Natural Forest and adjacent Kebeles, where shrubs were the most encountered forms of medicinal plants. Additionally, Bekele & Ramachandra (2015) identified the widespread utilization of shrubs for medicinal purposes in the Dugda-Dawa and Abaya District of Borana Zone. Their study reported that shrubs, trees, herbs, and climbers accounted for 45.2%, 26.7%, 18.5%, and 9.6% of the total medicinal plants, respectively. However, the findings of Gebre (2005) in Konso Special District of SNNPRS and Amenu (2007) in Ejaji of Chelia District in West Shewa differed from these findings, reporting that herbaceous plants were the most harvested for medicinal purposes. This disparity could be attributed to agroecological variations in these areas.

3.3 Medicinal Plant Parts Used for Remedy preparation

Among the medicinal plants documented, roots were widely used for the preparation of remedies, accounting for 47.7% of the total medicinal plants, followed by leaves (13.6%). Medicinal plants with barks being used accounted for 9.1%, while both roots and leaves were used in 9.1% of cases, and other plant parts accounted for 9.1% (Figure 3). These findings contrast with previous studies conducted by Abebe & Hagos (1991), Tamene (2000), Amenu (2007), Tolosa (2007), and Yineger & Yewhalaw (2007), which found that leaves were the most used plant parts for remedy preparations to treat health problems, followed by roots. The differences in the relative abundance of herbaceous and woody medicinal plants, which arise from agroecological variations and factors like grazing and encroachment, may play a role in these disparities. Nevertheless, it is crucial to recognize that the collection of plant components, including roots and barks, could adversely affect the survival and sustainability of medicinal plants within the study region.

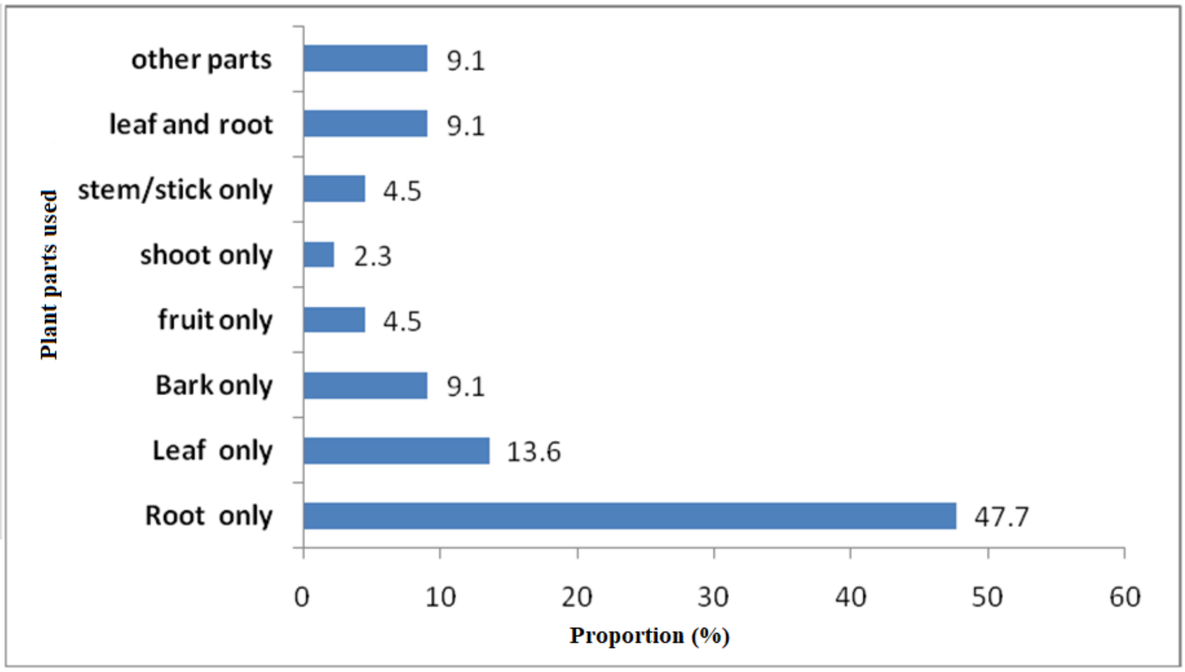

Figure 3. Medicinal plants parts used for preparation of remedies

3.4 Method of Preparation of Remedies

According to Dale *et al.* (2005), Borana pastoralists extensively utilize the available plant resources in their rangelands. It was observed that certain medicinal plants were used to prepare remedies for multiple diseases. The preparation of remedies from these medicinal plants can involve various methods. For example, a leaf of *Solanum giganteum* is rubbed to treat nasal bleeding, while decoctions from the same plant are used to treat the evil eye. Similarly, the latex at the shoot tip of *Croton macrostachyus* is used to treat *Tenea corporis*, while decoctions from the root of the same plant are used for rabies and snake bites, and the bark of *Croton macrostachyus* is utilized for intestinal parasites. In the current study area, decoction was found to be the most employed method for remedy preparation, accounting for 41.8% of the remedy preparation methods, followed by rubbing, juice extraction, and hot and cold infusions (Figure 4).

It is important to note that the methods of remedy preparation utilized by communities may vary from one place to another or from one district to another. For instance, previous studies conducted by Abebe & Hagos (1991), Tamene (2000), Yineger & Yewhalaw (2007), Amenu (2007), and Tolosa (2007) have reported that pounding and powdering, or crushing and squeezing, were the most used methods for remedy preparation.

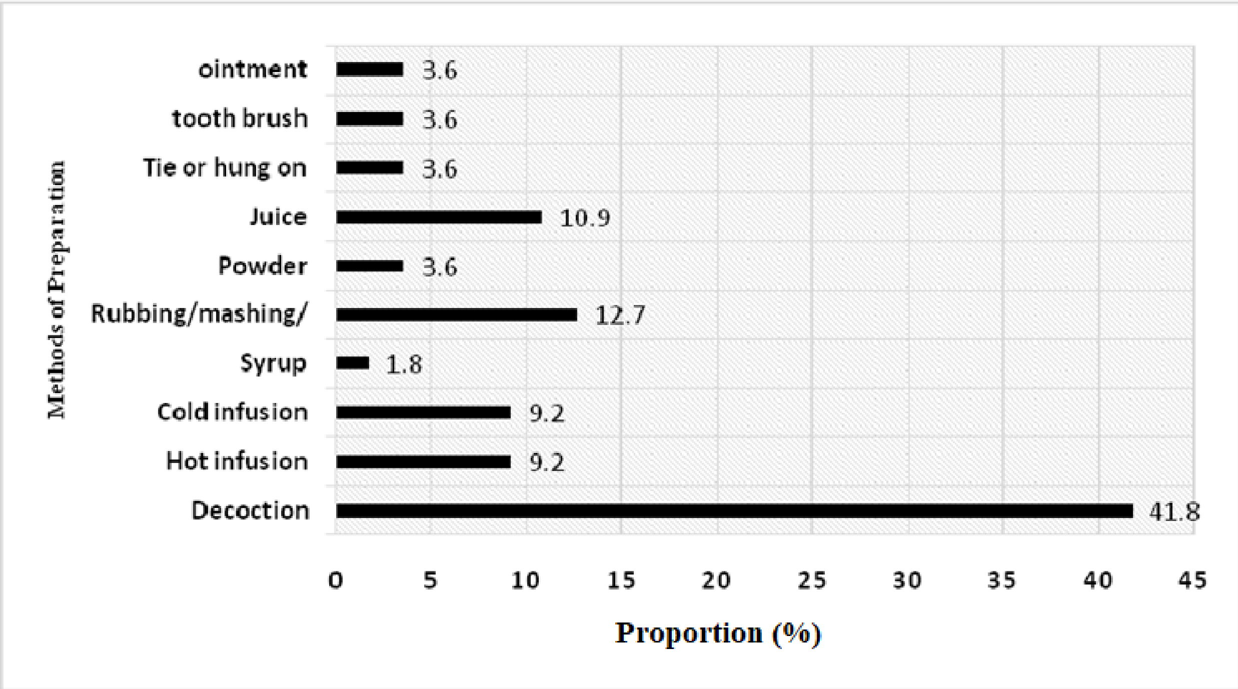

Figure 4. Modes of remedy preparations

In the study area, remedies were formulated using either a single medicinal plant or a mixture of various medicinal plant species. The analysis indicated that 88.46% of the remedies were derived from a single medicinal plant, whereas 11.54% were created from a combination of plants. This observation is consistent with the findings of Hunde (2001) and Tolasa (2007), which also reported a greater percentage of remedies being prepared from a single medicinal plant.

Borana pastoralists extensively utilized the available plant resources in their rangelands (Dale *et al*., 2005). Certain medicinal plants were found to be used for the preparation of remedies targeting multiple diseases. These remedies can be prepared using different methods. For example, the leaf of Solanum giganteum is rubbed to treat nasal bleeding, while decoctions from the same plant are used to address the evil eye. Similarly, the latex found at the shoot tip of Croton macrostachyus is used to treat Tenea corporis, whereas a decoction made from the root of the same plant is employed for the treatment of rabies and snake bites. Additionally, the bark of Croton macrostachyus is utilized for addressing intestinal parasites.

Regarding the forms in which medicinal plants were used, the majorities (77.27%) of the encountered plants in the study area were used in fresh form, while 22.73% were used both in fresh and dry conditions (Table 4). This reliance on fresh plant material limits the availability of medicinal plants during different seasons of the year. During the dry season, community members reported having to travel long distances in search of specific medicinal plants, as they were not readily available in the vicinity of their homes.

Table 4. List of medicinal plants in the study area used in fresh and both fresh & dry forms

Medicinal Plants used in fresh form	Medicinal plants used in both fresh and dry forms
Albizia anthelmintica (A. Rich.) Brongn.	*Acokanthera schimperi* (A.DC.) Schwevinf
Aloe secundiflora Engl.	*Boscia mossambicensis* Klotzsch.
Asparagus racemosus Wild.	*Carissa edulis* Vahl.
Balanites aegyptica (L.) Del.	*Croton dichogamus* Pax
Barleria spinesepala (Ait.) Benth.	*Croton macrostachyus* Del.
Bidens hildebrandtii O. Hoffm.	*Ehretia cymose* Honn.
Calpurnia aurea (Ait.) Benth.	*Euclea divinorum* Heirn
Capparis tomentosa Lam.	*Grewia tembensis* Fresen
Cissus quadrangularis L.	*Grewia villosa* Wild
Crinum abyssinicum Hochst. Ex A. Rich	*Zanthoxylum chalybeum* Engl.
Cucumis dipsaceus Ehrenb. ex Spach	
Dichrostachys cinerea (L) Wight et Arn.	
Euphorbia nubica NE.Br.	
Euphorbia schizacantha Pax.	
Gnidia stenophylla Gilg.	
Indigofera volkensii Taub.	
Kedrostis pseudogijef (Gilg.) C. Jiffrey	
Lanea revea (Chiov.) Sacleux	
Ocimum lamiifolium Hochst. Ex Benth	
Ormocarpum trichocarpum (Taub.) Engl	
Pappea capensis Eckl. & Zeyh.	
Plumbago zeylanica L.	
Searsia tenuinervis (Engl.) Moffett	
Senegalia brevispica (Harms) Seigler & Ebinger	
*Senegalia mellifer*a (Vahl) Seigler & Ebinger	
Solanum giganteum Jacq.	
Solanum incanum L.	
Solanum somalense Franchet	
Steganotaenia araliacea Hochst	
Sterculia stenocarpa H. Winkler	
Vachellia etbaica (Schweinf.) Kyal. & Boatwr.	
Vachellia nilotica (L.) P.J.H.Hurter & Mabb.	
Vachellia tortilis (Forssk.) Galasso & Banfi	
Withania somnifera (L.) Dunal	

3.5 Routes of Administration of Remedies

Internal routes of administration accounted for the highest proportion (59.7%) compared to external modes of administration (40.3%). Among the internal routes, oral application (53.73%) of remedies was relatively more common. Similarly, painting and washing (7.46% each) were relatively more prevalent among the external routes of administration (Table 5).

For remedies administered orally, it was observed that they were often consumed with milk tea, curdled milk, honey, salts, or 'Maqado' and sugar. These additional ingredients were used to mitigate the smell, discomfort, potency, and taste of the medicine.

Table 5. Modes of administrations/applications of remedies

Mode of use	Routs of application	Percentage (%)
Internal	Oral (solid, semi-solid, or liquid form)	53.73
	Inhale vapor of decoction, infusion, or smoke	5.97
External	Chewing & spitting on the affected body part	5.97
	Steam or vapor bath	5.97
	Poultice	2.99
	Hanging	2.99
	Compressing	2.99
	Painting or rubbing	7.46
	Washing	7.46
	Using the plant as a tooth brush	4.47

Remedies administered by traditional healers often lack precise measurements and standards for preparation and administration. Measurements are often estimated using terms such as hand full, pinch, finger length, or a number of leaves. Oral remedies are measured using units like 'kookii', 'nyaree', 'galasa', and 'Xaasaa' (cup, glass, tin). Furthermore, the administration and measurements can vary among different traditional healers. This finding is consistent with the studies conducted by Getahun (1976), Sofowora (1993), and Abebe (1986), which also highlighted the lack of precise measurements and standardization as a drawback in the traditional healthcare system.

Traditional healers believe that if a person is given an overdose of a remedy, consuming milk can counteract its effects. Additionally, adverse effects of traditional medicines can be mitigated or regulated by consuming milk or other additives such as honey, coffee, or tea. Similar results have been reported by Giday *et al*. (2009), Tamene (2000), and Amenu (2007). Abebe (1986) also identified the use of additive substances in the preparation of herbal remedies.

Informants mentioned that there are specific pre- or post-conditions that patients need to fulfill before or after taking certain remedies. Failure to meet these conditions can lead to severe adverse effects or even death. For instance, a patient using *Aloe secundiflora* should avoid consuming meat and milk until the treatment is completed, as it may have fatal effects. There are also situations where patients are advised not to look into water or a mirror, avoid washing or bathing, and expose themselves to the sun for specific periods of time continuously for seven to fourteen days while undergoing treatments for rabies. Similar practices have been reported by Amenu (2007) and Tolosa (2007).

Certain medicinal plants are well-known among community members, while others are kept secret and known only by traditional healers. For example, *Ocimum lamifolium*, *Solanum giganteum*, *Euphorbia schizacantha*, and *Croton macrostachyus* are commonly used at home by community members for preparing remedies to treat febrile illness, nasal bleeding, influenza (common cold), and ringworm, respectively. However, the treatment of other ailments such as evil eye, hemorrhoids, gonorrhea, ulcers, rabies, and snake bites is entrusted to traditional healers who specialize in preparing remedies based on the stage, complexity, and condition of the patients. Similar practices have been reported in the studies conducted by Tolosa (2007) and Tamene (2011). Therefore, depending on the nature or type of health problem, local people in the study area attempt to manage their health issues at home before seeking other options.

The diagnosis and treatment methods employed by traditional healers depend on the specific ailment. When a patient visits a local traditional healer, the practitioner typically conducts an interview and visually inspects the patient to identify the illness or health problem. The interview focuses on gathering information about the symptoms and the onset of the health problem. The practitioner then visually examines the patient's eyes, tongue, skin color, urine color, body temperature, and checks for sores or wounds before preparing and prescribes remedies.

According to the respondents, three main factors influence their choices for treatment when they fall ill. These factors include the ease of access to treatment, the perceived effectiveness of the treatment, and the cost associated with it. In terms of access, local healers are conveniently located within reachable distances from modern healthcare institutions in the locality.

In this community, there is a traditional rule of "pay once and be treated until you are cured" that is followed by traditional healers and their clients. This finding is consistent with the study conducted by Tolosa (2007). According to this rule, once payment is made for the treatment of a particular health problem, no further payment is requested by the traditional healer until the patient is cured. Clients typically present coffee beans and chewable tobacco ('Buna-fi-tambo') as a gift or payment after receiving treatment from a local healer. This gift is locally known as 'Darara.' After the patient recovers from their illness, it is customary for them to invite the healer to their home, hold a 'Bunaqala' ceremony, and receive blessings from the healer. In cases where a patient is unable to make a payment, they may offer a few blades of fresh grass to the healer as a sign of respect and acknowledgment of the treatment. This is known as 'Irressaa' in the local context. In some regions of the country, monetary payments are made instead. According to the informants, if the practice of 'Darara' is avoided, they believe that the curative value of the remedies will fail, and the disease may reappear in the patient.

3.6 Medicinal Plants Knowledge Transfer

According to the information obtained from the local administration in 3.6 of the study, it was found that there is a higher number of male traditional healers compared to female traditional healers in the study area. The transfer of medicinal plant knowledge and healing practices among traditional healers is typically passed down to a family member or a close relative. However, the choice of individuals for knowledge transfer is not the same among family or community members. In this context, parents (traditional healers) in the study area tend to prefer boys over girls for the transfer of medicinal plant knowledge. This preference is attributed to boys spending more time on farms and fields with their parents compared to girls. Consequently, boys have a better opportunity to learn about various medicinal plants in their locality while engaging in activities with traditional healers.

The informants have indicated that the transfer of medicinal plant knowledge to males holds greater importance compared to females. This belief stems from the assumption that there is a higher likelihood of losing medicinal plant knowledge within the community or village when females marry individuals from outside their community and relocate to other areas. However, there are exceptions where females in the community may have the chance to acquire medicinal plant knowledge from their healer parents and be entrusted to practice healing. This typically occurs when they are trusted by their parents to maintain secrecy about the knowledge and healing practices or when there are no boys in their family. This situation has contributed to a relatively higher number of male healers in the study area. Similar findings were reported by Tamene (2011) and Teklehaymanot & Giday (2006), who noted that traditional knowledge is primarily passed down from a parent to an elder son. Tamene (2011) also observed that female traditional healers tend to stay within proximity to their residence or village and do not frequently venture far in search of medicinal plants. Thus, the medicinal plant knowledge of female traditional healers is often limited to cultivated plants in their home gardens or those found in the vicinity of their homesteads.

Most traditional healers prefer not to impart knowledge about medicinal plants and healing practices to their family members at a young age. Instead, they select a trusted individual within the family whom they believe will maintain secrecy regarding medicinal plant knowledge and traditional healing practices. Training typically begins when the traditional healer is advanced in age and can no longer travel to search for medicinal plants in the field. The chosen individual is gradually trained by allowing them to search for and collect medicinal plants from the garden or field, but they are not initially allowed to perform healings.

A person who receives medicinal plant knowledge and healing practice from their healer parent is required to take a solemn oath (referred to as 'Kaku' locally) to keep all the acquired knowledge about medicinal plants and traditional medications confidential. Finally, the individual who is trained to become a healer receives blessings from their parent or transferrer, which empowers them to administer traditional medicines to patients in need, carrying the curative abilities inherited from their parent.

According to key informants, the transfer of knowledge regarding medicinal plants and traditional medicine in the study area faces challenges due to the lack of interest displayed by most youths in acquiring traditional medicine knowledge. It was mentioned that this disinterest among the younger generation may be attributed to the influence of Western religions, modern education, the proliferation of health centers, and the community's attitude towards modern medicine. These findings align with the works of Gebreegziabher (1991), Hunde (2001), Gebre (2005), and Tolosa (2007), who have reported that older individuals possess relatively more knowledge about medicinal plant use compared to younger members of the same community. This indicates a decline in traditional medicine knowledge, alongside the practice of secrecy. The diminished knowledge among younger community members may be linked to their lack of interest in traditional medicines, which can be attributed to the impact of modernization, including increased access to modern education and health services.

3.7 Preference Ranking

Among the medicinal plants used to treat snake bites in the study area, certain plants are more popular and preferred. According to the preference ranking results (Table 6), *Senegalia mellifera* holds the highest preference for treating snake bites. It is ranked first among the five medicinal plants used for this purpose in the area. Following *Senegalia mellifera*, *Dichrostachys cinerea* and *Senegalia brevispica* are ranked second and third, respectively, indicating their relatively high preference. On the other hand, *Kedrostis pseudogijef* and *Searsia tenuinervis* are ranked fourth and fifth, respectively, suggesting their lower preference compared to the other plants.

Not all medicinal plants contain the same content and concentration of chemical compounds or phytochemicals. The preference ranking of medicinal plants based on their efficiency reveals that traditional healers in the study area, drawing from their life experiences, have identified the most effective medicinal plants for addressing specific ailments.

Table 6. Preference ranking of medicinal plants used to treat snake bite

Factors	Informants							Total	Rank
	I1	I2	I3	I4	I5	I6	I7		
Senegalia brevispica	3	2	3	4	3	3	4	22	3^{rd}
Senegalia mellifera	5	5	4	2	5	5	5	31	1^{st}
Dichrostachys cinerea	4	4	5	5	4	4	3	30	2^{nd}
Kedrostis pseudogijef	1	1	0	3	4	2	1	12	4^{th}
Searsia tenuinervis	2	3	1	1	0	0	2	9	5^{th}

Note: I = Informant

3.8 Direct Matrix Ranking

Despite their medicinal value, several medicinal plants in the study area have been reported to serve multiple purposes beyond medicine. These include forage, traditional cleansing, construction of houses and corrals, firewood, charcoal, farm or household implements, shade, rituals, and as a source of edible wild plants (Author *et al.*, 2021). Based on the direct matrix ranking, *Lanea rivae*, *Vachellia tortilis*, and *Grewia villosa* emerged as the top three preferred medicinal plant species due to their diverse range of uses (Table 7). Conversely, *Vachellia nilotica* received the lowest score and was ranked last, indicating its relatively lower preference compared to other multipurpose plants listed in the table. In terms of total scores in the direct matrix (Table 7), these multipurpose medicinal plants were primarily favored for their forage value, followed by their use in house and corral construction, and as a source of medicine (Author *et al.*, 2021).

As noted by Dale *et al.* (2005), the Borana pastoralists make extensive use of the plant resources found in their rangelands, with almost fifty percent of the plant species in Borana being utilized for various purposes, akin to other regions within the country. Although the primary use category for many indigenous rural communities is medicinal value (Coe & Anderson, 1999), it is considered second in significance for the community in the area under study. The local population demonstrates a significant reliance on plant resources for forage, which reflects the dominant livestock production system in the region. This observation is consistent with the findings reported by Dale *et al.* (2005).

Table 7. Direct Matrix ranking of seven selected medicinal plants

Multipurpose plants	Forage	Medicine	Traditional cleansing	House/Corrals construction	Firewood	Charcoal	Farm/House implements	Shade tree	Ritual	Wild edible	Total Score	Rank
Boscia mossambicensis	21	16	17	24	10	10	6	30	35	0	169	6^{th}
Grewia tembensis	31	21	0	21	28	20	22	0	0	30	173	5^{th}
Grewia villosa	28	35	0	28	17	4	21	0	30	20	183	3^{rd}
Lanea rivae	35	30	35	26	13	0	27	0	20	19	205	1^{st}
Pappea capensis	35	28	0	12	35	12	23	0	0	32	177	4^{th}
Vachellia nilotica	12	13	0	35	15	35	24	28	0	0	162	7^{th}
Vachellia tortilis	22	17	13	35	19	35	20	35	0	0	196	2^{nd}
Total Score	184	160	65	181	137	116	143	93	85	101		
Rank	1^{st}	3^{rd}	10^{th}	2^{nd}	5^{th}	6^{th}	4^{th}	8^{th}	9^{th}	7^{th}		

3.9 Threats to Medicinal Plants and Associated Knowledge

Herbal remedies hold significant importance for the rural population in Ethiopia, as modern medications are often inaccessible or prohibitively expensive. Abebe (1996) indicated that nearly 80% of Ethiopians depend on traditional herbal remedies, a fact that is also applicable to the pastoralist community within the current study area. Traditional healers in this region have voiced their concerns regarding the gradual reduction of some of the most valuable medicinal plants. There have been minimal efforts directed towards the conservation of these medicinal plants in the study area, as noted by key informants and through personal observations. Factors induced by human activity, along with extended dry seasons, threaten the survival of medicinal plant species. Major threats to these plants in the area include livestock grazing, bush encroachment, wood cutting for construction, charcoal production, and firewood collection. Among these threats, livestock grazing and charcoal production were identified as the most severe, ranking first and second, respectively, as shown in Table 8.

The prevalence of woody medicinal plants (shrubs and trees) in the study area, compared to herbaceous species, suggests that herbs are more vulnerable to various hazards such as livestock grazing, trampling of seedlings, climate change, and encroachment. Traditional healers in the area employ several methods, such as crushing and storing powdered forms of medicinal plants, to preserve the ingredients when they are unable to obtain fresh plants during the dry season. This finding is consistent with the research conducted by Duguma & Mesele (2019). Moreover, cultural beliefs and traditional practices in the study area may have an impact on medicinal plants, as well as the associated local knowledge and practices.

Key informants have revealed that medicinal plant knowledge and associated practices are often kept secret by traditional healers, with the information being shared only among practitioners. Traditional healers refrain from disclosing the names of medicinal plants or showing the actual plants to patients, believing that the effectiveness of traditional remedies would diminish if patients were aware of the plant sources. In some cases, traditional healers assign names to medicinal plants by adding the prefix "Qorsa" to the name of the corresponding illness, aiding in their identification. For example, a plant used to treat Mich is named "Qorsa Michi," signifying the medicine for Mich.

Lack of conservation efforts for ethnomedicinal plant species, despite their perceived importance, has also been highlighted by traditional healers in the study area.

Table 8. Factors threatening medicinal plant

Factors	Informants						Total	Rank
	I1	I2	I3	I4	I5	I6		
Charcoal production	5	7	6	7	6	7	38	2^{nd}
Cultural taboo	2	1	2	1	1	1	8	6^{th}
Firewood collection	4	5	5	4	2	3	23	4^{th}
House construction	6	4	4	5	3	4	26	3^{rd}
Livestock grazing	7	6	7	6	7	6	39	1^{st}
Over utilization	3	3	3	3	5	5	22	5^{th}

Note: I = Informant

4 Conclusion

The pastoral community of Arero District possesses a rich indigenous knowledge of medicinal plants and traditional medicine, which they rely on to address a wide range of ailments. Despite the availability of modern medicine, traditional medicine remains highly valued due to its affordability, accessibility, therapeutic efficacy, and cultural significance. Traditional healers play a crucial role in simplifying healthcare complexities within the community. However, the lack of standardized dosing of remedies should be addressed, as it may pose risks to patients' health, potentially leading to fatal outcomes.

The knowledge of medicinal plants is primarily limited to traditional healers and a few elderly individuals within the community. The secretive nature of medicinal plant knowledge, coupled with gender biases and a lack of motivation, poses a threat to the preservation of local medicinal plant knowledge and practices in the study area. Without appropriate interventions, there is a risk of losing this valuable knowledge in the near future, exacerbated by the oral transmission of knowledge. It is important to recognize that medicinal plants not only serve as a source of traditional medicine but also hold potential for the development of new drugs. However, numerous medicinal plant species are reported to be under threat from factors such as encroachment, climate change, overharvesting, fire, and overgrazing. Traditional healers in the study area have also acknowledged their limited involvement in conservation activities for medicinal plants in their surroundings. To ensure sustainable management of the pastoral system and improve healthcare within the pastoralist community, development programs should prioritize the sustainable use and conservation of plant resources, with a specific focus on medicinal plants.

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Conflict of Interest

The authors declare no conflict of interest.

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Annex

List of medicinal plant species encountered in the study area, growth form, and use (S = Shrub, T = Tree, H = Herb, C = Climber, WC = Woody Climber)

Scientific name	Vernacular name	Plant family	Growth form	Plant parts used	Ailments treated	Application
Acokanthera schimperi (A.DC.) Schwevinf	Qaraaruu	Apocynaceae	T	Root & Stem	Rabies	Taking an extract/juice of the plant orally.
Albizia anthelmintica (A. Rich.) Brongn.	Awaachoo	Fabaceae	S	Root	Liver disease, Impotence, & Gonorrhea	Washing body with its decoction, inhaling the vapor, and drinking a cup of it daily for 3-7 days.
Aloe secundiflora Engl.	Hargeessa	Aloaceae	S	Leaf & Root	Rabies, Sinus, Common cold, Eye disease, & Cancer	Ingesting hot infusion mixed with *Panicum ruspolii* bark for 3-7 days to treat Rabis; ingesting cold infusion & placing few drops of its latex on the head to treat Sinus Common cold, & Eye disease; & ingesting decoction with *Croton macrostachyus* bark for 7 days to treat Cancer.
Asparagus racemosus Wild.	Sariitii	Asparagaceae	C	Leaf	Skin burns	Rubbing leaf and mounting on a burned area.
Balanites aegyptica (L.) Del.	Baddanalu'oo	Balantiaceae	T/S	Root	Torn removal and torn wound	Chewing/mashing and mounting on a wound.
Barleria spinesepala (Ait.) Benth.	Qilxiphee	Acanthaceae	H	Root	Prolonged diarrhea and vomiting	Taking the decoctions with yoghurt or curdled milk.
Bidens hildebrandtii O. Hoffm.	Abunee	Asteraceae	S	Root & Leaf	Common cold & Skin infection	Ingesting decoction orally to treat Common cold; and washing an infected body parts with cold infusion for 3 days to treat Skin infection.
Boscia mossambicensis Klotzsch.	Qalqacha	Capparidaceae	T	Bark	Hemorrhoid & Evil eye	Ingesting decoction with juice from *Solanum incanum* root to treat Hemorrhoid; & ingesting tea made from the powder to treat Evil eye.
Calpurnia aurea (Ait.) Benth.	Ceekataa	Fabaceae	S	Leaf	Ecto-parasites (ticks, mites, bedbugs, fleas)	Washing cloths & beds with the cold infusion mixed with salt.
Capparis tomentosa Lam.	OgooraGaalaa	Capparidaceae	S	Root	Skin rush and body pain	Inhaling hot infusion vapor, washing infested body part with it, and drinking small amount.
Carissa edulis Vahl.	Dhagamsa	Apocynaceae	S	Root	Glandular swelling, Headache, & Toothache	Ingesting decoction daily for 7 days to treat Glandular swelling & Headache; and putting hot/boiled root on tooth during the tooth pain.
Cissus quadrangularis L.	Cophiisoodduu	Vitaceae	WC	Root	Hemorrhoids	Ingesting decoction orally.
Crinum abyssinicum Hochst. Ex A. Rich	Butewarabesaa	Amaryllidaceae	H	Root	Rabies	Taking a cupful of cold infusion, that was left for 2-3 days, daily for 7 to 14 days.
Croton dichogamus Pax	Mookofa	Euphorbiaceae	S	Root	Common cold; Allergy	Taking a hot infusion mixed with milk.
Croton macrostachyus Del.	Makkaniisa	Fabaceae	T	Shoot, Root, & Bark	Rabies; Snake bite, Intestinal parasites including *Tenea corporis*, & Cancer	Rubbing a sap on infected body part until recovery to treat Rabies & Snake bite; and taking decoction orally for 3-7 days to treat *Tenea corporis*, other intestinal parasites, & Cancer.
Cucumis dipsaceus Ehrenb. *ex* Spach	Buratee	Cucurbitaceae	C	Fruit	Stomachache & Breast ache	Ingest decoction to treat Stomachache; & heating the fruits & painting the hot sap on the injured breast to treat Breast-ache.
Dichrostachys cinerea (L) Wight et Arn.	Jirimee	Fabaceae	S	Leaf & Root	Wound	Washing the wounded part of the body with a hot infusion
Ehretia cymose Honn.	Ulaagaa	Boraginaceae	S	Root	Liver disease	Inhaling decoction vapor, wash the body with its water, & drink some amount for 5-7 days.
Euclea divinorum Heirn	Mi'eessaa	Ebenaceae	T/S	Root	Mitch	Taking droplets of water diluted powder orally.
Euphorbia nubica NE.Br.	Aannoo	Euphorbiaceae	S	Root, Shoot, & Bark	Rabies, Stomachache, Menstruation irregularity, Gonorrhea, & Common cold	Ingesting decoction mixed with milk to treat these health problems.

Scientific name	Vernacular name	Plant family	Growth form	Plant parts used	Ailments treated	Application
Euphorbia schizacantha Pax.	Harkeena	Euphorbiaceae	S	Root	Gonorrhea & Common cold	Taking the decoction mixed with milk for 3 days.
Gnidia stenophylla Gilg.	Aarsaa	Ascelpiadaceae	H	Root	Gonorrhea	Drinking a cup of decoction every morning for 7-14 days.
Grewia tembensis Fresen	Dheekkaa	Tiliaceae	S	Stem	Magic; Evil spirit	Brushing teeth with stick of the plant when needed
Grewia villosa Wild	Ogomdii	Tiliaceae	S	Root	Snake bite	Taking cold infusions orally every day till recovery.
Indigofera volkensii Taub.	Gurbiihoolaa	Fabaceae	H	Leaf	Bleeding due to cut of body part	Mounting mashed leaves on the injured body part.
Kedrostis pseudogijef (Gilg.) C. Jiffrey	Gaaleeadii	Cucurbitaceae	C	Stem	Snake bite	Applying the exudates on the affected body part for 3 days.
Lanea revea (Chiov.) Sacleux	Handaraka	Anacardiaceae	T	Bark	Abdominal Pain	Taking the juice extract during the pain.
Ocimum lamiifolium Hochst. Ex Benth	Hancabbii	Lamiaceae	H	Leaf	Fibril illness	Applying cold infusion on body or drink with coffee until recovery.
Ormocarpum trichocarpum (Taub.) Engl	Buutiyyee	Fabaceae	T	Root	Intestinal parasite & Ulcerated wound	Taking 1-2 water cups of the decoction orally before having a breakfast for 3 days to treat Intestinal parasite; and applying a chewed root on wound for 3 days to treat Ulcerated wound.
Pappea capensis Eckl. & Zeyh.	Biiqqaa	Sapindaceae	T	Bark	Rabies & Snake bite	Taking hot infusion orally.
Plumbago zeylanica L.	Igaaji	Plumbaginaceae	H	Shoot	Glandular swelling	Mounting mashed leaf on swelled part or wound for 2 days in 2–3-days gap.
Searsia tenuinervis (Engl.) Moffett	Daboobessa	Anacardiaceae	S	Leaf	Skin allergy	Applying juice on infected area at night before bed.
Senegalia brevispica (Harms) Seigler & Ebinger	Hammareessa	Fabaceae	T	Root	Epilepsy	Applying 2-3 drops of extract/juice through nose
Senegalia mellifera (Vahl) Seigler & Ebinger	Saphansagurracha	Fabaceae	S	Root	Snake bite	Chewing & spitting juice/extract on an infected body part
Solanum giganteum Jacq.	Hiddiiloonii	Solanaceae	S	Leaf & Root	'*Dingetegna*', Nasal bleeding, & Evil eye	Rubbing and smelling leaf immediately to treat '*Dingetegna*' & Nasal bleeding; and taking a tea cupful of decoction of root with milk orally twice a day for Evil eye.
Solanum incanum L.	Hiddiiwaatoo	Solanaceae	S	Root	Evil eye & Hemorrhoids	Ingesting decoction with milk twice a day for Evil eye; and taking decoction orally every morning until recovery to treat Hemorrhoids.
Solanum somalense Franchet	Hiddiigaagee	Solanaceae	S	Root	Cancer appearing on an external body part	Applying powder on the affected body part.
Steganotaenia araliacea Hochst	Luqaaluqqee	Apiaceae	T	Root	Menstruation problem (Irregularity)	Mixing 2-3 glasses of decoction with sheep butter ('*dhadhahoola*') and taking orally every morning for up to 3-7 days.
Sterculia stenocarpa H. Winkler	Qararrii	Sterculiaceae	T	Bark	Nasal bleeding	Tying the bark on head.
Vachellia etbaica (Schweinf.) Kyal. & Boatwr	. Alqabeessa	Fabaceae	T	Bark	Nasal bleeding	Tying a bark of the plant on head during bleeding.
Vachellia nilotica (L.) P.J.H. Hurter & Mabb.	Burquqqee	Fabaceae	T	Fruit	Sinus & Ulcerated wound	Ingesting decoction to treat Sinus; & spiting the juice on a ulcerated wound every morning, before breakfast, for 3 days.
Vachellia tortilis (Forssk.) Galasso & Banfi	Dhadacha	Fabaceae	T	Seed & Latex	Urine retention problem & Asthma	Ingesting decoction of fresh seeds boiled with *Sansevieria ehrenbergii* to treat the Urine retention problem & Asthma.
Withania somnifera (L.) Dunal	Hiddiixirooftuu	Solanaceae	S	Root	Evil eye	Feeding milk mixed cold infusion to infants.
Zanthoxylum chalybeum Engl.	Gaddaa	Rutaceae	T	Leaf & Root	Asthma magic	Taking 1-2 cups of syrup orally & brushing teeth with it.