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Environmental degradation and food security in Somalia

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Abstract
Somalia grapples with significant land degradation due to soil erosion, deforestation, and overgrazing. These environmental stressors diminish agricultural productivity, further exacerbating food insecurity among the population. This study examines the impact of environmental degradation on food security in Somalia. The autoregressive distributed lag (ARDL) model was utilized with annual time-series data from 1990 to 2019. The empirical results show significant negative impacts of environmental degradation and gross domestic product (GDP) on food security, persisting in the short and long terms. However, population growth was found to have an insignificant effect on food security. Notably, while agricultural land expansion exhibits a negative effect in the short term, it emerges as a positive contributor to food security in the long term, highlighting its pivotal role in bolstering production capacity. The study suggests policy reform to prioritise initiatives for sustainable land management, focusing on reforestation, soil conservation, and watershed management. These practices are critical for mitigating environmental degradation, preserving natural resources, and enhancing the resilience of agricultural systems to climate change.

Keywords Somalia · Food security · Environmental degradation · ARDL model · Population growth · GDP

JEL Classification Q54 · Q10 · 013 · Q13

1 Introduction

The World Economic Summit 1974 defined food security as the *"availability of adequate world food supplies of basic foodstuffs to sustain a steady expansion of food consumption and to offset fluctuations in production and prices."* This definition underscores the importance of ensuring consistent access to food for all individuals. Food security is crucial for ensuring good quality of life, overall well-being, and economic growth. Statistics reveal that in Sub-Saharan Africa, 240 million people lack access to adequate food [1]. Recognizing the critical significance of food security, the United Nations has made it the second most important target of the Sustainable Development Goals (SDGs) after poverty.

The goal is to eradicate hunger and all forms of malnutrition by 2030, ensuring universal access to safe, nutritious, and sufficient food throughout the year. To accomplish this objective, it is imperative to establish sustainable food production systems, resilient agricultural methods, and fair access to land, technology, and markets. Importantly, it requires international cooperation in infrastructure and technology investments to enhance agricultural productivity, highlighting the shared responsibility in achieving food security. The "zero hunger" policy, adopted in 2015, aims to address the nutritional needs of the world's population, which is projected to reach 8.5 billion by 2030, 9.7 billion in 2050, and 11.2

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billion in 2100 (United Nations, 2016). This underscores the urgency of concerted efforts and innovative strategies to ensure food security for current and future generations, emphasizing the need for sustainable development practices and global cooperation to address food insecurity worldwide.

Food security and environmental degradation are closely intertwined [2]. Conducted an empirical study to investigate the impact of food security on environmental degradation across countries from 1984 to 2019. Their findings indicate a significant relationship, demonstrating that food security contributes to increased ecological deterioration. Environmental degradation resulting from human activities refers to the deterioration of natural resources such as water, oxygen, and soil [3].

Agriculture is the backbone of Somalia's economy, accounting for over 75% of the gross domestic product (GDP) and 93% of the total revenue [4]. According to the Global Development Center (GDC) in Somalia, one of the world's safest nations in terms of climate change, environmental considerations, particularly climate change, are the most serious issues. Climate change appears to be critical to food security in Somalia. This issue is exacerbated by the prolonged civil war and various forms of violence that have ravaged the nation, making Somalia one of the world's poorest countries [5].

Studying the causal connections between CO_2 emissions and food security in Somalia is crucial for several key reasons. First, food insecurity has been a persistent issue in Somalia since 1991 and has worsened over time [6]. By 2021, the number of people facing food insecurity had risen significantly, with projections estimating that 3.4 million people will experience acute food insecurity in Somalia [7]. Additionally, the country has faced recurring droughts and floods since the 2010–2011 drought, exacerbating food insecurity. Alongside climate variability, Somalia's agricultural sector is hindered by outdated farming methods and is primarily dominated by smallholder systems. Key food crops, such as maize, sorghum, wheat, and beans, have experienced declining productivity in recent years, highlighting the detrimental impact of climate change on crop yields and threatening the country's progress toward achieving food security [8]. Secondly, agriculture is the backbone of Somalia's economy, contributing over 75% to the gross domestic product (GDP) and accounting for 93% of total revenue [4]. Climate change seriously threatens this critical sector, as Somalia is particularly vulnerable to its effects. According to the Global Development Center (GDC), climate change is one of the most severe environmental issues facing Somalia, and its impact is closely tied to food security. Given Somalia's reliance on agriculture for economic growth and sustenance, understanding how CO_2 emissions influence agricultural productivity is essential. This knowledge will help researchers and policymakers develop strategies to mitigate the negative effects of climate change while strengthening the resilience of the agricultural sector. Such insights are crucial for adapting to changing climatic conditions and ensuring the sustainability of agricultural practices in Somalia [4]. Finaly, Agriculture is the primary source of livelihood for a large portion of Somalia's population. Examining the relationship between CO_2 emissions and crop yield is crucial for addressing food security challenges.

Somalia and several other countries in the Horn of Africa have experienced frequent food insecurity as a result of drought, climatic fluctuations, and war [9]. Food insecurity has been a persistent issue in Somalia since 1991. In 2021, the number of people experiencing food insecurity in the country has increased, and this trend is anticipated to continue [6]. A total of 3.4 million people are projected to be acutely food insecure in Somalia [7]. This issue is particularly severe among displaced populations and poor rural communities whose sources of food and income are heavily affected by natural disasters. Additionally, the country has faced recurring droughts and floods since the 2010–2011 drought, worsening food insecurity across the country [8]. On the other hand, Somalia has a relatively small amount of forested land, covering only approximately 10.5% of the nation's total land area. Much of the country's tropical forests, initially located along the Shabelle and Jubba Rivers, reclaimed agricultural land [10]. Between 2000 and 2021, Somalia has suffered an annual deforestation rate of 429,000 ha. This equates to an average annual deforestation rate of, on average, 4.9%. Despite the prospective value of Somalia's natural resources, their natural capital is currently at risk. Land degradation is currently considered to be between 23 and 30 per cent. Between 2000 and 2015, due to land degradation, Somalia lost 147,704 square kilometres. Several factors are responsible for this loss including soil erosion, biological degradation, and gully erosion. Most urban and rural Somalian households have used firewood and charcoal for years. Moreover, the country grapples with significant land degradation due to soil erosion, deforestation, and overgrazing. These environmental stressors diminish agricultural productivity, further exacerbating food insecurity among the population [11]. Persistent conflict and displacement are compounding challenges that disrupt agricultural activities, undermine livelihoods, and exacerbate food insecurity, particularly in vulnerable communities. Furthermore, Somalia's limited infrastructure and institutional capacity hinder efforts to address environmental degradation and food security effectively. Inadequate infrastructure, including deficient roads, storage facilities, and market access impedes the efficient distribution of food and agricultural inputs. Meanwhile, weak institutional capacity undermines initiatives to address environmental degradation

and enhance food security within the country. Climate change, including rising temperatures and carbon dioxide emissions, is a major contributor to food insecurity [12].

Food insecurity in Somalia is influenced by various factors, particularly climate change, which is closely linked to rising CO2 emissions. While Somalia's carbon emissions are relatively low (see Fig. 1), the country is highly vulnerable to the effects of global climate change, especially in its agricultural sector. In this context, it is essential to note that in 2019, Environmental Degradation (ED) experienced a slight increase, rising from 0.042826293 in 2018 to 0.043175461 in 2019, indicating a minor but noteworthy change. Increased CO2 emissions contribute to global warming, resulting in more frequent and severe droughts, floods, and extreme weather events in Somalia. These climate-related disruptions significantly impact crop yields, livestock health, and water resources, ultimately reducing food production and availability.

Figure 1 illustrates the relationship between the log-transformed Food Production Index (LFOI) and the Environmental Degradation Index (ED) from 1990 to 2019. The figure offers insight into how environmental changes may influence food production and food security over time.

Between 1990 and 1992, the LFOI experienced a sharp decline, indicating a significant drop in food production. During this period. This drop in food production coincided with a slight increase in environmental degradation. The decline in food production likely reflects the effects of environmental deterioration, which may have reduced soil fertility and agricultural output. This reduction in food production suggests a period of heightened food insecurity.

After 1992, the FPI gradually recovered, as indicated by the upward trend in the LFOI, while the ED index remained relatively stable. However, between 2004 and 2010, the period saw minor fluctuations in food production, with LFOI stagnating despite some environmental improvement. This could indicate that other factors, such as market conditions or socio-political instability, contributed to limiting food production gains during these years. From 2010 onwards, both indices showed relative stability, though food production saw a slight dip in 2015 before stabilizing again towards 2019. In 2019, environmental degradation saw a slight increase, but the impact on food production remained minimal, with LFOI staying relatively constant. Overall, the sharpest decline in food production and food security occurred in the early 1990s, when environmental degradation seemed to have had the most pronounced impact.

While existing studies have contributed valuable insights into the influence of food security on environmental degradation, there still needs to be a notable gap in understanding the specific mechanisms through which environmental degradation impacts crop production in Somalia. For example, a study conducted by [13] light on the role of CO2 emissions, agricultural methane emissions, and environmental degradation in crop production in Somalia. Their findings suggest a relationship, where CO2 and agricultural methane emissions positively affect crop productivity in the long run, while environmental degradation negatively affects them. However, although this study provides substantial empirical evidence, it primarily focuses on assessing the direct effects of emissions on crop production without delving into the underlying mechanisms or pathways through which environmental degradation influences agricultural outcomes. Therefore, there is a significant research gap in understanding the intermediary factors and processes through which ecological degradation affects crop productivity in Somalia. This includes how CO2 and other forms of environmental degradation directly affect food security in Somalia. By addressing this research gap, this study aims to provide a comprehensive understanding of the complex relationship between environmental degradation and food security in Somalia, offering

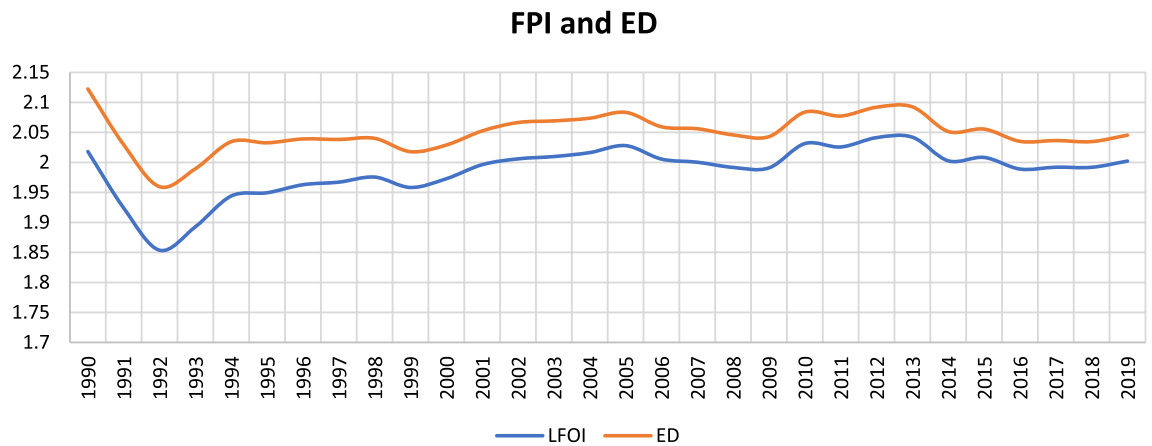

Fig. 1 Food Production Index (FPI) and the Environmental Degradation Index (ED) (1990–2019). The Food Production Index (FPI) has been log-transformed to visualize trends better and reduce skewness in the data

insights that can inform effective strategies and policies for sustainable agriculture and food security in the region. The specific objectives of this study are to examine the long-run relationships among CO2, agricultural productivity, GDP per capita, population, and food security.

To achieve these goals, this study applies an Autoregressive Distributed Lag (ARDL) Bounds Testing Approach to explore the causal connection between CO2 emissions and food security in Somalia. The ARDL approach is particularly well suited for this study because it offers several advantages over other econometric models. The ARDL model offers flexibility in the order of integration because it can be applied regardless of whether the underlying variables are purely I(0), purely I(1), or a mixture of both. Another key advantage of the ARDL model is its ability to simultaneously estimate short- and long-run dynamics, thereby providing a comprehensive view of the relationship between variables. This is critical to understanding how CO2 emissions and other factors affect agricultural productivity over different time horizons.

Our main findings indicate that in the long run, environmental degradation and GDP have significant and negative impacts on food security, persisting in both the short and long terms. However, population growth was found to have an insignificant effect on food security. Notably, agricultural land expansion, while exhibiting a negative effect in the short term, has emerged as a positive contributor to food security in the long term, highlighting its pivotal role in bolstering production capacity. These results underscore the need for sustainable policies that address environmental degradation and economic factors, while supporting long-term agricultural development.

This study contributes to the environmental economics and food security literature in several ways. First, it provides a detailed analysis of the long- and short-run effects of environmental degradation on food security in Somalia, a region that faces unique environmental and socio-economic challenges. By employing an Autoregressive Distributed Lag (ARDL) Bounds Testing Approach, this study captures both the immediate and sustained impacts of CO2 emissions and other environmental stressors on food security.

Second, this study addresses a significant gap in the literature by investigating the intermediary mechanisms through which environmental degradation affects food security, particularly focusing on the interaction between economic factors such as GDP and environmental stressors. This comprehensive approach offers practical insights to policymakers seeking to improve food security and agricultural resilience in the face of environmental and economic challenges. Finally, the findings of the study provide policy-relevant insights that are not only applicable to Somalia but also to other developing nations facing similar environmental and food insecurity challenges. This makes this research globally relevant and contributes to the larger discourse on sustainable agricultural development and food security.

The remainder of this paper is organized as follows. The first section provides an introduction to the topic, followed by a review of the theoretical and empirical literature in section two. The methodology is presented in section three, Section four offers the empirical findings, while sections five and six offer a discussion the results and conclusions of the study, respectively.

2 Literature review

This literature provides an escalating overview of studies in various scenarios of variables of interest. Food security refers to food availability, accessibility, acceptance, and cost. It is when all people have physical, social, and economic access to adequate, safe, and nutritious food that they meet their dietary requirements and food preferences for an active and healthy life. It plays a crucial role in the existence of humans and is required for a healthy life, labor, and economic output [14]. A lack of food security leads to political instability, hunger, malnutrition, dependency on food imports, and negative consequences on trade imbalances [15]. Food security is a crucial indicator of a country's agricultural sector development. The ability of a nation to feed is a fundamental expectation. Therefore, when an agricultural sector can supply nutritious food at an affordable cost, this signifies a significant stride in development.

Somalia and several other countries in the Horn of Africa have experienced frequent food insecurity as a result of drought, climatic fluctuations, and war. Furthermore, since the outbreak of the war in 1991, no government has been able to control the majority of Somalia's land. Violence has made people even more vulnerable by destroying their informal economies and traditional ways of coping.

Somalia has a relatively small amount of forested land, covering only approximately 10.5% of the nation's total land area. This is because much of the country's tropical forests, which were initially located along the Shabelle and Jubba rivers, have reclaimed agricultural land [10]. Between 2000 and 2021, Somalia has suffered an annual deforestation rate of 429,000 ha. This equates to an average annual deforestation rate of, on average, 4.9 per cent. Despite the prospective value of Somalia's natural resources, their natural capital is currently at risk. Land degradation is currently considered to be

between 23 and 30 per cent. Between 2000 and 2015, due to land degradation, Somalia lost 147,704 square kilometres. Several factors are responsible for this loss including soil erosion, biological degradation, and gully erosion. Most urban and rural Somalian households have used firewood and charcoal for years.

Somalia faces a unique confluence of challenges, where environmental degradation intertwines with food security issues amid decades of conflict, political instability, and recurrent droughts. A country's vulnerability to environmental crises is starkly evident in its susceptibility to frequent droughts exacerbated by climate change. These droughts have led to crop failures, livestock deaths, and widespread food shortages, amplifying food insecurity nationwide. Moreover, the country grapples with significant land degradation due to soil erosion, deforestation, and overgrazing. These environmental stressors diminish agricultural productivity, further exacerbating food insecurity among the population.

In addition to environmental factors, poverty remains a significant challenge in Somalia, with approximately 70% of the population living below the poverty line [16]. Prolonged civil conflict, political instability, and environmental adversities have deeply rooted poverty in the country, making it the sixth most impoverished nation in sub-Saharan Africa. Understanding the dynamics of poverty is crucial as it directly intersects with food security, exacerbating vulnerabilities within the population.

2.1 Theoretical framework

The theoretical framework of this study is premised on the Malthusian theory, which states that population growth directly impacts resources, especially food supply. If not matched by improvements in agricultural productivity, this could lead to potential resource scarcity and increased prices. This theory originates from Thomas Malthus's 1798 work. It suggests that while the population grows, food production Increases.

Malthus's theory further argues that population growth reduces savings, increases the dependence ratio, and affects social services such as health and education while contributing to environmental deterioration [17]. These factors hinder economic development by reducing natural resources, personal consumption, and savings. The Malthusian model emphasises that when population expansion outweighs economic development, food supply shortages become unavoidable, resulting in increased consumer expenses, decreased living standards, and escalating poverty. Nevertheless, the framework needs to consider technical developments more adequately, particularly in agricultural productivity, which has profoundly altered the correlation between population increase and food availability since Malthus's time. Furthermore, it neglects the demographic transition hypothesis, which posits that population growth rates diminish as economies advance. Research by [18] and others have investigated the link between environmental deterioration, food insecurity, and population growth, supporting the idea that population growth exerts pressure on resources and food production.

2.2 Empirical issues in literature

CO2 emissions, primarily associated with human activities, such as burning fossil fuels and deforestation, significantly affect global climate change. A critical aspect of this impact is its effect on food security worldwide. Numerous empirical studies have investigated the direct effect of elevated CO2 levels on food security. For instance, [19] concluded that elevated CO2 levels increased the biomass and yield of C3 crops by approximately 20–40%. The impact of CO2 emissions on food availability extends beyond crop productivity and includes changes in land use, water availability, and agricultural practices. Empirical studies have shown that climate change, driven in part by CO2 emissions, can alter precipitation patterns, exacerbate droughts, and increase the frequency of extreme weather events, all of which can affect agricultural production and food availability [20]. According to [18], empirical evidence indicates an inverse correlation between food production and environmental degradation. This suggests that, as environmental degradation increases, food security becomes increasingly threatened [21]. Identified a positive relationship between CO2 emissions and food security. This implies that higher CO2 emissions are associated with improved food security outcomes.

Additionally [22], examined the relationship between external debt, government expenditure, and carbon emissions in Somalia, highlighting the environmental consequences of unsustainable fiscal practices. Their results show that foreign debt and government spending positively and substantially affect CO2 emissions. This indicates that government policies should deliberately target ecologically friendly initiatives to reduce emissions and boost economic development. The literature supports the complicated relationship between economic issues, environmental deterioration, and food security. Similarly, a study by [23] demonstrated that FDI, GDP, and trade openness positively and significantly impact renewable energy consumption. This finding emphasizes the importance of foreign investment and economic growth in driving sustainable energy adoption, consistent with the broader goals of mitigating environmental degradation and

enhancing food security. However, the study highlighted that environmental degradation negatively impacts renewable energy consumption, emphasizing the complex relationship between economic development and sustainability [24]. Pointed out that the primary driver of environmental degradation is the continuous strain on ecosystems beyond their carrying capacities. Their research aimed to address the intertwined challenges of rural poverty and unsustainable agricultural practices, shedding light on policy recommendations for fostering sustainable agricultural production in Nigeria. Agricultural areas and agricultural labour is pivotal in shaping food security outcomes worldwide. Numerous empirical studies have investigated the direct effects of agricultural area and labour on food production and, for example, identified a positive relationship between CO2 emissions and food security. This implies that higher CO2 emissions are associated with improved food security outcomes [25]. Reviewed the international evidence on the influence of urban agriculture on food security. Although the results vary, the collective findings indicate that urban agriculture contributes modestly, yet positively, to food security. Specifically, it facilitates improved availability and accessibility of fresh fruits and vegetables for households experiencing food insecurity. Similarly, investments in agricultural labour can improve access to food by creating employment opportunities and boosting household income [26]. Nwokoro and Chima [24] demonstrated that agricultural land expansion and population growth have a favourable impact on food production.

GDP per capita is a crucial indicator of economic development and household purchasing power and can significantly influence food security outcomes. Numerous empirical studies have investigated the relationship between the GDP per capita and food availability. For instance [21], reveal that GDP per capita has a positive impact on food security. This implies that higher GDP per capita contributes to improving food security outcomes [27]. Discovered a substantial correlation between GDP and environmental degradation in Somalia. However [24], observed an inverse relationship between food production and gross domestic product (GDP) per capita. Food production tends to decrease as GDP per capita increases, highlighting the potentially complex relationship between economic factors and agricultural productivity.

Population growth is a crucial factor for understanding the dynamics of food security [21]. Identified a positive association between the population and food security, suggesting that higher population levels contribute to improved food security outcomes. This finding underscores the importance of considering demographic trends when addressing global food security challenges. In contrast [24], found that, while agricultural land expansion and population growth positively influence food production, the effect of population growth alone on food production is negligible. This aligns with Malthusian theory, which posits that population growth may outpace the rate of food production, leading to potential food shortages. According to [28], Carbon dioxide (CO 2) emissions negatively affect maize production [29]. Found that countries that experienced a projected decrease in population growth tended to have higher levels of food security. This suggests that a slowdown or decline in population growth rates may positively impact food security outcomes in these nations. These findings highlight the relationship between population dynamics and food security. Although population growth may stimulate agricultural expansion and productivity, it may also strain resources and pose challenges to food production sustainability. Understanding these dynamics is essential for policymakers and stakeholders to formulate effective strategies for ensuring food security in a rapidly changing world.

The literature highlights the relationships among CO2 emissions, food security, agricultural productivity, economic growth, and population. Although existing studies provide valuable insights, there is a critical knowledge gap regarding the direct and indirect effects of CO2 emissions on food security in Somalia. This study aims to fill this gap by exploring these connections using the Autoregressive Distributed Lag (ARDL) Bounds Testing Approach. Considering environmental and socioeconomic factors, this study will offer a foundation for developing effective adaptation and mitigation strategies that contribute to sustainable agriculture and food security in Somalia.

Figures 2, 3, 4, 5 and 6 show the trends in CO2 emissions, food security, agricultural productivity, GDP per capita, and Population in Somalia, respectively.

3 Methodology

3.1 Data collection

This study employs annual time-series data covering the period from 1990 to 2019. The food production index, environmental degradation, agricultural area, population, and gross domestic product were among the variables. The data were obtained from the World Bank and Organisation of Islamic Cooperation Countries (OIC) database SESRIC. The time frame was determined based on the availability of data for all variables. Table 1 presents descriptions and details of the data sources. CO2 emissions, measured in millions of tonnes, are a proxy for environmental degradation. Agricultural

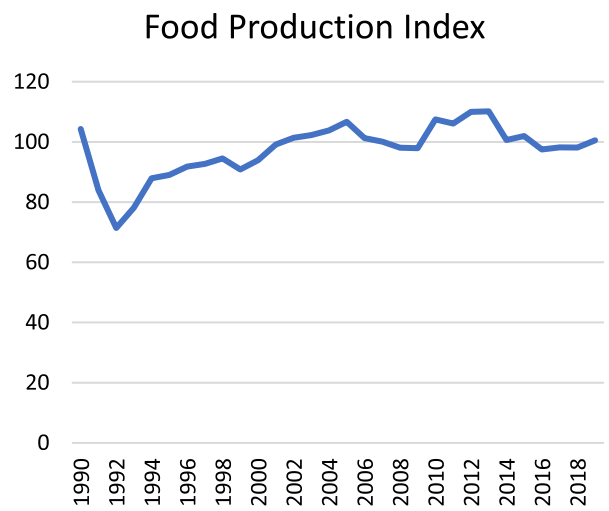

Fig. 2 Food Production Index (2004–2006 = 100)

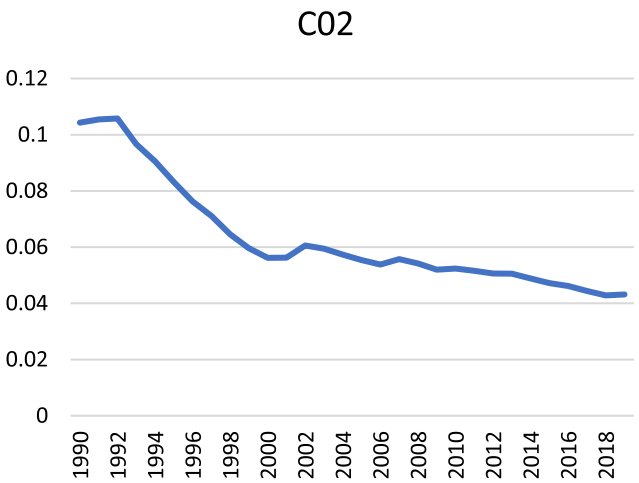

Fig. 3 CO2 emissions (in millions of tones)

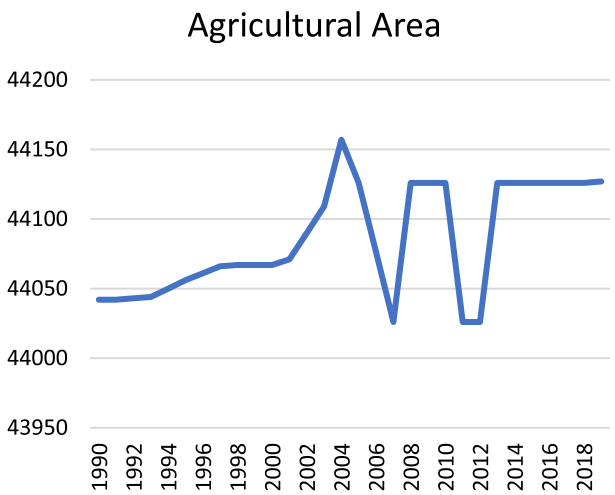

Fig. 4 Agriculture, value-added, constant 2015 prices, annual change (per cent)

productivity is represented by agriculture value-added, while GDP per capita is used as a proxy for economic growth. Population is estimated based on the total number of people. Food security is measured using the Food Production Index (FPI), which tracks food production in metric tonnes. The authors likely chose the Food Production Index (FPI) as a proxy for food security for several reasons, despite the existence of the Global Food Security Index (GFSI): The Food

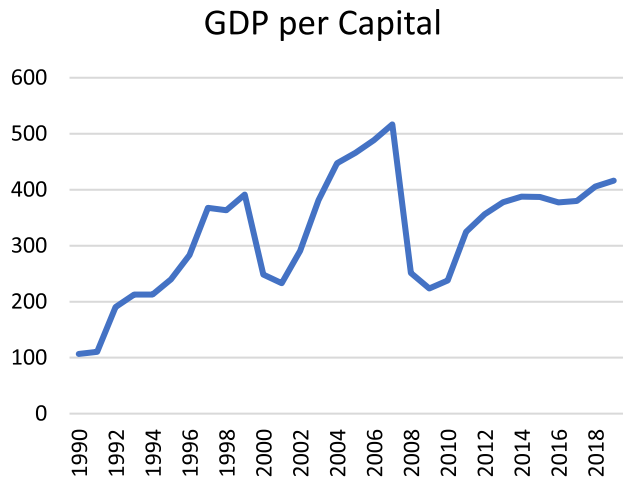

Fig. 5 GDP per capita was constant in 2010 US dollars

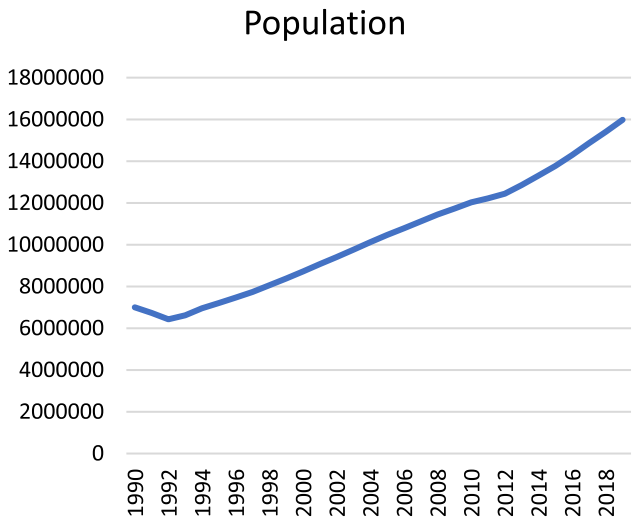

Fig. 6 Population, Total

Table 1 Variable description and date sources

Variables	Explanations	Years	Data sources
Food security	Food Production Index	1990–2019	Sesric
Environmental Degradation (ED)	Represented by CO2 emissions (in millions of tones)	1990–2019	World bank
Agricultural Productivity (AP)	Agriculture, value-added, constant 2015 prices, annual change (per cent)	1990–2019	Sesric
Gross Domestic Product (GDP)	GDP per capita was constant in 2010 US dollars	1990–2019	Sesric
Population	Population, Total	1990–2019	Sesric

Source: Authors' estimations

Production Index (FPI) is often more readily available, especially in countries like Somalia, where comprehensive data collection can be challenging. FPI provides annual agricultural output data, making it easier to track trends over time. The Global Food Security Index (GFSI), on the other hand, might not always have consistent, timely data for Somalia, especially in the context of its various dimensions (availability, accessibility, utilization, and stability), which may require more complex surveys and indicators. The FPI directly measures food production output, offering a clear view of the food supply side, a crucial determinant of food security. Using this index allows the authors to closely examine how changes in environmental degradation and agricultural productivity affect the domestic production of food. Several extant studies,

including [30] and [31] have also used the FPI as a reliable measure of food security. Table 1 provides an overview of the variables used in the study along with their explanations and sources.

3.2 Model specification

This study uses the ARDL bound test established by Pesaran et al. [32] to examine the cointegration between the estimated variables. The ARDL method has several advantages over the previous cointegration techniques. First, the ARDL method can be applied to the underlying regressors regardless of their order of integration, that is, [I (0)], [I (1)], or a combination of both. However, it must be confirmed that none of the variables are [I (2)]. Second, the ARDL model is suitable for small sample sizes and differentiates short- and long-term effects. Third, it simultaneously estimates the long- and short-run coefficients. This feature makes it easier to distinguish between the long-run and short-run effects of independent variables on the dependent variable.

To investigate the impact of environmental degradation, agricultural area, population, and gross domestic product on food security in Somalia, we specify the following model, building on the previous empirical works of [30] and others. The theoretical framework of this study is grounded in the Malthusian theory, which emphasizes the relationship between population growth and resource constraints, particularly food supply. Several extant studies, including [18] expressed the theoretical as follows:

$$FPI_t = \beta_0 + \beta_1 ED_t + \beta_2 POP_t + \beta_3 AGR_t + \beta_4 GDP_t + \varepsilon \tag{1}$$

FPI denotes the food production index, ED denotes environmental degradation, AGR denotes agricultural area, POP is Population, and GDP is the gross domestic product. t and $\mathcal{E}$ represent the time and error terms, respectively. Parameters β1, β2, β3, β4, and β5 are the long-term elasticity of the food production index for environmental degradation, agricultural productivity, and GDP is the gross domestic product, respectively. The main objective of this study is to analyse the short- and long-run associations of the food production index for environmental degradation, agricultural productivity, and GDP as the gross domestic product. Hence, we express the ARDL long- and short-run models of variables as follows:

$$\begin{aligned}\Delta FPI_t = {} & \alpha_0 + \beta_1 FPI_{t-1} + \beta_2 ED_{t-1} + \beta_3 POP_{t-1} + \beta_4 AGR_{t-1} + \beta_5 GDP_{t-1} + \sum_{i=0}^{q} \Delta\alpha_1 FPI_{t-k} \\ & + \sum_{i=0}^{p} \Delta\alpha_2 ED_{t-k} + + \sum_{i=0}^{p} \Delta\alpha_3 POP_{t-k} + \sum_{i=0}^{p} \Delta\alpha_4 AGR_{t-k} + \sum_{i=0}^{p} \Delta\alpha_5 GDP_{t-k} + \varepsilon_t\end{aligned} \tag{2}$$

where α_0 is the constant, α_1–α_5 are the coefficients of the short-term variables, β1-β5 are the elasticities of the long-run parameters, q indicates the explained optimal lags, p represents the optimal lags of the explanators, Δ is the first difference sign showing short-run variables, and ε_t is is the error term. The ARDL cointegration approach begins with bound testing, which is then regressed using Ordinary Least Squares (OLS). The null hypothesis (H0): β1 = β2 = β3 = β4 = β5 = β6 = β7 = β8 = 0 implies that the variables are not cointegrated in the long run, whereas the alternative hypothesis (H1): β1 ≠ β2 ≠ β3 ≠ β4 ≠ β5 ≠ β6 ≠ β7 ≠ 0 implies that the variables are cointegrated in the long run. [32] proposed that if the calculated F-test value exceeds the upper-bound critical value, the null hypothesis of no cointegration is rejected, indicating a long-term relationship. By contrast, if the estimated value of the F-test is less than the critical value, the null hypothesis cannot be rejected, indicating no long-term relationship. The results remain inconclusive if the estimated F-test value falls between the upper and lower critical values.

4 Results and analysis of the estimation

4.1 Descriptive statistics and result of unit root test

The statistical values of various normalities are presented in Table 2 along with the results of the summary measurements across variables. A total of 30 samples of Somalia time-series data from 1990 to 2019 were included in each variable. The food production index had an average of 4.57, with the highest and lowest values being 4.70 and 4.27, respectively. We found that the highest and lowest LEXR values for environmental degradation were 0.11 and 0.04,

Table 2 Descriptive statistics

Variables	FPI	ED	POP	GDP	AGR
Mean	4.573646	0.063206	16.12115	5.711328	70.27412
Median	4.591668	0.055974	16.14676	5.885151	70.25457
Maximum	4.701843	0.105785	16.58693	6.247462	70.38767
Minimum	4.268298	0.042826	15.67620	4.669459	70.17885
Std. Dev	0.096996	0.019350	0.279856	0.392019	0.063610
Observations	30	30	30	30	30

FBI Food Production Index, *ED* Environmental Degradation, *POP* Population, *GDP* Gross Domestic Product, *AGR* Agricultural Productivity

Source: Authors' estimations

respectively, while the mean was 0.06. The population averaged 16.12, with the highest and lowest values being 16.58 and 15.67, respectively. In addition, GDP had an average of 5.71, with Somalia's highest and lowest GDP values being 6.25 and 4.67, respectively. We also found that the average agricultural land area was 70.24, with Somalia's highest and lowest values being 70.39 and 70.18, respectively.

Table 3 presents the results of the unit root tests using augmented Dickey (ADF) and Phillips (PP) methods. Notably, GDP was stationary at this level, implying that these variables exhibited stability without needing differencing. Conversely, FPI, ED, POP, and AGR become stationary at the first difference. In the PPP test, all variables are stationary at the first difference, except GDP, which is stationary at the level. Consequently, the null hypothesis is accepted, acknowledging the presence of a unit root for certain variables at level.

4.2 Bound cointegration ARDL long-run coefficient

To determine the optimal lag length for cointegration analysis, we used the Akaike criterion (AIC), Schwarz-Bayesian criterion (SBC), and information criterion (IC). AIC found that the two lags were the most effective. Following the estimations in the bound's tests listed in Table 4, we calculated an F-statistic of 7.985186, which is higher than the upper bound critical value of 5.06. This means that we reject the null hypothesis and conclude that there is a cointegration relationship between exchange rate, GDP, money supply, imports, and inflation.

Table 3 Result of unit root test

	ADF			PP		
Variables	T-statistics	Prob	Order	T-statistics	Prob	Order
FPI	− 5.1218	0.0003***	I (1)	− 5.5309	0.0001***	I (1)
ED	− 6.017810	0.0000***	I (1)	− 2.8625	0.0726*	I (0)
POP	− 4.1863	0.0035***	I (1)	− 4.8553	0.0006***	I (1)
AGR	− 6.5681	0.0000***	I (1)	− 8.5179	0.0000***	I (1)
GDP	− 3.7798	0.0081***	I (0)	− 3.6453	0.0108**	I (0)

Source: Authors' estimations

(*) Significant at the 10% level; (**) Significant at the 5% level; (***) Significant at the 1% level and (no) Not Significant

Table 4 Bound cointegration ARDL long run coefficient

F-Bounds Test		Null Hypothesis: No levels relationship		
F-statistic	Value	Signif	I(0)	I(1)
	7.985186		Asymptotic: n = 1000	
		10%	2.45	3.52
		5%	2.86	4.01
		2.5%	3.25	4.49
		1%	3.74	5.06

4.3 Long–run and short–run results

As the estimates in Table 5 show, the regression analysis reveals crucial insights into the dynamics between critical variables and food security in Somalia in the long-run.

The analysis shows a negative and statistically significant correlation between environmental degradation and food security, with a significance level of 1%. Specifically, a 1% increase in environmental degradation leads to a 5.3% decrease in food security in Somalia in the long term. This indicates that environmental deterioration poses a significant challenge to food security. This indicates that, as environmental degradation worsens, food security in Somalia declines. This underscores Somalia's agricultural sector's vulnerability to climate change and environmental degradation. Urgent measures, such as sustainable land management practices, including reforestation efforts and soil conservation, are imperative to mitigate these adverse impacts and bolster food production resilience.

The result also shows a negative and statistically significant correlation between GDP and food security, with a significance level of 1%. Specifically, a 1% increase in GDP leads to a 0.3% decrease in food security in Somalia in the long term. While economic growth is crucial for improving food availability and access, this analysis implies that certain factors associated with GDP per capita may hinder food security outcomes. This complexity calls for a deeper understanding and a subtle approach to economic development policies, focusing on inclusive growth strategies that prioritize food security alongside economic advancement.

Similarly, the study shows a negative and statistically significant correlation between Population growth and food security, with a significance level of 1%. Specifically, a 1% increase in Population growth leads to a 0.2% decrease in food security in Somalia in the long term. This indicates that other factors might play a more critical role in determining food security. However, the negative coefficient (– 0.226458) suggests that population growth still poses a challenge, emphasizing the need for effective family planning, education, and healthcare policies to ensure equitable access to food resources.

In contrast, agricultural land in Somalia had a positive and significant relationship with food security, with a significance level of 1%. Specifically, a 1% increase in agricultural land leads to a 1.2% decrease in food security in Somalia in the long term. The positive coefficient (1.250189) of agricultural land signifies its crucial role in enhancing food security. This highlights the potential for improvement by investing in agriculture, particularly in terms of supporting smallholder farmers with access to resources and promoting sustainable practices. Such investments have emerged as a promising avenue for bolstering food production and livelihood in rural communities. Although environmental deterioration and population growth pose significant challenges to food security in Somalia, strategic interventions and policy measures can mitigate these risks. The findings also underscore the need for a holistic approach to economic development that prioritizes food security along with GDP growth. Moreover, investments in agriculture have emerged as a cornerstone of sustainable food security outcomes, emphasizing the importance of targeted support for the agricultural sector. Thus, HI, H3, and H4 were accepted. However, H2 is rejected because the population growth is not significant.

Table 6 presents the Error Correction Model (ECM) determined short-term adjustments. Environmental deterioration, population, GDP, and agricultural land had a statistically significant negative connection with the dependent variable in the near term. A negative error correction term was considered statistically significant. Negative (ECM-1) suggests that variables will be fixed at 0.46 per cent to return to the long-run equilibrium.

Table 5 Long–Run coefficients

Variable	Coefficient	t-Statistic	Prob
ED	– 5.300991*	– 1.757769	0.1023
POP	– 0.226458	– 1.660990	0.1206
GDP	– 0.332040*	– 1.771056	0.1000
AGR	1.250189*	1.826223	0.0909

Source: Authors' estimations

Table 6 Error Correction Model (ECM)

Case 3: Unrestricted constant and no trend				
Variable	Coefficient	Std. Error	t-Statistic	Prob
C	– 35.46854	4.904512	– 7.231819	0.0000
D(ED(-1))	– 5.922468	2.606560	– 2.272140	0.0407
D(POP)	– 2.435163	1.013459	– 2.402823	0.0319
D(GDP(-2))	0.085798	0.032281	2.657809	0.0197
D(AGR(-1))	– 0.242855	0.101899	– 2.383298	0.0331
ECT(-1)*	– 0.459561	0.063601	– 7.225706	0.0000

Source: Authors' estimations

* p-value incompatible with t-Bounds distribution

4.4 Diagnostic and stability tests

To further validate the stability and robustness of our model, we conducted several diagnostic tests. Ensuring the absence of autocorrelation, heteroscedasticity, and non-normality, as well as confirming the correct specification of the model, is crucial. The expectation is that all test statistics should be statistically insignificant to confirm the model's robustness.

The results, presented in Table 7, show that the Breusch–Godfrey LM test for autocorrelation indicates no evidence of autocorrelation, as the F-statistic is statistically insignificant. Similarly, the Breusch–Pagan–Godfrey test for heteroscedasticity reveals a statistically insignificant F-statistic, suggesting that heteroscedasticity is not present among the error terms. The Jarque–Bera test for normality confirms that the variables are normally distributed. Additionally, the CUSUM squares test demonstrates the stability of the model. Overall, the diagnostic tests confirm that the model is free from heteroscedasticity, serial correlation, and is correctly specified, ensuring its robustness.

5 Conclusion

This study measured the impact of environmental degradation on food security in Somalia. We relied on a comprehensive set of yearly time-series data for Somalia, spanning 1990–2019, resulting in 30 observations. The ARDL model was applied to econometrically investigate the relationship between the latent variables. The empirical data reveal that stark reality-environmental degradation and GDP have profound negative impacts on Somalia's food security, both in the short and long term. This stark finding underscores the urgent need for action, as these factors consistently and significantly undermine food security, leaving Somalia grappling with the persistent challenge of ensuring access to sufficient and sustainable food supply.

Interestingly, our study did not find a significant long-term impact of population growth on food security in Somalia. This finding suggests that other factors that are yet to be fully understood may play a pivotal role in determining the country's food security situation.

Agricultural land exhibits a positive and significant association with food security in the long term, and its impact appears nuanced in the short run, displaying a negative effect. This suggests that immediate increases in agricultural land may temporarily disrupt food security, possibly because of factors such as land conversion or adjustment periods. However, over the long term, the expansion of agricultural land has emerged as a significant contributor

Table 7 Diagnostic and stability test results

Test	F-statistics	Prob. Value
Autocorrelation	2.2693	0.1401
Heteroscedasticity	6.5000	0.8380
Normality		0.214
CUSUMQ	Stable	

to enhanced food security through increased production capacity. This underscores the importance of considering both short-term and long-term benefits in agricultural policy and planning. This ensures a balanced approach that addresses immediate needs, while fostering sustainable growth in food security over time.

6 Discussion

Food security and environmental degradation are closely intertwined. Somalia and several other countries in the Horn of Africa have experienced frequent food insecurity as a result of drought, climatic fluctuations, and war. Furthermore, since the outbreak of the war in 1991, no government has been able to control the majority of Somalia's land. Violence has made people even more vulnerable by destroying their informal economies and traditional ways of coping. Somalia has a relatively small amount of forested land, covering only approximately 10.5% of the nation's total land area. Much of the country's tropical forests, initially located along the Shabelle and Jubba Rivers, reclaimed agricultural land. Between 2000 and 2021, Somalia has suffered an annual deforestation rate of 429,000 ha. This equates to an average annual deforestation rate of, on average, 4.9 per cent. Despite the prospective value of Somalia's natural resources, their natural capital is currently at risk. Land degradation is currently considered to be between 23 and 30 per cent. Between 2000 and 2015, due to land degradation, Somalia lost 147,704 square kilometres.

Several factors are responsible for this loss including soil erosion, biological degradation, and gully erosion. Most urban and rural Somalian households have used firewood and charcoal for years. This study measured the impact of environmental degradation on food security in Somalia. The ARDL model was applied to econometrically investigate the relationship between latent variables. The results reveal that all the variables in this study are statistically significant in explaining food security in Somalia. Specifically, environmental degradation, population, and per capita positively affect food security.

The study revealed a noteworthy negative and statistically significant relationship between environmental degradation and food security, with a significance level of 10%. A 1% increase in environmental degradation leads to a 5.3% decrease in food security in Somalia in the long term. In simpler terms, the significant negative relationship between environmental degradation and food security in Somalia indicates that as environmental conditions worsen, food security outcomes deteriorate. This implies that factors such as deforestation, soil erosion, and climate variability directly impact a country's availability, access, and utilization of food resources. Food production in Somalia has been steadily hindered by the ongoing degradation of natural resources, including deforestation, soil erosion, and water shortages, affecting agricultural output. The degradation of ecosystems has significantly diminished the availability of fertile land and water—both essential for sustainable farming. The decline of this resource is accelerated by several factors, such as unpredictable and extreme weather patterns, fragmented and underdeveloped markets, inadequate value addition, and restricted access to quality agricultural inputs like seeds, fertilisers, and animal vaccines, all of which hinder productivity and decrease efficiency.

These challenges have significantly impacted crop productivity. Ongoing instability, ineffective government institutions, and the subsequent degradation of essential infrastructure, including flood control, irrigation systems, and transportation networks, particularly in southern areas, exacerbated the situation.

Moreover, extensive deforestation has accelerated desertification across large regions of the nation. The unsustainable use of natural resources—such as land fragmentation, unrestricted grazing, and unlawful land enclosure—has diminished communities' ability to deal with droughts. Environmental and structural challenges have substantially reduced agricultural production and weakened the ability of local people to deal with unfavourable climatic and economic circumstances. Consequently, Somalia's agricultural sector, which relies heavily on natural resources, is vulnerable to the adverse effects of environmental degradation. Practically, this finding underscores the urgent need for interventions to mitigate environmental degradation and build resilience in food production systems. Efforts such as sustainable land management practices, reforestation initiatives, and soil conservation measures are imperative to address the root causes of environmental deterioration and safeguard food security for the Somalian population. Thus, HI is accepted, which aligns with previous research findings by [18], further reinforcing the significance of addressing environmental degradation as a key component of efforts to improve food security.

GDP also has a negative relationship with food security in Somalia, with a significance level of 10%. A 1% increase in GDP leads to a 0.33% decrease in food security in Somalia in the long term. Although agriculture is a crucial catalyst for economic development, the sector has poor productivity in Somalia owing to several constraints, such as an unfavourable climate, recurrent climatic disturbances, inadequate infrastructure, insufficient technology, and minimal

investment levels. This agricultural underperformance directly impacts food availability, clarifying why GDP growth does not result in improved food security outcomes. Several key factors contribute to the disconnect between Somalia's economic growth and food security. First, due to climate change, Somalia has experienced more frequent and severe droughts and floods. These events have adversely affected crop production and displaced rural populations to urban areas. Secondly, economic growth is insufficient to employ all those capable of working, affecting Somalis' capacity to acquire sufficient food (SDG 8) [33]. Finally, weak infrastructure hinders the transportation of food to markets and vulnerable populations (SDG 9) [33]. This finding suggests a complex relationship between economic development and food security. While economic growth is essential for improving food availability and access, this analysis implies that certain factors associated with GDP per capita may hinder food security outcomes. This calls for a subtle approach to economic development policies that focuses on inclusive growth strategies that prioritize food security and economic advancement. Somalia has experienced prolonged political instability, conflict, and economic fragility, which has hampered its economic development and resilience. Fluctuations in GDP growth, often influenced by factors such as conflict, droughts, and global economic trends, directly affect the purchasing power and livelihoods of the population. Thus, H3 is accepted and the result is in line with that of [24].

In contrast, agricultural land had a positive and significant relationship with food security in Somalia, with a significance level of 10%. This implies that increased agricultural land is associated with improved food security in the country. A 1% increase in GDP leads to a 1.25% increase in food security in Somalia in the long term. In simpler terms, as the availability and quality of agricultural land increases, the ability to produce food and ensure access to it also improves, thereby enhancing food security. This indicates that expanding agricultural land is related to enhanced food security. It suggests that the larger proportion of land designated for agriculture than the overall land area enhances the possibility of increased food production. To capitalize on this, the government must increase the percentage of land designated for agricultural use. This can be achieved by implementing policies that limit the invasion of agricultural land for residential and industrial use. Furthermore, supporting farmers by assisting with land clearing and access to fertilizers will help enhance soil fertility, further boosting the country's agricultural productivity and food security. Investing in agriculture, particularly supporting smallholder farmers with access to resources and promoting sustainable practices, has emerged as a promising avenue for bolstering food production and livelihoods in rural communities. Agricultural land is a fundamental resource for cultivating crops and raising livestock in Somalia, where agriculture is a vital component of livelihood and food production. Expansion of agricultural land can lead to increased agricultural output, thereby enhancing food availability for the population. This increase in agricultural land provides farmers with space to grow crops and raise animals, ultimately improving food security by increasing the quantity of food produced. Thus, H4 is accepted, and the result is in line with [24].

The study revealed a noteworthy negative and statistically significant relationship between Population growth and food security, with a significance level of 10%. A 1% increase in Population growth leads to a 0.23% decrease in food security in Somalia in the long term. Population growth, although not significantly affecting food security in the long run in Somalia, indicates that other factors might play a more critical role in determining food security. However, the negative coefficient (-0.226458) suggests that population growth still poses a challenge, emphasizing the need for effective family planning, education, and healthcare policies to ensure equitable access to food resources. This result indicates that population growth can lead to increased demand for food, placing additional pressure on agricultural production systems that are already facing challenges such as climate change, low investment, and infrastructural deficits. Thus, H2 is accepted, and this result is in line with [28].

7 Conclusion and policy implications

This study measured the impact of environmental degradation on food security in Somalia. We relied on a comprehensive set of yearly time-series data for Somalia, spanning 1990–2019, resulting in 30 observations. The ARDL model was applied to econometrically investigate the relationship between the latent variables. The empirical data reveal that stark reality-environmental degradation and GDP have profound negative impacts on Somalia's food security, both in the short and long term. This stark finding underscores the urgent need for action, as these factors consistently and significantly undermine food security, leaving Somalia grappling with the persistent challenge of ensuring access to sufficient and sustainable food supply.

Interestingly, our study did not find a significant long-term impact of population growth on food security in Somalia. This finding suggests that other factors that are yet to be fully understood may play a pivotal role in determining the country's food security situation.

Agricultural land exhibits a positive and significant association with food security in the long term, and its impact appears nuanced in the short run, displaying a negative effect. This suggests that immediate increases in agricultural land may temporarily disrupt food security, possibly because of factors such as land conversion or adjustment periods. However, over the long term, the expansion of agricultural land has emerged as a significant contributor to enhanced food security through increased production capacity. This underscores the importance of considering both short-term and long-term benefits in agricultural policy and planning. This ensures a balanced approach that addresses immediate needs, while fostering sustainable growth in food security over time.

Based on the findings of this study, several recommendations can be proposed to address the challenges of food security in Somalia amid environmental degradation, population growth, and economic dynamics. First, prioritizing initiatives aimed at sustainable land management, such as reforestation, soil conservation, and watershed management, is crucial. These practices can help mitigate environmental degradation, preserve natural resources, and enhance the resilience of agricultural systems to climate change. Additionally, integrating population considerations into national policies and development plans is essential to ensure that population dynamics are factored into sustainable development and food security strategies. Efforts to enhance economic stability should be prioritized through fiscal discipline, monetary policy coordination, and institutional reforms. This includes strengthening regulatory frameworks, improving governance, enhancing transparency to attract investments, and fostering economic growth. Investing over the long term in irrigation infrastructure, equipment, and water infrastructure for domestic consumption and livestock rearing is critical. Expanding and modernizing irrigation systems can increase agricultural productivity while reliable water access supports human consumption and livestock, contributing to overall food security. Furthermore, expanding agricultural land is vital, as it is the foundation for food production, providing the space and resources necessary for cultivating crops and raising livestock. An increase in agricultural land area can lead to a higher agricultural output, thereby improving food availability for the population. Finaly, Support programs that enhance food availability at the domestic level stabilise access for the most food-insecure populations, and build resilience are necessary. This could encompass activities that improve access to agricultural and livestock assets.

Although this study provides valuable insights into the relationship between environmental degradation, population, GDP, and food security in Somalia, it is subject to certain limitations. One notable constraint is the reliance on yearly time-series data covering 1990–2019, resulting in a relatively small sample size of only 30 observations. This limited timeframe may not fully capture the intricacies and variability of environmental degradation, population dynamics, GDP fluctuations, and food security outcomes in Somalia. Future research efforts should consider conducting longitudinal studies using more extensive and temporally detailed datasets to address these limitations and to advance our understanding of these complex interrelationships. By analyzing trends and dynamics over a more extended period, researchers can gain deeper insights into the evolving nature of environmental degradation, population growth, economic development, and food security outcomes in Somalia.

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Declarations

Competing interests The authors declare no competing interests.

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