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Analyzing the impact of macroeconomic variables on deforestation in Somalia: evidence from an ARDL model

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ABSTRACT
Somalia, a country challenged by ongoing conflict and economic instability, faces significant environmental degradation, particularly deforestation. This study investigates the effects of key macroeconomic variables, economic growth, population growth, and inflation, on deforestation from 1993 to 2021. Using the Autoregressive Distributed Lag (ARDL) model, the analysis explores both short- and long-term relationships. Stationarity of variables was tested through ADF, PP, and Zivot-Andrews unit root tests, while diagnostic tests ensured the robustness of the model. The results confirm the Environmental Kuznets Curve (EKC) hypothesis, indicating that economic growth initially intensifies deforestation but later contributes to its decline after a critical GDP level. Population growth is found to significantly drive deforestation in the long run, whereas inflation shows no notable impact. These findings underscore the need for policies that foster sustainable economic growth, manage population pressures, and conserve natural resources. The study recommends integrated strategies, including community-based initiatives and regulatory reforms, to promote environmental sustainability in Somalia.

IMPACT STATEMENT
This study analyzes the relationship between macroeconomic factors economic growth, population growth, and inflation and deforestation in Somalia using an ARDL approach. By confirming the Environmental Kuznets Curve hypothesis, the research provides new insights into how economic development initially accelerates but eventually mitigates environmental degradation. The findings offer valuable guidance for policymakers in designing strategies that balance economic growth with environmental sustainability, particularly in conflict-affected and developing regions like Somalia.

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1. Introduction

Somalia, a country characterized by prolonged conflict, economic instability, and fragile ecosystems, presents a unique case study for examining the influence of economic factors on environmental degradation, particularly deforestation. The need to understand this dynamic is crucial as Somalia's environment faces increasing pressures from various socio-economic factors, including economic growth, population expansion, and inflation. The relationship between economic activities and environmental sustainability, especially in developing countries, has garnered increasing attention in recent research.

In light of Somalia's distinct socio-economic and environmental challenges, it presents a unique context for examining the factors driving deforestation. Over the past decades, Somalia has experienced significant forest degradation, driven by a combination of factors, including rapid population growth, economic volatility, and limited environmental governance. The consequences of deforestation, such as desertification, loss of biodiversity, and reduced agricultural productivity, pose severe threats to the country's sustainability. Furthermore, Somalia's dependency on forest resources for fuelwood and livelihoods exacerbates these environmental issues. Therefore, Somalia serves as an important case study to

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explore how macroeconomic factors, such as economic growth, population expansion, and inflation, influence deforestation in a fragile state.

Somalia's environmental challenges have been significantly exacerbated by its socio-political instability, which has persisted for over three decades. This instability has not only hampered economic development but has also led to unsustainable exploitation of natural resources, particularly forests (Mohamoud & Hussein, 2021). The issue of deforestation in Somalia is critical, as it results in the deterioration of ecosystems, a decrease in biodiversity, and an aggravation of climate change effects. (Abdi, 2021). Despite the critical nature of these issues, there is a limited understanding of how economic growth, population expansion, and inflation contribute to deforestation in this context (Ismail & Osman, 2022).

The Environmental Kuznets Curve (EKC) theory proposes that while economic growth initially leads to increased environmental damage, it eventually leads to improvements in environmental quality once a certain level of income is achieved (Grossman & Krueger, 1995). However, in the context of Somalia, where economic growth is often unsustainable and driven by the exploitation of natural resources, this relationship may not hold (Barbier, 2004). Previous studies have shown that in low-income countries, economic growth often leads to increased deforestation as forests are cleared for agriculture, infrastructure development, and fuelwood extraction (Bhattarai & Hammig, 2001). This study aims to test this hypothesis in the Somali context, examining whether economic growth continues to exacerbate deforestation or if there are mitigating factors at play.

While the general EKC hypothesis has been widely discussed, the specific application of this theory to deforestation, known as the Environmental Kuznets Curve for Deforestation (EKCd), is equally important in understanding the relationship between economic growth and deforestation. The EKCd posits that, in the early stages of economic development, deforestation tends to increase as industrialization, agricultural expansion, and urbanization put pressure on forest resources. However, as countries reach higher levels of economic development, deforestation may begin to slow down or even reverse. This is often attributed to factors such as the adoption of sustainable agricultural practices, the introduction of environmental policies, and improved technological solutions that reduce the reliance on forest resources. Given the unique socio-political and environmental context of Somalia, this study will explore whether the EKCd hypothesis holds, or if the country's ongoing conflict and resource dependency have led to an exacerbation of deforestation despite economic growth.

Additionally, a newer hypothesis known as the Load Capacity Curve for deforestation (LCCd) is gaining attention. The LCCd hypothesis, an extension of the Load Capacity Curve (LCC), emphasizes the limits of ecosystems' ability to sustain deforestation without crossing thresholds that lead to irreversible environmental damage. This concept offers valuable insights into how socio-economic and environmental pressures interact to determine sustainable resource use. By incorporating these frameworks, this study contextualizes Somalia's deforestation within broader theoretical discourses.

In addition to economic growth, population growth is another critical factor in Somalia's deforestation crisis. High population growth rates, coupled with displacement due to conflict and natural disasters, increase demand for land, energy, and food. These factors drive land conversion and overuse of forest resources (Hansen et al., 2021). With one of the highest population growth rates globally, Somalia is particularly vulnerable to the negative effects of demographic pressures on its environment (Somalia, 2022). This research examines how population expansion over the past three decades has influenced deforestation in Somalia, providing valuable insights for future development and environmental policies.

Through the use of advanced econometric techniques, including the Autoregressive Distributed Lag (ARDL) model, this research provides a comprehensive analysis of the long-term and short-term effects of economic growth, population growth, and inflation on deforestation in Somalia. By offering targeted policy recommendations, this study contributes to the global discourse on sustainable development and environmental protection (Nkengfack et al., 2021; Shiferaw et al., 2021). The findings are expected to inform policymakers, environmentalists, and development practitioners on how to effectively manage the complex interaction between economic pressures and environmental sustainability in fragile contexts such as Somalia (Usman & Balsalobre-Lorente, 2022).

Understanding the dynamics of deforestation in Somalia is crucial for both academic inquiry and policy formulation. From an academic perspective, this research bridges a gap in the existing literature by focusing on a conflict-affected and environmentally vulnerable state. From a policy standpoint, the findings offer valuable guidance for designing targeted interventions to mitigate deforestation, enhance resilience against climate change, and promote sustainable development in Somalia. This study emphasizes the importance of integrating economic and environmental strategies to address deforestation effectively.

This study aims to investigate the impact of economic growth, population expansion, and inflation on deforestation in Somalia between 1993 and 2021. By employing the ARDL methodology, the research seeks to provide empirical evidence on the short- and long-term relationships between these variables and forest degradation. The study contributes to the limited body of literature on deforestation in fragile states, offering a nuanced understanding of the economic and demographic drivers of environmental change. It also provides actionable insights for policymakers to address deforestation sustainably in Somalia.

1.1. Research objectives

The primary objective of this research is to conduct a comprehensive analysis of the multifaceted factors contributing to deforestation in Somalia, with a particular focus on the roles of economic growth, population expansion, and inflation. Specifically, this study seeks to assess the impact of economic growth on deforestation, exploring whether increased economic activity exacerbates environmental degradation or if it offers opportunities for sustainable development. Additionally, the research aims to analyze the influence of population expansion, considering how rising demographic pressures are accelerating the conversion of forested areas into agricultural and residential land. Furthermore, the study examines the effect of inflation on deforestation, investigating how economic instability drives communities to exploit natural resources unsustainably. By employing advanced econometric models, this research aspires to provide robust, evidence-based policy recommendations that can guide the sustainable management of Somalia's natural resources, balancing economic development with environmental conservation on an international scale.

1.2. Theoretical framework

This study adopts a multifaceted theoretical framework to examine the dynamics of deforestation in Somalia. The framework is built upon the relationships between three key variables economic growth, population growth, and inflation, and their theoretical influence on deforestation processes in Somalia. Each variable is explored through relevant economic and environmental theories, providing a basis for understanding their impact on deforestation in the context of Somalia's socio-economic and political environment.

1.2.1. Economic growth and deforestation

The study draws upon the EKC hypothesis to explore the relationship between economic growth and environmental degradation. According to the EKC, economic growth initially leads to an increase in environmental degradation, including deforestation, due to increased demand for natural resources and industrialization. However, as countries reach higher income levels, they may shift towards cleaner technologies, stricter environmental regulations, and more sustainable land-use practices, leading to a reduction in environmental damage. This framework is applied to Somalia, where the interaction between economic growth and environmental sustainability is complicated by factors such as ongoing conflict, limited infrastructure, and reliance on natural resources. The study aims to assess whether Somalia's economic growth follows the traditional EKC pattern or whether other socio-political factors hinder the possibility of such a reversal, leading to a continued cycle of deforestation.

1.2.2. Population growth and deforestation

Demographic theories link population growth to environmental pressures, with increasing population densities exacerbating deforestation through greater demand for land and resources. In the case of Somalia, rapid population growth places intense pressure on the country's fragile ecosystems, as more land is cleared for agriculture, housing, and energy needs. Additionally, population growth leads to greater demand for fuelwood, which is a primary energy source in rural areas. This heightened demand for resources accelerates deforestation, as forests are cleared to meet the needs of a growing population. The theoretical connection between population growth and deforestation emphasizes the challenges Somalia faces in managing both population growth and environmental sustainability. This study investigates how increasing population size may push Somalia's forest ecosystems beyond their capacity to regenerate, leading to irreversible deforestation.

1.2.3. Inflation and deforestation

Inflation, often overlooked in environmental research, plays a crucial role in shaping deforestation dynamics. The theory of inflationary pressures suggests that as inflation increases, the cost of living rises, which often leads to increased exploitation of natural resources. In Somalia, high inflation rates can exacerbate poverty, driving households to depend more heavily on the environment for fuelwood, charcoal, and other resources. Inflation can also distort economic incentives, making it more difficult for individuals and communities to adopt sustainable practices due to the rising costs of alternatives. For example, in the face of high inflation, communities may clear more forests to generate income from timber or charcoal production. Thus, inflation can intensify deforestation by pushing individuals to exploit natural resources as a means of survival. This framework integrates inflation as a critical economic variable that affects deforestation, especially in regions with weak governance and limited access to alternative livelihoods.

1.2.4. Integrating economic and demographic drivers

This theoretical framework underscores the complex interactions between economic growth, population growth, and inflation in driving deforestation. In Somalia, these factors are intertwined with political instability, conflict, and economic underdevelopment, creating a unique context for deforestation. The study aims to provide a comprehensive understanding of how these variables collectively contribute to environmental degradation and how policies could address the underlying drivers of deforestation in Somalia.

2. Literature review

2.1. Introduction

Deforestation is a pervasive global challenge, deeply intertwined with economic, demographic, and environmental factors. Studies have consistently highlighted its adverse effects on biodiversity, climate stability, and socio-economic systems. In Somalia, the deforestation crisis is exacerbated by decades of conflict, economic instability, and dependence on natural resources, underscoring the urgent need for context-specific research. This chapter reviews relevant literature, focusing on the relationship between economic growth, population expansion, inflation, and deforestation, while identifying gaps in current research and linking findings to Somalia's unique socio-economic and environmental context.

2.2. Overview of deforestation studies

Global deforestation studies reveal that the primary drivers include agricultural expansion, logging, and urbanization. Research in Sub-Saharan Africa has shown that unsustainable practices and weak governance accelerate forest loss, with severe consequences for livelihoods and ecosystems. For instance, Njora and Yılmaz (2022) investigated the effects of deforestation on the environment and agriculture in Kenya, highlighting how agricultural activities, population growth, and poor governance contribute to forest loss. The study emphasizes the negative impacts of deforestation, including climate change, water loss, decreased biodiversity, and habitat destruction. Leblois et al. (2017) identified agricultural trade as a key driver of deforestation in developing countries, with its impact varying based on a country's forest cover. Their findings highlight the challenges of balancing economic development with forest conservation, particularly in nations reliant on agricultural exports. Villoria et al. (2014) explored the effects of agricultural technological progress on deforestation, noting its potential to either mitigate or exacerbate forest loss depending on regional contexts. Hosonuma et al. (2012) identified agriculture and fuelwood harvesting as key contributors to deforestation in developing regions.

2.3. Economic growth and deforestation

Several studies have explored the complex relationship between economic growth and deforestation, with conflicting results based on geographic context, the stage of economic development, and policy interventions. Early research often suggested a direct link between economic growth and increased deforestation, driven by the expansion of agricultural activities, infrastructure development, and the exploitation of natural resources. For instance, Barbier (2003) explores the relationship between economic growth and agricultural land expansion in Latin America, focusing on the role of resource booms in driving economic development and the cyclical nature of this growth. The relationship between economic growth and deforestation in Brazil has been explored in recent studies, including the work by De Barros (2021). This study examines the EKC for deforestation, revealing an inverted U-shaped relationship, where deforestation increases up to a certain threshold of economic growth, after which it begins to decline. The findings also highlight the importance of spatial spillovers and heterogeneity, indicating that factors such as soil suitability and trade openness play significant roles in the deforestation process. Ajanaku and Collins (2021) examine the relationship between economic growth and deforestation in Africa, testing the EKC hypothesis. Their empirical results confirm the validity of the EKC for deforestation in Africa, with a turning point at US $3000, suggesting that deforestation increases up to a certain economic threshold before it begins to decline.

2.4. Load capacity curve for deforestation (LCCd) hypothesis

The concept of LCC has been widely applied in ecological studies to understand how natural systems can absorb environmental pressures before reaching a critical tipping point. The LCCd hypothesis builds on this foundational concept, proposing that ecosystems, particularly forests, have a finite capacity to withstand deforestation pressures before environmental degradation becomes irreversible. This concept offers a significant contrast to the EKCd, which implies that as nations develop economically, deforestation rates may initially rise but eventually decline as wealth leads to better environmental governance, cleaner technologies, and sustainable practices.

Previous studies have applied the LCCd to analyze various factors influencing deforestation. For example, Ayad et al. (2024) used the LCCd to investigate deforestation in Brazilian forests from 1970 to 2019, revealing the significant effects of population growth, energy consumption, and trade openness on forest sustainability. Their results affirm the relevance of the LCCd in understanding forest biocapacity and shaping effective environmental policies. Ayad and Djedaiet (2024) employed the LCC to evaluate environmental issues in G7 nations from 1980 to 2021, confirming its relevance in understanding the U-shaped relationship between GDP and ecological sustainability. Their study highlights the importance of LCC as a robust ecological indicator in policy-oriented research. Ayad and Lefilef (2024) explored the Fishing Grounds Load Capacity Curve (FGLCC) hypothesis in the context of China's marine ecosystem from 1980 to 2019, confirming a nonlinear relationship between economic growth and marine environmental conditions. Their study highlights the necessity of sustainable policies to mitigate environmental degradation. Pata and Tanriover (2023) investigated the LCC hypothesis for the top ten tourism destinations but found it invalid, highlighting the need for eco-friendly tourism to enhance environmental sustainability. Huang et al. (2023) analyzed the LCC hypothesis in India and identified an N-shaped relationship between eco-friendly technology and environmental degradation from 1975 to 2021.

2.5. Gaps in existing research

Several gaps emerge from the review of existing literature:

Limited Focus on Somalia: Most deforestation studies concentrate on global or regional trends, with few addressing Somalia's unique socio-economic and environmental context.

Underexplored Role of Inflation: While economic growth and population dynamics are well-studied, inflation's impact on deforestation remains inadequately examined.

Integration of Theoretical Frameworks: Few studies combine frameworks like EKC and LCCd to analyze deforestation, particularly in conflict-affected regions like Somalia.

3. Materials and methods

3.1. Data

This research uses annual time series data spanning from 1993 to 2021 to evaluate how economic growth, inflation, and population growth influence deforestation in Somalia. The data is obtained from the World Development Indicators and the SESRIC database. The dependent variable is deforestation, measured by changes in arable land area. The independent variables include economic growth (measured by GDP), inflation (measured by the GDP deflator), and population growth (measured by the population growth rate).

3.2. Hypothesis

This study proposes the following hypotheses to examine the effects of economic growth, population expansion, and inflation on deforestation in Somalia:

3.2.1. Economic growth

H_0a: Economic growth in Somalia does not significantly impact deforestation in the short term.

H_1a Economic growth in Somalia significantly increases deforestation in the short term.

H_0b: Economic growth in Somalia does not exhibit an Environmental Kuznets Curve (EKC) relationship with deforestation in the long term.

H_1b: Economic growth in Somalia follows an EKC relationship with deforestation in the long term.

3.2.2. Population growth

H_0c: Population growth in Somalia does not significantly contribute to deforestation.

H_1c: Population growth in Somalia significantly increases deforestation by driving resource demand.

3.2.3. Inflation

H_0d: Inflation does not significantly affect deforestation in Somalia.

H_1d: Inflation significantly contributes to deforestation as rising costs drive higher forest resource use.

3.3. Environmental Kuznets curve (EKC) hypothesis analysis

The EKC hypothesis posits an inverted U-shaped relationship between economic growth and environmental degradation. To test this hypothesis in the context of deforestation, the study utilized a quadratic regression model that includes both linear and squared terms of GDP to capture the non-linear relationship. The dependent variable was the logarithm of deforestation rates lnDefor, while the independent variables included the logarithm of GDP (lnGDP) and its squared term $\ln GDP^2$. Additional control variables were also incorporated into the model, including the logarithm of population growth (lnPop) to account for demographic pressures and the logarithm of inflation (lnInf) to assess economic stability impacts.

The turning point of the EKC, which indicates the level of economic growth where deforestation begins to decline, was calculated using the formula $-\frac{\beta_1}{2\beta_2}$. This approach allows for the identification of critical economic thresholds and the dual effects of economic growth on environmental outcomes. The EKC analysis thus provides insights into whether economic growth in the studied region exacerbates deforestation initially and mitigates it at higher levels of GDP. Several researchers have used the EKC to analyze the relationship between various variables. For example, Mohamud & Hassan (2024) employed the EKC framework to examine the relationship between economic growth and environmental degradation, confirming an Inverted U-shaped relationship using Johansen cointegration and VECM methodologies.

3.4. Model specification

To investigate the impact of macroeconomic variables on deforestation, this study employs the Autoregressive Distributed Lag (ARDL) model developed by Pesaran et al. The ARDL model is particularly suitable for analyzing the relationships between variables that may exhibit different orders of integration (I(0) or I(1)) without requiring the variables to be co-integrated. Additionally, it is robust in small sample sizes and capable of estimating both short-term and long-term dynamics between the variables.

The model is grounded in economic theory, particularly the EKC hypothesis, which suggests that the relationship between economic growth and environmental degradation follows an inverted U-shape. This theory implies that, in the early stages of economic growth, deforestation may increase as a result of industrialization and urbanization, but as economies mature, environmental policies and higher income levels may lead to a reduction in deforestation. Several researchers have employed the ARDL model to analyze the short-run and long-run relationships between various macroeconomic variables and economic growth. For example, Adenomon and Ojo (2020) applied the ARDL modeling technique to examine both the short-run and long-run effects of inflation rate, unemployment rate, and interest rate on real gross domestic product per capita as a proxy for economic growth in Nigeria over the period from 1984 to 2017.

The ARDL model can be specified as follows:

$$DF_t = \beta_0 + \beta_1 GDP_t + \beta_2 INF_t + \beta_3 POP_t + \varepsilon_t, \tag{1}$$

where DF_t is Deforestation, INF_t is inflation, POP_t is population growth rate, and ε_t random errors. The random error term ε_t is assumed to follow a normal distribution with a mean of 0 and constant variance.

3.5. Stationarity test

To examine the stationarity of the variables, this study utilizes the Augmented Dickey-Fuller (ADF), Phillips-Perron (PP) test and the Zivot-Andrews test, ensuring robust insights into the time series properties.

3.5.1. Augmented Dickey-Fuller (ADF)

The ADF test will be applied to determine whether the variables are stationary, thereby preventing erroneous conclusions. ADF test checks if a time series is stationary, which means its statistical properties do not change over time. Stationarity tests are used to determine the appropriate time series model to use. Various studies have employed the ADF test to assess the stationarity of variables, such as Worden et al. (2019); Ajewole et al. (2020); and Roza et al. (2022). The ADF test is based on the following regression:

$$\Delta y_t = \alpha + \beta t + \gamma y_{t-1} + \sum_{i=1}^{p} \delta_i \Delta y_{t-i} + \varepsilon_t, \tag{2}$$

where y_t is the time series, $\Delta y_t = y_t - y_{t-1}$ is the first difference of y_t, α is the intercept, t is the time trend, p is the lag order and ε_t is the error term. The random error term ε_t is assumed to follow a normal distribution with a mean of 0 and constant variance.

3.5.2. Phillips-Perron (PP) test

The PP test is applied to test whether the time series data contains a unit root. Unlike conventional methods, it adjusts for serial correlation and heteroscedasticity in the error term without relying on additional lagged difference terms. This makes it a reliable tool for small samples and datasets with correlated errors, offering a robust alternative to other unit root tests. The PP test modifies the standard Dickey-Fuller test to address serial correlation and heteroskedasticity in the residuals. Several researchers have used the PP test to check the stationarity of variables, including Bature et al. (2024); Hussein and

Hmood (2024); and Ruhi et al. (2024). The general form of the test equation is as follows:

$$\Delta Y_t = \alpha + \beta t + \gamma Y_{t-1} + \sum_{i=1}^{p} \delta_i \Delta Y_{t-i} + \varepsilon_t, \tag{3}$$

where Y_t is the variable under consideration, ΔY_t is the first difference of Y_t, α is a Constant term, β is the Coefficient of the time trend, γ is the Coefficient to be tested for the presence of a unit root ($\gamma = 0$ under the null hypothesis) and ε_t is the Error term. The random error term ε_t is assumed to follow a normal distribution with a mean of 0 and constant variance.

3.5.3. Zivot-Andrews test

Recognizing the possibility of structural changes in the data, the Zivot-Andrews test is conducted. This test improves on traditional unit root tests by allowing for a single structural break in the time series, which could occur in the level, trend, or both. The Zivot-Andrews test has been utilized by various researchers, such as Okoli et al. (2024); Micheal et al. (2023); and Adeleye et al. (2021). The test is based on the following regression model:

$$Y_t = \mu + \theta D_t + \beta t + \gamma Y_{t-1} + \delta_1 \Delta Y_{t-1} + \cdots + \delta_k \Delta Y_{t-k} + \varepsilon_t, \tag{4}$$

where D_t is a dummy variable capturing the structural break. $D_t = 1$ *if* $t > T_B$ (break point) and $D_t = 0$ otherwise, t is time trend, μ is intercept term, β is Coefficient of the time trend, γ is the Coefficient for the lagged level of Y_t, ΔY_{t-i} is the lagged first difference of Y_t, T_B is the point where the structural break occurs, determined endogenously by the test. The random error term ε_t is assumed to follow a normal distribution with a mean of 0 and constant variance.

By employing both tests, this study ensures a rigorous examination of the data's stationarity properties while accounting for serial correlation and potential structural changes, which is essential for accurate econometric modeling.

3.6. Co-integration test

The Johansen co-integration test is employed to identify long-term equilibrium relationships among the variables. If a co-integrating relationship is found, the study will proceed with a Vector Error Correction Model (VECM) to capture both short-term dynamics and long-term equilibrium. Co-integration tests, such as the Johansen test, determine whether a long-term equilibrium relationship exists between two or more non-stationary time series. Co-integration tests are often applied in economic studies to analyze the long-term relationships between variables. For instance, Johansen (1988) used this method to explore the co-integration among multiple time series in econometric models. The Johansen test is based on the following VECM

$$\Delta y_t = \Pi y_{t-1} + \sum_{i=1}^{k-1} \Gamma_i \Delta y_{t-i} + \varepsilon_t, \tag{5}$$

where Π and Γ_i are matrices of coefficients, y_t is a vector of non-stationary time series and Δy_t represents the differenced series. The random error term ε_t is assumed to follow a normal distribution with a mean of 0 and constant variance.

3.7. Model diagnostics

Diagnostic tests are essential to validate the reliability of the econometric model and its estimates.

3.7.1. Normality test

The study adopts the Jarque-Bera (JB) test to assess whether the residuals of the regression model are normally distributed. The normality of residuals is a key assumption of the Classical Linear Regression Model (CLRM). Normality tests are crucial in validating assumptions of parametric tests. Gujarati (2004) used the JB test in the context of regression models to ensure the residuals followed a normal distribution.

The JB test is a common normality test based on skewness and kurtosis and calculated as:

$$JB = \frac{n}{6}\left(S^2 + \frac{(K-3)^2}{4}\right), \tag{6}$$

where n is the sample size, S is the skewness of the data and K is the kurtosis of the data.

3.7.2. Serial correlation test

The Breusch-Godfrey LM test is used to detect the presence of serial correlation in the model's residuals. Serial correlation can indicate model misspecification, which can lead to biased estimates. Serial correlation tests are vital in time series analysis (King, 2001). Breusch (1978) and Godfrey (1978) used these tests to assess the presence of serial correlation in econometric models. Mathematically the the Breusch-Godfrey LM test is expressed as:

$$Y_t = \alpha + \beta X_t + \varepsilon_t. \tag{7}$$

The test then regresses the residuals ε_t on lagged residuals and other variables to check for serial correlation. The random error term ε_t is assumed to follow a normal distribution with a mean of 0 and constant variance.

3.7.3. Heteroscedasticity

Heteroscedasticity tests are used to check if the variance of the error term is constant across observations (Munir, 2023). The Breusch-Pagan test is employed to check eroscedasticity, which occurs when the variance of the error terms is not constant across observations. Addressing heteroscedasticity ensures the efficiency and validity of the OLS estimators. Breusch and Pagan (1979) applied this method to econometric models to ensure the reliability of OLS estimators. The Breusch-Pagan test for heteroscedasticity is based on the following regression:

$$\hat{\varepsilon}_t = \alpha_0 + \alpha_1 X_t + u_t, \tag{8}$$

where $\hat{\varepsilon}_i$ are residuals obtained from the original regression, X_t is the independent variable, and u_t are iid random errors.

3.7.4. CUSUM test

The Cumulative Sum (CUSUM) test is applied to assess the stability of the model's parameters over time. In econometrics, it is primarily employed to identify structure (Muthuramu & Maheswari, 2019). It is useful in detecting structural breaks or changes in the mean value of a sequence of observations. Brown et al. (1975) applied the CUSUM test to evaluate the stability of coefficients in regression models. The CUSUM statistic is calculated as:

$$W_t = \sum\nolimits_{i=1}^{t} \hat{\varepsilon}_i, \tag{9}$$

where $t = 1,2,\dots,n$, and $\hat{\varepsilon}_i$ are residuals.

4. Results

This chapter explores the impact of macroeconomic variables on deforestation in Somalia, analyzing descriptive statistics, unit root tests, econometric findings, diagnostic tests, and ARDL model estimation.

4.1. Descriptive statistics of macroeconomic variables and deforestation in Somalia

The Table 1 presents descriptive statistics for the key macroeconomic variables, GDP, inflation (INF), and population growth, along with deforestation rates in Somalia, over the period from 1993 to 2021. This statistical summary provides an overview of the data distribution, which are essential for understanding the central tendency and variability in the dataset. These descriptive statistics lay the foundation for further econometric analysis, helping to interpret the relationship between these macroeconomic factors and deforestation.

Table 1. Summary of descriptive statistics for macroeconomic variables and deforestation in Somalia.

Variables	Observations	Mean	Median	Max	Min	St. Dev
Deforestation	29	6.028	6.035	6.053	6.000	0.015
GDP	29	9.521	9.536	9.833	9.184	0.213
INF	29	2.031	2.017	2.207	1.809	0.121
POP Growth	29	0.517	0.543	0.699	0.196	0.102

The Table 1 shows a summary of the descriptive statistics for deforestation and the selected macroeconomic variables GDP, inflation (INF), and population growth in Somalia over 29 observations from 1993 to 2021. The mean deforestation rate is 6.03, with minimal variability (standard deviation of 0.0155), indicating that deforestation levels have remained relatively consistent over the period studied. The median value (6.03) closely matches the mean, further suggesting a normal distribution. The range is very narrow (6.00 to 6.05), reinforcing the observation of stability in deforestation rates.

The mean GDP is approximately 9.52, with a standard deviation of 0.213, indicating some variation in economic output over the years. The GDP values range from a minimum of 9.18 to a maximum of 9.83, suggesting moderate fluctuations in Somalia's economic performance during the study period.

Inflation has a mean of 2.03, with a standard deviation of 0.213, which is comparable to GDP's standard deviation of 0.1206.

The mean population growth rate is 0.52, with a standard deviation of 0.1206, suggesting some variability in the growth rate over time. The population growth rate ranges from 0.20 to 0.70, reflecting varying rates of population expansion during the study period.

These descriptive statistics highlight the relatively stable deforestation rates in Somalia against the backdrop of fluctuating macroeconomic conditions. The data suggests a complex relationship between economic factors and deforestation, which will be further analyzed in subsequent sections of the research.

4.2. Trend analysis

Trend analysis plays a crucial role in understanding the evolution of deforestation, economic growth, inflation, and population dynamics in Somalia. By examining these trends, the research identifies key patterns and shifts that have occurred over time, shedding light on the socio-economic factors driving these changes. This analysis is vital for informing policy decisions aimed at promoting sustainable development and environmental conservation in the region.

4.2.1. Analysis of deforestation trends in Somalia

The study investigates the historical patterns of deforestation in Somalia from 1993 to 2021, revealing periods of both stability and significant environmental degradation. This section explores the patterns and trajectory of deforestation in Somalia over the study period. The findings highlight the influence of economic activities, population pressures, and policy changes on the country's forest cover. Understanding these patterns is essential for developing targeted interventions to curb deforestation and protect Somalia's natural resources.

The Figure 1 illustrates the logged deforestation rate (LnDefor) over a given period. The graph displays fluctuations in deforestation levels, with notable increases and decreases observed at different intervals.

From 1993 to 2000, the trend shows a gradual increase in deforestation, which remains relatively stable until around 2002. A sharp rise is observed between 2002 and 2005, indicating a significant increase in deforestation during this period. However, this is followed by a steep decline around 2006, suggesting a temporary reduction in deforestation rates.

Following this decline, the trend demonstrates variability, with alternating periods of increase and decrease, particularly evident around 2008 and 2012. After 2012, the deforestation rate appears to stabilize, showing little to no change until 2021. Overall, the trend suggests that while there have been periods of increased deforestation, particularly in the early 2000s, efforts to reduce deforestation may have had some impact, leading to more stable levels in recent years.

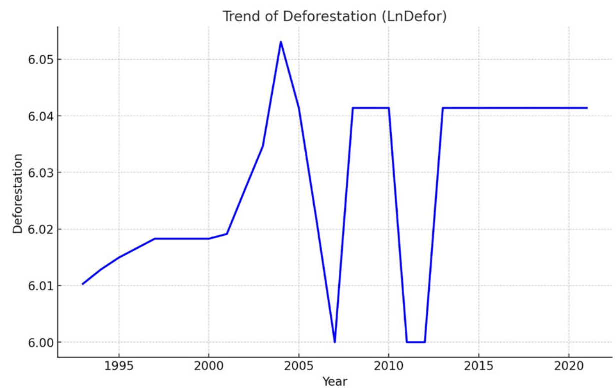

Figure 1. Analysis of deforestation trends in Somalia (1993–2021).

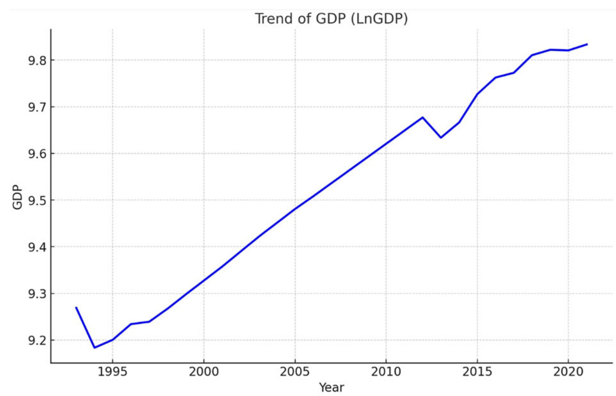

Figure 2. Analysis of long-term economic growth (LnGDP).

4.2.2. Analysis of long-term economic growth (LnGDP) in Somalia

The long-term economic growth of Somalia, measured through the natural logarithm of GDP (LnGDP), is analyzed to understand its fluctuations and overall trajectory from 1994 to 2021. The research explores how economic expansion and contraction periods align with broader political and economic events, providing insights into the relationship between sustained economic growth and deforestation. These insights are crucial for balancing economic development with environmental sustainability. This part focuses on the trends in Somalia's economic growth, represented by the LnGDP.

Figure 2 shows the LnGDP over a specified time period. The trend line demonstrates a general upward trajectory, indicating continuous economic growth.

Initially, between 1994 and 1996, there is a slight decline in GDP, but starting around 1996, the GDP begins to increase steadily. This growth continues uninterrupted until approximately 2012, where a minor dip is observed, possibly reflecting a brief economic downturn or slower growth phase.

After this dip, the GDP resumes its upward trend, indicating recovery and further economic expansion. By 2021, the GDP reaches its peak value in the series, reflecting sustained growth over the period observed, with only minor fluctuations. The overall trend suggests a positive long-term economic outlook with occasional short-term variability.

4.2.3. Analysis of inflation trends over time

The research tracks the inflation rate in Somalia over three decades, examining its fluctuations and how these shifts correlate with deforestation. By analyzing the relationship between inflationary pressures and natural resource exploitation, particularly during periods of economic instability, the study provides valuable information for policymakers seeking to stabilize the economy while protecting the environment.

Figure 3 represents the natural logarithm of inflation rates from 1994 to 2021. The vertical axis displays the logarithmic values of inflation, while the horizontal axis covers the timeline in years. The graph

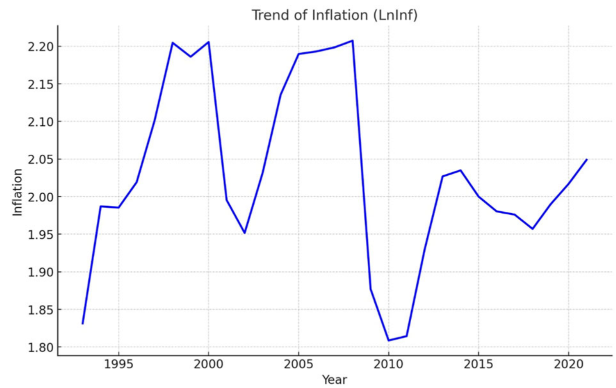

Figure 3. Fluctuations in inflation trends (LnINF) in Somalia (1993–2021).

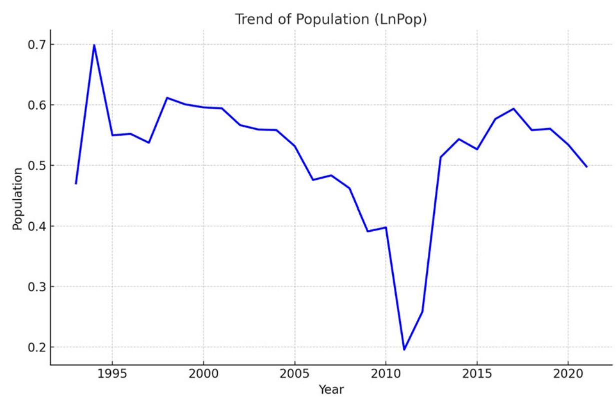

Figure 4. Population growth trends (LnPOP Growth) in Somalia (1994–2021).

shows notable fluctuations in inflation during the period. From 1994 to around 1996, inflation experienced a steady increase, peaking slightly above 2.0. This trend continues until the late 1993s, where the inflation rate stabilizes with minor ups and downs until around 2000.

A significant rise is observed between 2002 and 2008, where the inflation logarithmic value approaches 2.2, marking a period of heightened inflationary pressure. However, this increase is followed by a sharp decline around 2010, indicating a significant drop in inflation during that year.

Post-2010, inflation begins to recover but remains unstable, with a series of fluctuations. The rate experiences a gradual increase after 2015, culminating in another upward trend as it approaches 2021, suggesting rising inflationary tendencies towards the end of the observed period.

4.2.4. Population growth rate over time

The study assesses the population growth trends in Somalia, identifying the factors driving demographic changes and their impact on land use and deforestation. The increasing demand for agricultural land, particularly in rural areas, has intensified deforestation. Understanding these dynamics is critical for crafting policies that address both population growth and environmental sustainability. This section investigates the trend in Somalia's population growth over the study period, identifying key factors that have driven demographic changes.

The Figure 4 represents the natural logarithm of population growth over a span of years, specifically from 1994 to 2021. The vertical axis measures the logarithmic value of population growth, while the horizontal axis indicates the years. From the graph, we observe that the population growth rate exhibited significant fluctuations during this period. Initially, between 1994 and 1996, there was a sharp increase in population growth, as indicated by the rise in the graph. However, after 1996, the growth rate began to stabilize with minor variations until the early 2000s.

A noticeable decline in the growth rate occurs around 2008, continuing until it reaches its lowest point in 2010–2011. This suggests a period of considerable reduction in population growth during these years. Post-2011, the growth rate experiences a recovery, showing an upward trend until around 2014–2015, after which it fluctuates slightly but generally trends downward again towards 2021. Overall, the graph reflects periods of growth, stability, and decline in the population growth rate over time, indicating the dynamic nature of population changes within the observed years.

4.3. Unit root test results for stationarity of key macroeconomic variables

The stationarity of key macroeconomic variables GDP, inflation, population growth, and deforestation is tested to determine their stability over time. The results from unit root tests are crucial for ensuring that the variables are suitable for econometric modeling. This step is necessary to prevent misleading inferences in subsequent analyses and to enhance the reliability of the model's estimations. In this section, the stationarity of the key macroeconomic variables GDP, inflation, population growth, and deforestation sis tested using unit root tests.

Table 2 presents the stationarity analysis conducted using the ADF and PP tests. These tests examine whether the variables are stationary at their levels or require differencing for stability. The ADF test indicates that lnDeforestation is stationarity at the level (I(0)), with a t-statistic of -3.534, which exceeds the 5% critical value (−2.976), and a *p*-value of 0.0147, rejecting the null hypothesis of a unit root. The PP test, however, provides a weaker indication of stationarity, as the t-statistic is -2.725 with a *p*-value of 0.083, slightly above the significance threshold. Despite this variation, the variable appears stationary in the majority of tests.

Both ADF and PP tests confirm that lnGDP is non-stationarity, with t-statistics far from the critical values and *p*-values of 0.971, indicating the presence of a unit root. This suggests that the variable is not stationary at the level and requires differencing to achieve stationarity.

The ADF test suggests that the lnINF is stationarity at the level, with a t-statistic of b3.053, close to the 5% critical value (−2.976), and a significant *p*-value of 0.0425. The PP test, however, shows weaker evidence for stationarity, with a t-statistic of −2.688 and a *p*-value of 0.089, failing to confirm the ADF results. However, after first differencing, strong stationarity is achieved at the 1% level across both tests.

Both ADF and PP tests indicate that the lnPOP Growth is non-stationarity at the level, with t-statistics of −2.394 (ADF) and −2.449 (PP), falling short of the critical values. The corresponding p-values of 0.152 and 0.138 suggest the null hypothesis of a unit root cannot be rejected. This variable requires differencing for further analysis.

In light of these findings, the ARDL methodology is appropriate, as it accommodates variables integrated of order I(0) and I(1). For robustness, the analysis should consider applying the augmented ARDL framework or additional unit root tests to strengthen the validity of the econometric model.

Table 3 is the stationarity analysis of Zivot-Andrews Test results, which examines the structural breaks and stationarity of variables. For the variable Deforestation, the test statistic -5.448 is less than the critical value at the 5% significance level −5.08. This indicates that the variable is stationary with a structural break at the 16th observation.

For LnPop, the test statistic −3.301 is greater than the 5% critical value (-5.08), showing that the variable is not stationary, even with a structural break identified at the 18th observation.

The variable LnInflation has a test statistic of −7.298, which is lower than the 5% critical value −5.08. This suggests that the variable is stationary with a structural break occurring at the 16th observation.

Lastly, for LnGDP, the test statistic −5.018 is slightly greater than the 5% critical value -5.08, implying that the variable is not stationary, even though a structural break is present at the 20th observation.

Table 2. Stationarity analysis of deforestation, GDP, inflation, and population growth using ADF and PP Tests.

Dickey-Fuller (ADF) test (I(0))						The Phillips-Perron (PP) Test (I(0))				
		Critical values					Critical values			
Variables	t-Statistic	1%	5%	10%	*p*-value	t-Statistic	1%	5%	10%	*p*-value
lnDef	−3.534	−3.700	−2.976	−2.627	0.015	−2.725	−3.689	−2.972	−2.625	0.083
lnGDP	0.253	−3.689	−2.972	−2.625	0.971	0.253	−3.689	−2.972	−2.625	0.971
lnINF	−3.053	−3.700	−2.976	−2.627	0.043	−2.688	−3.689	−2.972	−2.625	0.089
lnPOP Growth	−2.394	−3.689	−2.972	−2.625	0.152	−2.449	−3.689	−2.972	−2.625	0.138

Table 3. Stationarity analysis using Zivot-Andrews unit root test.

		Critical values			
Variables test statistic		1%	5%	10%	Potential break point
Deforestation	−5.448	−5.57	−5.08	−4.82	16
LnPop	−3.301	−5.57	−5.08	−4.82	18
LnInflation	−7.298	−5.57	−5.08	−4.82	16
LnGDP	−5.018	−5.57	−5.08	−4.82	20

Table 4. Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) test results for differenced data.

Dickey-Fuller (ADF) Test (I(1))						The Phillips-Perron (PP) test (I(1))				
		Critical values					Critical values			
Variables	t-statistic	1%	5%	10%	*p*-value	t-statistic	1%	5%	10%	*p*-value
lnGDP	−7.406	−3.700	−2.976	−2.627	0.000	−9.600	−3.700	−2.976	−2.627	0.000
lnINF	−4.149	−3.700	−2.976	−2.627	0.003	−4.170	−3.700	−2.976	−2.627	0.003
lnPOP Growth	−6.527	−3.700	−2.976	−2.627	0.000	−6.483	−3.700	−2.976	−2.627	0.000

Table 5. Validation of environmental Kuznets curve hypothesis for deforestation.

Variables	Coefficient	Std. Error	t-Statistic	p-Value
Intercept	−8.548	6.081	−1.406	0.173
LnGDP	3.010	1.280	2.353	0.027
$LnGDP^2$	−0.155	0.067	−2.314	0.030
LnINF	−0.022	0.021	−1.083	0.289
LnPOP	0.112	0.027	4.115	0.000

Table 4 presents the results of unit root tests (ADF and PP) for determining the stationarity of the variables. The tests were conducted at the first difference I(1), which evaluates whether the variables become stationary after differencing once. Both the ADF and PP tests reveal that all the variables are stationary at the first difference, as indicated by the t-statistics exceeding the critical values at the 1%, 5%, and 10% significance levels. Additionally, the corresponding p-values are well below 0.05 for each variable, confirming stationarity at I(1).

Table 5 presents the results of the EKC hypothesis analysis confirms an inverted U-shaped relationship between economic growth (LnGDP) and deforestation (LnDefor), supporting the EKC hypothesis. The coefficient of LnGDP is positive (3.010, $p = 0.027$), indicating that at lower levels of GDP, deforestation increases with economic growth. However, the squared term of GDP ($LnGDP^2$) has a significant negative coefficient (−0.155, $p = 0.030$), suggesting that deforestation decreases after GDP surpasses a certain threshold. This turning point, calculated as $-\frac{\beta_1}{2\beta_2}$, is approximately 9.68 in logarithmic terms, indicating that economic growth initially exacerbates deforestation but mitigates it as GDP grows beyond this level.

Additionally, the analysis highlights the role of population growth (LnPop) as a significant driver of deforestation, with a positive coefficient of 0.112 ($p < 0.001$. This finding underscores the pressure exerted by population expansion on forest resources. Conversely, inflation (LnInf) has an insignificant effect on deforestation, as indicated by its coefficient of −0.022 ($p = 0.289$).

The model's overall performance is robust, with an R-squared value of 59.2%, indicating that the predictors explain approximately 59.2% of the variability in deforestation. The significant F-statistic further validates the model's adequacy. These findings provide strong evidence for the EKC hypothesis, emphasizing the dual role of economic growth in initially driving and later alleviating deforestation, while also highlighting the critical impact of population growth on environmental degradation.

4.4. ARDL bounds test results for long-run relationship among variables

The ARDL bounds test is applied to investigate the existence of a long-run equilibrium relationship among the macroeconomic variables and deforestation. The results confirm whether the variables are co-integrated, indicating a stable long-term association. Understanding these long-run relationships is the key for formulating policies that support sustainable economic growth while minimizing environmental degradation.

The results presented in Table 6 provide an analysis of the long-run relationship between deforestation (lnDFR) and its determinants: GDP, inflation (lnINF), and population growth (lnPOP). The calculated F-statistic value is 11.243, which is greater than the upper critical value (I(1): 5.966) at a 1% significance level. This indicates that there is strong evidence to reject the null hypothesis of no long-run relationship among the variables. The results confirm the existence of a statistically significant long-run relationship between deforestation and its determinants.

The bounds test values for 1%, 5%, and 10% levels are included for I(0) (lower bound) and I(1) (upper bound). Since the F-statistic exceeds the upper bound critical value (5.966 at 1%), it strengthens the conclusion that a long-run equilibrium relationship exists.

The dependent variable (lnDFR) is explained by the independent variables (lnGDP, lnINF, and lnPOP) in the context of the ARDL framework. These variables together contribute to explaining the long-run changes in deforestation.

4.5. Long-run coefficients of macroeconomic variables in the econometric model

The long-run coefficients of the macroeconomic variables are estimated to quantify their impact on deforestation. These coefficients provide insights into how economic growth, inflation, and population expansion influence deforestation over the long term. This section details the estimated long-run coefficients of the key macroeconomic variables within the econometric model. The coefficients quantify the long-term impact of economic growth, inflation, and population expansion on deforestation, providing insights into the magnitude and direction of these effects.

Table 7 presents the long-run coefficients of the econometric model examining the effects of key macroeconomic variables on the dependent variable, with all variables log-transformed for elasticity interpretation. The coefficient for LnGDP is 0.052 indicates a positive relationship between GDP and deforestation. A 1% increase in GDP leads to approximately a 0.052% increase in deforestation, holding other factors constant. The result is highly significant at the 1% level, suggesting strong evidence of this relationship.

The coefficient for LnINF is 0.012 shows a positive but statistically insignificant relationship between inflation and deforestation. This implies that changes in inflation do not significantly impact deforestation levels in the long run.

The coefficient for LnPOP is 0.024 reflects a positive and significant relationship between population growth and deforestation at the 1% level. A 1% increase in population growth results in a 0.024% increase in deforestation, emphasizing the critical role of demographic factors.

Table 6. Long-run relationship analysis of deforestation, GDP, inflation, and population growth using ARDL bounds test.

				Bounds test	
Dependent variable	Independent variables	F- statistics	Significance level	Critical values	
lnDFR	lnGDP, lnINF, lnPop	11.243	1%	I(0): 4.614,	I(1): 5.966
Bounds test critical values					
Significance level		I(0)			I(1)
1%		4.614			5.966
5%		3.272			4.306
10%		4.614			5.966

Table 7. Estimation of long-run elasticities for GDP, inflation, and population in the econometric model.

Explanatory variables	Coefficients	Standard Errors	Significance level
LnGDP	0.052	0.003	*** 1% level
LnINF	0.012	0.011	Not Significant
LnPop	0.024	0.004	*** 1% level
Constant	5.481	0.637	*** 1% level

Table 8. Estimation of short-run coefficients and model diagnostics for GDP, inflation, population, and deforestation.

Explanatory variables	Coefficients	Standard errors	Significance level
LnDFR(-1)	3.538	0.397	***1% level
LnGDP	0.686	0.103	***1% level
LnINF	0.145	0.018	***1% level
LnPop(t-1)	−0.199	0.035	***1% level
ECT(-1)	−0.087	0.503	***1% level
Diagnostics tests			
Test	Statistic		Probability value
Serial correlations	0.187		0.836
Heteroskedasticity	0.872		0.624
Jarque-Bera	0.764		0.683

The constant term is 5.481 is statistically significant at the 1% level, capturing the base level of deforestation when all explanatory variables are zero.

4.6. Short-run dynamics and diagnostic tests of the econometric model

The short-run dynamics of the econometric model are analyzed to understand the immediate effects of changes in GDP, inflation, and population growth on deforestation. Diagnostic tests are conducted to evaluate the model's validity and reliability, ensuring that the estimates are robust and free from issues like autocorrelation or heteroskedasticity. These findings are important for making informed short-term policy decisions that align with long-term sustainability goals. Here, the focus shifts to the short-run dynamics of the model, examining how immediate changes in GDP, inflation, and population growth affect deforestation. The section also includes diagnostic tests to evaluate the model's validity and reliability, ensuring that the short-run estimates are robust and free from econometric issues such as autocorrelation or heteroskedasticity.

Table 8 outlines the short-run dynamics of the model, highlighting the influence of various explanatory variables on the dependent variable. Coefficients, along with standard errors (in parentheses) and significance levels (indicated by stars), reveal the following key findings: LnDFR(-1) exhibits a positive and statistically significant effect (coefficient: 3.538434), indicating that prior deforestation levels strongly impact the current period. LnGDP also positively influences the dependent variable (coefficient: 0.685656), reflecting the significant short-run impact of economic growth. Similarly, LnINF contributes positively (coefficient: 0.145331), showing that inflationary pressures are relevant in the short-run. Conversely, LnPOP(t-1) negatively affects the dependent variable (coefficient: -0.199298), suggesting that higher population growth in the previous period reduces the current period's dependent variable. The Error Correction Term (ECT(-1)) has a negative coefficient of -0.0867122, indicating a slower adjustment to long-run equilibrium, though it is less statistically significant.

The diagnostic tests confirm model reliability

Serial Correlation: With a test statistic of 0.187112 and a *p*-value of 0.8362, no significant autocorrelation issues are present. It suggests no evidence of serial correlation in the model, confirming the reliability of the results.

Heteroskedasticity: A test statistic of 0.872055 and *p*-value of 0.6237 suggest constant error variance. It indicates the absence of heteroskedasticity, validating the model's variance assumptions.

Normality (Jarque-Bera Test): The test statistic of 0.763966 and p-value of 0.682507 indicate normally distributed residuals. It confirms that the residuals are normally distributed, which is essential for the validity of the regression model.

4.7. Stability assessment of the econometric model using CUSUM and CUSUMSQ tests

In this final section, the stability of the econometric model over time is assessed using CUSUM (Cumulative Sum) and CUSUMSQ (Cumulative Sum of Squares) tests. These tests check whether the model's parameters remain consistent throughout the study period, confirming that the relationship between the variables and deforestation has not changed significantly over time.

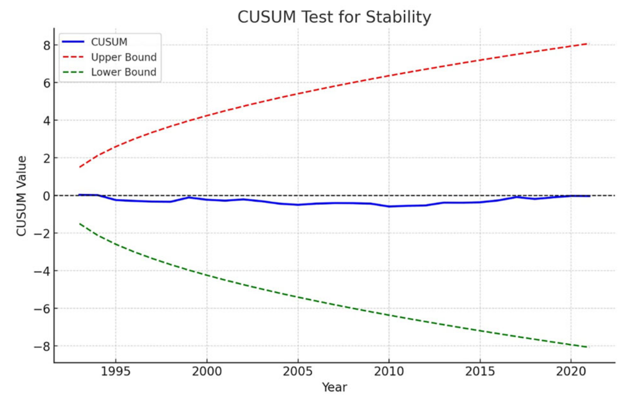

Figure 5. CUSUM test for model stability.

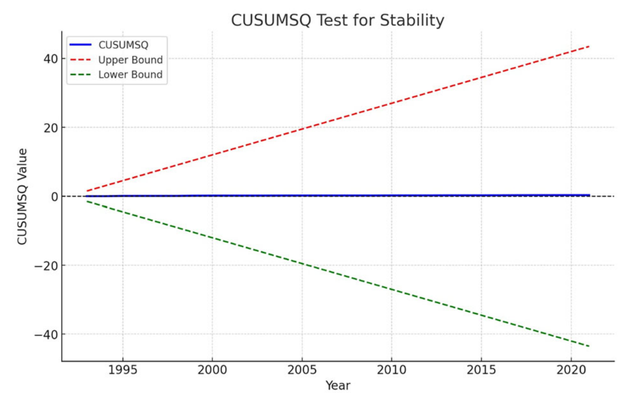

Figure 6. CUSUMSQ test for model stability.

Figure 5 shows the results of the CUSUM test, which is used to evaluate the stability of the regression model's coefficients over time. The plot features a cumulative sum line for the residuals, along with critical boundaries. Stability is confirmed if the cumulative sum line remains within these boundaries throughout the observed period. In this case, the model appears stable as no boundary crossings are detected, indicating that the regression coefficients are consistent over time without significant structural breaks.

Figure 6 presents the results of the CUSUMSQ test, which assesses the stability of the variance of residuals. This plot displays the squared cumulative sum line alongside the critical boundaries. The test statistic stays within the critical bounds for the entire period (the CUSUMSQ line does not cross the boundaries). This confirms the absence of any significant variability or instability in the model and reinforces the conclusion that the relationships between deforestation, GDP, inflation, and population growth are consistent and reliable over time.

Both tests (CUSUM and CUSUMSQ) validate the robustness and reliability of the econometric model used for analyzing the macroeconomic determinants of deforestation in Somalia.

5. Discussion of results

5.1. Key findings and their implications

The analysis of macroeconomic variables (GDP, inflation, and population growth) on deforestation in Somalia provides several key findings. Firstly, the study confirms the presence of an EKC relationship, where deforestation initially increases with economic growth but decreases as GDP surpasses a certain threshold. This supports the inverted U-shaped hypothesis, highlighting the dual role of economic growth in environmental degradation and potential mitigation. Population growth emerges as a significant driver of deforestation, indicating that the pressure exerted by population expansion on forest resources is substantial. However, inflation does not significantly impact deforestation, suggesting that other macroeconomic factors, such as income and population, are more influential.

These findings have important implications for policymakers, particularly in balancing economic growth with environmental conservation. Economic growth in Somalia could be leveraged to develop sustainable forest management practices, particularly once the economy surpasses the critical GDP threshold, as suggested by the EKC hypothesis.

5.2. Theoretical contributions

This study contributes to the existing literature by providing empirical evidence from Somalia that supports the EKC hypothesis, contributing to the broader debate on the relationship between economic growth and environmental degradation. The study's approach, which incorporates both long-run and short-run dynamics through ARDL modeling, offers a novel perspective on the impact of macroeconomic variables on deforestation in a developing country context. The study's focus on Somalia, a country with unique socio-political and economic challenges, adds value to the global discourse on sustainable development in the context of deforestation.

5.3. Policy implications

The findings underscore the importance of controlling population growth and implementing policies that promote economic growth in a way that minimizes environmental damage. Policymakers should consider investing in sustainable agricultural practices, reforestation programs, and policies that curb population pressures on forest resources. As Somalia's economy grows, it is essential to monitor deforestation rates closely and implement policies that balance economic development with environmental sustainability. The identification of the turning point in the EKC relationship suggests that the government should focus on policies that encourage sustainable growth once the economy exceeds the critical GDP threshold.

6. Concussion

This study examined the impact of macroeconomic variables—GDP, inflation, and population growth—on deforestation in Somalia using the ARDL modeling approach. The findings confirm the EKC hypothesis, indicating that deforestation initially rises with economic growth and later declines beyond a certain income level. Population growth was identified as a key contributor to deforestation, while inflation showed no significant long-term effect.

These insights contribute to the understanding of how macroeconomic dynamics influence environmental outcomes in developing countries. The study provides a foundation for policymakers to design strategies that align economic development with environmental sustainability in Somalia.

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Fatima conceived the presented idea. Mohmud and Atta Gul performed the statistical analysis and computations. Mohamud Hussein took the lead in crafting the introduction and literature review sections. Additionally, he verified the analytical methods and computations employed throughout the research, ensuring the robustness and accuracy of the study's findings. All authors contributed equally to the work. All authors have read and approved the final version of the manuscript.

Ethical approval

This study follows ethical practices during the writing process. We declare that this manuscript is original, has not been previously published and is not currently being considered for publication elsewhere.

Consent to participate

Not applicable.

Consent for publication

Not applicable.

Authors' contributions

CRediT: **Mohamud Hussein Mohamud:** Methodology; **Fatima Salah Abdirahman**: Conceptualization; **Atta Gul**: Writing – original draft.

Disclosure statement

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Data availability statement

The datasets used in this study are available from the author upon reasonable request.

References

Abdi, A. (2021). The impact of deforestation on biodiversity and climate change in Somalia. *Journal of Environmental Science and Policy*, *15*(2), 123–134. https://doi.org/10.1016/j.jenvp.2021.12.002

Adeleye, B. N., Nathaniel, S., Ogunrinola, I., & Ikuemonisan, E. (2021). Financial deepening and income inequality in Nigeria: Evidence from Zivot-Andrews and Gregory-Hansen structural break analyses. *Studies of Applied Economics*, *39*(8), 1–16. https://doi.org/10.25115/eea.v39i8.4348

Adenomon, M. O., & Ojo, R. O. (2020). Autoregressive distributed lag modeling of the effects of some macroeconomic variables on economic growth in Nigeria. *Folia Oeconomica Stetinensia*, *20*(2), 1–19. https://doi.org/10.2478/foli-2020-0032

Ajanaku, B. A., & Collins, A. R. (2021). Economic growth and deforestation in African countries: Is the environmental Kuznets curve hypothesis applicable? *Forest Policy and Economics*, *129*, 102488. https://doi.org/10.1016/j.forpol.2021.102488

Ajewole, K. P., Adejuwon, S. O., & Jemilohun, V. G. (2020). Test for stationarity on inflation rates in Nigeria using augmented dickey fuller test and Phillips-persons test. *Journal of Mathematics*, *16*(2020), 11–14.

Ayad, H., & Djedaiet, A. (2024). Does the unemployment rate matter for environmental issues in the G7 nations? New testing for the environmental Phillips curve using the load capacity factor. *Environment, Development and Sustainability*, 1–31.

Ayad, H., & Lefilef, A. (2024). Unveiling new insights into China's marine ecosystem: Exploring the fishing grounds load capacity curve. *Journal of Cleaner Production*, *450*, 141507. https://doi.org/10.1016/j.jclepro.2024.141507

Ayad, H., Hassoun, S. S., Abdelkader, S. B., & Sallam, O. A. A. J. (2024). Assessing deforestation in the Brazilian forests: An econometric inquiry into the load capacity curve for deforestation. *Forest Policy and Economics*, *159*, 103135. https://doi.org/10.1016/j.forpol.2023.103135

Barbier, E. B. (2003). Explaining agricultural expansion, resource booms and growth in Latin America. *Environment, Development and Sustainability*, *5*(3/4), 437–458. https://doi.org/10.1023/A:1025781130650

Barbier, E. B. (2004). Explaining agricultural expansion, resource booms and growth in Latin America. *Environment and Development Economics*, *9*(3), 363–383. https://doi.org/10.1017/S1355770X04001570

Barbier, E. B. (2004). Explaining agricultural land expansion and deforestation in developing countries. *American Journal of Agricultural Economics*, *86*(5), 1347–1353. https://doi.org/10.1111/j.0002-9092.2004.00688.x

Bature, T., Lasisi, K., Abdulkadir, A., & Adenomon, M. (2024). Testing for stationarity on selected linear and non-linear time series models of different orders. *FUDMA Journal of Renewable and Atomic Energy*, *1*(1), 90–102.

Bhattarai, M., & Hammig, M. (2001). Institutions and the Environmental Kuznets Curve for deforestation: A cross-country analysis for Latin America, Africa and Asia. *World Development*, *29*(6), 995–1010. https://doi.org/10.1016/S0305-750X(01)00019-5

Breusch, T. S. (1978). Testing for autocorrelation in dynamic linear models. *Australian Economic Papers*, *17*(31), 334–355. https://doi.org/10.1111/j.1467-8454.1978.tb00635.x

Breusch, T. S., & Pagan, A. R. (1979). A simple test for heteroscedasticity and random coefficient variation. *Econometrica*, *47*(5), 1287–1294. https://doi.org/10.2307/1911963

Brown, R. L., Durbin, J., & Evans, J. M. (1975). Techniques for testing the constancy of regression relations over time. *Journal of the Royal Statistical Society Series B: Statistical Methodology*, *37*(2), 149–163. https://doi.org/10.1111/j.2517-6161.1975.tb01532.x

De Barros, P. H. B. (2021). Relationship between economic growth and deforestation in Brazil: The role of spatial spillovers and heterogeneity. *Environment and Planning*, *16*.

Godfrey, L. G. (1978). Testing for higher order serial correlation in regression equations when the regressors include lagged dependent variables. *Econometrica*, *46*(6), 1303–1310. https://doi.org/10.2307/1913830

Grossman, G. M., & Krueger, A. B. (1995). Economic growth and the environment. *The Quarterly Journal of Economics*, *110*(2), 353–377. https://doi.org/10.2307/2118443

Gujarati, D. N. (2004). *Basic econometrics.* (4th ed.). McGraw-Hill.

Hansen, M. C., Potapov, P. V., Moore, R., Hancher, M., Turubanova, S. A., Tyukavina, A., … Townshend, J. R. (2021). The global forest change dataset: Monitoring forest cover and forest loss at high spatial resolution through time. *Nature Scientific Data*, *7*, 52. https://doi.org/10.1038/s41597-020-00691-2

Hosonuma, N., Herold, M., De Sy, V., De Fries, R. S., Brockhaus, M., Verchot, L., Angelsen, A., & Romijn, E. (2012). An assessment of deforestation and forest degradation drivers in developing countries. *Environmental Research Letters*, *7*(4), 044009. https://doi.org/10.1088/1748-9326/7/4/044009

Huang, Y., Villanthenkodath, M. A., & Haseeb, M. (2023). The nexus between eco-friendly technology and environmental degradation in India: Does the N or inverted N-shape load capacity curve (LCC) hypothesis hold?. In *Natural Resources Forum.* (Vol. 47, No. 2, pp. 276–297). Blackwell Publishing Ltd.

Hussein, M. A., & Hmood, M. Y. (2024). Nonstationary time series models using ARDL and NARDL estimation. *Journal of Economics and Administrative Sciences*, *30*(141), 439–456.

Ismail, M., & Osman, I. (2022). Economic factors driving deforestation in Somalia: A critical analysis. *Environmental Economics and Policy Studies*, *14*(4), 87–104. https://doi.org/10.1007/s10018-022-00321-y

Johansen, S. (1988). Statistical analysis of cointegration vectors. *Journal of Economic Dynamics and Control*, *12*(2–3), 231–254. https://doi.org/10.1016/0165-1889(88)90041-3

King, M. L. (2001). Serial correlation. *A Companion to Theoretical Econometrics*, 62–81.

Leblois, A., Damette, O., & Wolfersberger, J. (2017). What has driven deforestation in developing countries since the 2000s? Evidence from new remote-sensing data. *World Development*, *92*, 82–102. https://doi.org/10.1016/j.worlddev.2016.11.012

Micheal, V. A., Adenomon, M. O., & Nweze, N. O. (2023). Sample size simulation for unit root, structural break and regime shifts. *Science World Journal*, *18*(2), 259–266. https://doi.org/10.4314/swj.v18i2.13

Mohamoud, Y. A., & Hussein, S. M. (2021). Natural resource exploitation in Somalia: The role of governance and socio-economic factors. *Journal of African Development*, *22*(1), 77–89. https://doi.org/10.5325/jafrideve.22.1.0077

Mohamud, M. H., & Hassan, A. Y. (2024). Modelling the Relationship between Air Pollution and Economic Growth in Somalia. *International Journal of Energy Economics and Policy*, *14*(5), 558–565. https://doi.org/10.32479/ijeep.15527

Munir, M. D. (2023). Prediction of heteroscedastic data using linear regression and various machine learning models. *International Journal of Science and Research in Mathematical and Statistical Sciences*, *10*(1), 20.

Muthuramu, P., & Maheswari, T. U. (2019). Tests for structural breaks in time series analysis: A review of recent development. *Shanlax International Journal of Economics*, *7*(4), 66–79. https://doi.org/10.34293/economics.v7i4.628

Njora, B., & Yılmaz, H. (2022). Analysis of the effects of deforestation on the environment and agriculture in Kenya. *International Journal of Water Management and Diplomacy*, *1*(4), 91–110.

Nkengfack, H., Gnimassoun, B., & Sandwidi, B. W. (2021). Economic growth and environmental quality in Africa: Does income distribution matter? *Environment*. *Development and Sustainability*, *22*(2), 1325–1344. https://doi.org/10.1007/s10668-018-0246-6

Okoli, U. V., Ezenwobi, N. F., & Onugha, C. B. (2024). Zivot Andrews test for structural break: A consideration of government expenditure in Nigeria from pre to post sap Era. *Social Science Research*, *10*(2).

Pata, U. K., & Tanriover, B. (2023). Is the load capacity curve hypothesis valid for the top ten tourism destinations? *Sustainability*, *15*(2), 960. https://doi.org/10.3390/su15020960

Roza, A., Violita, E. S., & Aktivani, S. (2022). Study of inflation using stationary test with augmented dickey fuller & phillips-peron unit root test (Case in bukittinggi city inflation for 2014-2019). *EKSAKTA: Berkala Ilmiah Bidang MIPA*, *23*(02), 106–116. https://doi.org/10.24036/eksakta/vol23-iss02/303

Ruhi, S. B., Tithi, F. A., & Ahmed, D. F. (2024). The empirical evidence of the Phillips Curve in Bangladesh during 1991–2022. *An Econometric Approach*, Available at SSRN 4700648.

Shiferaw, A., Verhoeven, M., & Bulte, E. (2021). Population pressure, deforestation, and agricultural expansion: Evidence from Ethiopia. *World Development*, *144*, 105460. https://doi.org/10.1016/j.worlddev.2021.105460

Somalia, U. (2022). State of the World Population 2022. United Nations Population Fund. https://www.unfpa.org/sites/default/files/pub-pdf/UNFPA_PUB_2022_EN_State_of_World_Population.pdf

Usman, O., & Balsalobre-Lorente, D. (2022). Environmental sustainability in Africa: The role of renewable energy, income inequality, and political stability. *Journal of Environmental Management*, *303*, 113930. https://doi.org/10.1016/j.jenvman.2021.113930

Villoria, N. B., Byerlee, D., & Stevenson, J. (2014). The effects of agricultural technological progress on deforestation: What do we really know? *Applied Economic Perspectives and Policy*, *36*(2), 211–237. https://doi.org/10.1093/aepp/ppu005

Worden, K., Iakovidis, I., & Cross, E. J. (2019). On stationarity and the interpretation of the ADF statistic. In S. Pakzad (Ed.), *Dynamics of Civil Structures, Volume 2: Proceedings of the 36th IMAC, A Conference and Exposition on Structural Dynamics* 2018 (pp. 29–38). Cham, Switzerland: Springer International Publishing.