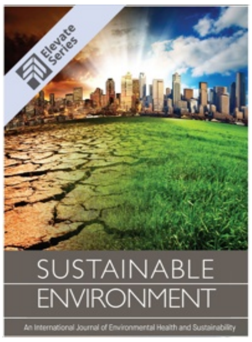

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Deciphering the connection: Exploring the relationship between finance, trade, and urbanization in the ecological fabric of African economies

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ABSTRACT
This study contributes to the Sustainable Development Goal 15 by examining the dynamics of balancing the ecological footprint and meeting fundamental human needs in terms of food and shelter. The analysis utilizes a panel dataset comprising 9 countries with ecological deficits, covering the period from 1971 to 2022. The estimators employed in the study are robust to cross-sectional dependence and allow for heterogeneous slope coefficients. The findings, based on the FE-DK and MMQR models, provide empirical evidence supporting the ecological deficit hypothesis. The validity of the ecological deficit hypothesis is verified by the inverted U-shaped nexus between economic growth and ecological deficits. Finance plays a mitigating role in reducing the ecological deficit for food, but it is associated with higher levels of deficit for shelter, particularly at the upper quantile. Trade openness exacerbates the ecological deficit for food, but it helps reduce the deficit for shelter. Robustness analysis, conducted using the half-panel jackknife multivariate Wald-type test, confirms that the covariates exhibit Granger-causal relationships with the ecological deficit. Bidirectional causal relationships are observed between the ecological deficit for food and squared economic growth. Additionally, bidirectional relationships exist between trade and urban population and the ecological footprint for shelter. The findings offer useful insights for policymakers and stakeholders that are working towards achieving sustainable development.

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Finance; trade; and Urbanization; ecological deficit; African

1. Introduction

In the aftermath of COP 28, the discussion around addressing ecological deficits in Africa resurrects within academic and policy circles, especially as the curtain draws on the sustainable development goals targeted by 2030. The Institute of Economics and Peace estimates the number of people living in countries facing grave ecological threats to peak 2.8 billion by 2050 compared to its 1.8 billion figures in 2023. The 2023 Ecological Threat Report (ETR) posits that countries in sub-Saharan Africa embodies the highest ecological threat compared to any other region covered in the report. The ETR posits that 19 out of 30 hotspot countries facing the highest ecological threats are geographically located in sub-Saharan Africa (see empirical evidence in Marti & Puertas, 2020). The ETR also highlighted the four most countries in the sub-region facing the highest ecological threats: Ethiopia, Niger, Somalia, and South Sudan. Other countries, such as Algeria, South Africa, Libya, Djibouti, Tunisia, Ghana, Egypt, Morocco, Sao Tome & Principe, Lesotho, Togo, and Comoros, are also on red alert when considering ecological footprint and bio-capacity available.

The United Nations recent projection on Africa's economic growth for 2024 alongside projected population increase by 2050 echoes the current state of African countries, especially in its over five decades pursuit of economic prosperity and all-round sectoral development (energy, transport, health, housing, agriculture). Indigenous Africans resort to encroachment of the ecosystem to satisfy their needs using improvised alternatives that deplete the natural ecosystem. Food & Agriculture Organization posits that Africa loses 4 million hectares of forest annually and Africa's drylands are more vulnerable to desertification and climate change effects which plunges Africa into deeper food crisis. The Ecological Threat report added succinctly that increase in demographic pressure, scarcity of water and natural disasters in countries elevates their ecological threats. The case falls back to how ecological funds throughout the sub-Saharan and the Arabian part of Africa are managed vis-a-vis the plan to restore the depleted ecosystem throughout Africa.

The triad: finance, trade, and urbanisation, is interrelated elements for growth actualisation and economic development in a broader perspective. The selected African economies are still regarded as laggards in the growth circles evidenced by the widely accepted tag of developing economies. The interrelatedness of the triad

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is explained; thus, first, finance made available through financial institutions stands as capital for business expansion, small and medium enterprises funding, infrastructural financing, and financing for other development-related activities (see Onyeiwu et al., 2021; Okere et al., 2022; Okolo et al., 2023). Consequently, as growth takes an upward spike in these developing economies, the level of urbanisation increases almost at the same pace as citizens are hunting for access to jobs, goods and services (Gross & Ouyang, 2021). Urbanisation paves the way for trade hubs alongside a heavy concentration of businesses, customers, and relevant institutions and infrastructure that aid the exchange of goods and services. Aside from the described positives attached to the triad, there are hanging negative consequences on environmental quality, especially in developing economies (see Okere et al., 2022; Muoneke et al., 2023a). The continuous quest for growth in these developing African economies will prompt a huge spike in trade volume and urbanisation levels which has a deteriorating impact on the environment in the absence of strong institutions.

The study is built on the loci of the ecological deficit hypothesis, which summarises the continuous defiance of traditional growth-enhancing activities at the detriment of ecological well-being. From a more specific perspective, this study extends the ecological deficit hypothesis to incorporate relevant socioeconomic factors such as urbanisation in studying the effects of macroeconomic and socioeconomic variables on ecological footprint in selected ecological deficit countries in Africa. The selection of finance in investigating the effects of economic and socioeconomic factors on ecological footprint is well pronounced in the literature (see Ahmed et al., 2021; Baloch et al., 2019; Liu et al., 2022; Murshed, 2024; Saqib et al., 2023; Zhang et al., 2022). Finance can contribute to a reduction in ecological footprint if it is invested in R&D activities capable of churning out high-end technologies that enhance energy efficiency in residential buildings, transport, corporates, agriculture, and industrial plants. Furthermore, finance targeted at ecosystem restoration projects across the board will also enhance reduction in the country's ecological footprint. However, the opposite seems to be the case, as numerous financial institutions within Africa provide finance for energy-intensive projects, especially to high-polluting industries, especially around plant expansion and energy-intensive equipment purchase (see Okere et al., 2021, 2022; Muoneke et al., 2022a; Okere et al., 2023). Finance remains an accessory to economic expansion for decades in the case of Africa and other developing economies; however, green finance rather than traditional finance contributes to the restoration of ecological balance (see Liu et al., 2023).

Dogan et al. (2019) asserted that urbanisation, exports, finance, and fossil fuel energy consumption are the common causes of anthropogenic pressure on the environment. The circle of economic prosperity holds sway in the case of trade, urbanisation, and ecological footprint nexus. In the case of Africa, the citing of economic activities to big cities contributes to the mass movement of indigenes from rural to urban areas. This, in turn, increases energy consumption and demographic pressure on prevailing infrastructural facilities alongside food, air and shelter (see Ahmed et al., 2020). On the other hand, Ali et al. (2016) posited that urbanisation may not have a negative impact on environmental quality through the channel of energy consumption if the income level of the citizens remains low. Charfeddine and Mrabet (2017) posited that urbanisation improves the environment in the long-run for MENA countries which may be as a result of proper urban management planning and availability of green technology. On the part of trade, emerging economies through the auspices of industrialisation aspire to acquire a positive trade balance which puts a strain on the environment through the process of extraction of raw materials and an energy-intensive production process. On the other hand, facilitation of transfer of environmental technologies through trade may overturn the negative effect on environment as opined by Opuala et al. (2023) in the case of West Africa. Nwaeze et al. (2023) posited that trade will reduce emissions in region with high environmental standards such as the EU.

Consequently, this study seeks to answer the following questions: (a) ascertain the impact of finance, trade, and urbanisation on ecological footprint in selected ecologically deficient countries in Africa, and (b) establish or verify the presence of an ecological deficit hypothesis between economic growth and ecological footprint in the selected countries. (c) Establish the threshold level of economic growth at which further expansion intensifies environmental impact? (d). determined other significant drivers of the ecological footprint of the selected African nation. This study contributes to the literature in two ways. First, the ecological footprint (deficit) was employed as a measure to assess environmental degradation within the Ecological Tapestry of African Economies. This choice was made because of the limitations of relying solely on CO2 as a comprehensive and reliable indicator of ecological performance. The ecological footprint serves as an indicator of the extent to which humanity depends on the Earth's ecosystems and natural resources. It is calculated by considering current technology and management practices, while accounting for the amount of land and water required to produce the necessary resources and absorb waste generated by humans. The overall ecological footprint comprises six key components: fishing grounds, cropland, forests, developed land, grazing land, and land allocated for carbon requirements. In our study, we grouped ecological footprint into i) ecological footprint in built-up land and forest product, that is, deficit in Shelter ii) ecological footprint in the area of cropland, fishing ground and grazing land, deficit on Food. This procedure helped us to be distinct from previous empirical attempts by focusing solely on ecological deficit countries in Africa, thereby enriching policy direction on the above topic. Second, existing studies such as Ahmed et al. (2020); Ali et al. (2016); Charfeddine and Mrabet (2017); Opuala et al. (2023); Nwaeze et al. (2023); Dimnwobi et al. (2021) concentrated on the effect of solely on modelling the conditional mean of the dependent variable (ecological footprint) among others. We take a step further to account for the conditional distribution of ecological deficit by using Method of Moments Quantile Regression (MM-QR) proposed by Machado and Silva (2019) to manage fixed effects in panel quantile models. By employing the MM-QR estimator, we investigate the impact of Finance, Trade, and Urbanization on the lower, median, and upper distributions of ecological deficit countries in Africa. Third, we take a step further to test whether a U-shaped curve or inverted U-shaped exists between economic growth and ecological deficit. In contrast to the linear specifications that have defined a sizable proportion of the empirical modelling in the literature, we bring to the fore the threshold level of economic growth, beyond which further expansion of economic wealth triggers the sustainability progress or decay. Finally, to inform policy deliberations, we extend our empirical analysis to reveal how finance, trade, and urbanization can contribute to resolving sustainability dilemmas in the Ecological Tapestry of African countries. Our empirical insights can, therefore, offer valuable guidance for policymakers in African nation suffering from ecological deficit and beyond.

The following section provides an overview of the existing empirical and theoretical literature relevant to the study. Subsequently, the third section presents the methodology. The fourth section presents the findings obtained from the analysis. Finally, the closing section concludes the study, summarizing the key findings and offering policy insights based on the results.

2. Literature review

2.1. Finance and ecological footprint nexus

The relationship between finance and ecological footprint in the case of Africa seems one-sided as the presence of strong institutions seems to command a positive effect for countries in Africa with high institutional quality. Murshed (2024) also sought to ascertain the validity of the ecological deficit hypothesis in selected mineral-exporting nations and investigated the role of FinTech financing on ecological footprint in selected mineral-exporting nations. Results showed an inverted U-shaped nexus between FinTech credits and ecological deficits and validated the pollution-haven hypothesis in the context of ecological deficits. Liu et al. (2022) did a comparative study between developed and developing economies on the finance-ecological footprint nexus. Results showed that financial development leads to a higher ecological footprint in developing economies, while the reverse is the case for developed economies. Ahmed et al. (2021) added to the findings of Liu et al. (2022) stating that economic globalization and financial development increase the ecological footprint of Japan. Baloch et al. (2019) extended the discussion to Belt and Road countries, and results showed that financial development increased ecological footprint in the selected 59 Belt and Road countries.

Navigating to the African scene, Okere et al. (2023) found that financial development increased carbon emission and carbon intensity in the case of Nigeria. On the other hand, Muoneke et al. (2023b) asserted that Africa is yet to attain the threshold of finance necessary to trigger transition to cleaner forms of energy. Aladejare and Nyiputen (2023) corroborated with Okere et al. (2023) and Muoneke et al. (2023b) stating that natural resources wealth, income growth, and globalisation increased ecological footprint in Africa. Ekeocha (2020) discovered a N-shaped curve between economic development and environmental degradation in Africa as opposed to the inverted-U shaped common in Murshed (2024) and Kizilgol and Ondes (2022). Dogan et al. (2019) debunked the findings of Muoneke et al. (2023b) and Okere et al. (2023) stating that financial systems in Nigeria, Mexico, and Indonesia are successful in directing financial resources to environmentally friendly sectors, which in turn increases environmental quality in the aforementioned countries.

Other authors utilised financial market integration as the measure of finance against ecological footprint. Zhang et al. (2022) found the effect of financial globalisation on ecological footprint to be positive in the case of BRICS nations, thus validating the existence of pollution-haven hypothesis in BRICS nations. Adebayo et al. (2022) also posited that globalisation has reduced environmental pollution in newly industrialised countries. Ahmad et al. (2021) asserted that financial integration and eco-innovation have reduced ecological footprints collectively in G7 economies. Aydin and Turan (2020) aligned with the findings of Ahmad et al. (2021) stating that financial openness reduces environmental pollution in India and South Africa only. Surprisingly, Usman, Makhdum, et al. (2020) documented that financial development reduced ecological footprint in 15 highest-emitting countries, which goes a long way to validate the claims raised by Abbasi and Riaz (2016). Furthermore, Chien et al. (2023) also posited that financial development reduced ecological footprint in ASEAN countries which may be due to the prevailing level of green technology and a strong institutional arrangement to direct finance to environmental-friendly sectors.

2.2. Trade and ecological footprint

The theoretical connection between trade and environmental quality emanates through the identified causal pathways stated thus, a) scale effect b) composition effect and c) technique effect. The scale effect represents the most direct impact of trade on the environment through the auspices of increased economic activity. As trade volumes ascend rapidly, overall economic activity increases parri-passu and has a multiplier effect on resource extraction, production, and consumption. The result often amounts to higher levels of environmental pollution and resource depletion. The intensity of resource extraction for the purpose of production, local consumption, and exports is at its highest pinnacle in developing economies in the Global South.

The composition effect gives rise to the pollution-haven hypothesis emanating from the desire of firms to lock in comparative advantage, specialisation, cost-savings, and other juicy benefits. The firms relocate their production facilities to economies with weaker environmental regulations. Due to the presence of weak environmental regulation in developing economies, firms will only invest in cleaner production process for countries with stricter environmental regulations. Trade at this point becomes a disservice to the environment. The technique effect favours environmental sanctity in developing economies, especially in Africa. Trade can facilitate the transfer of environmental innovation and technologies across national and international borders, which helps address the level of carbon emissions and other greenhouse gas emissions.

Nathaniel (2019) and Ali et al. (2016) in the case of Nigeria found that trade improved environmental quality and this finding was further expanded in the case of Indonesia, where Nathaniel (2020) found that trade reduces environmental degradation in the short and long-run. Usman, Kousar, et al. (2020) brought a unique perspective comparing upper-middle-income economies across Africa, Asia, Europe, and America. Usman, Kousar, et al. (2020) rightly noted that trade only reduces ecological footprint in Asia in line with Nathaniel (2020). On contrary, Usman, Kousar, et al. (2020) found that trade increased ecological footprint in the case of Africa and America. Dauda et al. (2020) opened policy insights through their empirical analysis confirming the existence of pollution haven hypothesis and pollution-halo effect in Tunisia, Algeria, Mozambique, Egypt, Kenya, Morocco, Mauritius, Zambia, and South Africa. The results of Dauda et al. (2020) exemplifies the existence of the positives and negatives of trade in the African countries.

Regional study conducted by Opuala et al. (2023) debunked the findings of Nathaniel (2019) and Ali et al. (2016) stating that trade in the West African region increases environmental decay. The highlight raised by Usman, Kousar, et al. (2020) on the inherent power of trade in engendering environmental sustainability in Asia is resurrected in Ansari and Khan (2021) and Chien et al. (2023). Ansari and Khan (2021) delved into specifics stating that composition effect and trade openness enable Asian countries to transfer environmental decimation to developing economies with weaker environmental regulations. Cutcu et al. (2023) documented those imports decreased ecological footprints in the top-ten fastest developing economies. Appiah et al. (2021) found that export and urbanisation increased environmental quality; however, the coefficients were negative but not significant.

2.3. Urbanisation and ecological footprint

Ali et al. (2016) raised an important point regarding urbanisation and ecological footprint nexus discourse. Ali et al. (2016) stated that high-level urbanisation may not prompt an increase in energy consumption in countries with low-income citizens. Muoneke et al. (2023a) dared to assess it in the case of Med-9 countries and discovered that urbanisation and government effectiveness increased environmental decay in Med-9 countries. The urban population is expected to double its current figures and the available urban infrastructure is inadequate to accommodate the teeming numbers of migrants from rural areas and migrants from foreign countries.

On the African scene, Nathaniel et al. (2020) and Yuzbashkandi et al. (2023) found that urbanisation contributes to environmental degradation in the Middle East and North African nations. There are perceivable conflicts in academic literature in the case of South Africa, S. Nathaniel et al. (2019) documented that urbanisation and energy use promote environmental quality in the long-run. On contrary, Nathaniel et al. (2021) documented that urbanisation increased ecological footprint in the case of South Africa, while human capital helped to reduce the adverse effect. The findings of Nathaniel et al. (2021) follows closely the findings obtained by Ahmed et al. (2020) in the case of G7 countries.

In highly populated countries such as India, Khan et al. (2023) found that urbanisation contributes to environmental quality in the long-run. The matter seems to follow the same path as in the case of GCC countries: Amer et al. (2022) documented that urbanisation does not hurt the environment. However, Salman et al. (2022) found that urbanisation affected ecological footprint in the case of Indonesia and Thailand. Reasons to support the results obtained by Salman et al. (2022) include the citing of over 10 million people in the Bangkok urban area of Thailand, which has adverse multiplier effects on transportation and air & water quality in the Metropolis.

3. Methodology

3.1. Data and materials

This study employs a total of 9 African countries from 1971 to 2022. The selected nations employed in this study[1] are based on the accessibility of data, and the increasing impact of ecological deficits in these economies, these countries were selected. There are 468 observations in total in this dataset. It follows that since $T >$ N, the panel data is made up of long series. The study focused on understanding how finance, trade, and urbanization have shaped the environmental aspects of basic human demands under rising demand for food, shelter, and the growing ecological deficit of African economies. The sources of data employed in this study and description are highlighted in Table 1.

3.2. Modeling strategy

The theoretical model employed in this study draws upon the IPAT framework (Environmental impact, Population Affluence, and Technology), initially introduced by Ehrlich and Holdren (1971). This model has been widely utilized in previous studies, including the works of (Nwani et al., 2023; Okere et al., 2021). In this study, we present the model as follows:

$$I = PAT \tag{1}$$

The limitations of the IPAT framework, including its monotonous and restrictive nature, as well as its inability to incorporate multiple environmental factors due to a gap in constant percentage return-to-scale, have been highlighted by Zhang and Lin (2012). In response to these limitations, Dietz and Rosa (1994) proposed an alternative model called Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT). STIRPAT was developed to overcome the shortcomings inherent in the IPAT framework. The STIRPAT model is expressed as follows:

$$I_{it} = \alpha \times P_{it}^{\theta_1} \times A_{it}^{\theta_2} \times T_{it}^{\theta_3} \times \varepsilon_{it} \tag{2}$$

Equation (2) presents above represents a multiplicative framework of the IPAT model, where α, θ_1, θ_2, and θ_3 denote the constant term and elasticities of environmental impact associated with anthropogenic variables, respectively. The term ε represents the white noise, while the subscripts i and t refer to the cross-section and time frame. To transform Equation (2) into logarithmic form, we reclined on extant study Dimnwobi et al. (2023). The extended STIRPAT model can be expressed as follows:

$$lnI_t = ln\alpha + \theta_1 lnP_{it} + \theta_2 lnA_{it} + \theta_3 lnT_{it} + \varepsilon_{it} \tag{3}$$

In the equation provided, the natural logarithm function is denoted as 'ln'. The variable A represents GDP per capita. The term T accounts for the residual value encompassing unobserved variables within the dynamic STIRPAT model, as proposed by Dietz and Rosa (1994). Drawing from both theoretical and empirical

Table 1. Descriptive statistics and correlation matrix

	Mean	Median	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis	JB	Prob	Observ
Panel A: Descriptive Statistics										
FOOD	17882021	7126569	141000000	532411	26262911	2.7276	10.7566	1753.5150	0.000	468
SHEL	7994469	3219872	46398078	52988	10126164	2.0202	6.5248	560.6063	0.000	468
GDP	2068.471	1498.651	6284.860	215.747	1660.762	0.8553	2.7224	58.5666	0.000	468
DCP	25.8626	20.2880	70.3819	1.9943	18.4023	0.8105	2.4054	58.1313	0.000	468
URB	27895492	10819274	219000000	443979	39273660	2.5853	10.1256	1511.4390	0.000	468
TRADE	62.5690	54.5720	188.6475	9.1358	33.8740	1.2560	4.4429	163.6483	0.000	468
Panel B: Correlation Matrix										
					FOOD	SHEL	GDP	DCP	POP	TRADE
FOOD					1.0000					
SHEL					0.9585	1.0000				
GDP					0.2435	0.2377	1.0000			
DCP					−0.0875	−0.0819	0.6712	1.0000		
URB					0.9886	0.9721	0.2346	−0.0914	1.0000	
TRADE					−0.3539	−0.4260	0.1102	0.1730	−0.3908	1.0000

foundations, the technology variable (T) is further elucidated by considering finance, trade and urbanization. These factors are essential for achieving the main objective of the study. The modified STIRPAT model is employed to assess the environmental impact of the ecological deficit in African economies.

$$lnECO_{it}^{sht,fod} = \alpha_0 + \theta_1 Y_{it} + \theta_2 Y_{it}^2 + \alpha_3 DCP_{it} + \theta_4 TRD_{it} + \theta_5 URB_{it} + \varepsilon_{it} \tag{4}$$

In this study, the hypothesis is that α_0 represents the intercept, while α_1 to α_4 are parameter estimates. The interpretation of these estimates depends on the signs, statistical significance, and magnitudes of the coefficients, assuming other factors remain constant (ceteris paribus). The signs of the parameter estimates are explained based on theoretical and empirical evidence documented in this study. The error term is represented as ε. The dependent variable in this study is defined in two ways: Shelter ECO_{it}^{sht}, which measures the ecological deficit in terms of built-up land and forest product, and Food$lnECO_{it}^{fod}$, which measures the ecological deficit in terms of cropland, fishing grounds, and grazing land. The independent variable is the natural logarithm of the ecological footprint in global hectares (gha) per person, which serves as a measure of environmental degradation in the selected African countries experiencing an ecological deficit. The variable Y_{it} represents affluence in the STIRPAT model and is proxied by GDP per capita in constant 2010 US dollars for each respective time period (t).

The variable (Y_{it}^2) represents the squared value of GDP per capita, which is included in line with the expectations of the traditional Environmental Kuznets Curve (EKC) theory, as indicated by previous studies such as Liu et al. (2023) and Zhang and Lin (2012). Additionally, the square of real GDP per capita accounts for the non-linear relationship between the shelter-based ecological deficit, food-based ecological deficit, and gross domestic product per capita. Consistent with the proposition by Lind and Mehlum (2010) and empirical evidence from emerging scholars like Muoneke et al. (2022b) and Nwani and Omoke (2020), the following interpretations can be made based on the signs of θ_1 and θ_2: If $\theta_1 > 0$ and $\theta_2 < 0$, it indicates the presence of an inverted U-shaped curve between real GDP per capita and the ecological deficit (both Shelter-based and Food-based). This suggests *ecological deficit hypothesis* and implies that initially, as GDP per capita increases, the ecological footprint also increases, but beyond a certain point, further economic growth results in a decrease in the ecological footprint. If $\theta_1 > 0$ and $\theta_2 < 0$, it implies an inverted U-shaped curve between real GDP per capita and the ecological deficit (both shelter-based and food-based). This indicates that initially, economic growth leads to a increase in the ecological deficit, but beyond a certain point, further economic growth results in an decrease in the ecological deficit.

The variable DCP_{it}it represents domestic credit to the private sector as a percentage of GDP. The rationale behind including this variable is that obtaining credit for acquiring raw materials may result in the depletion of natural resources. This, in turn, can lead to increased production, technological advancement, economic activity, consumption, and the pursuit of shelter, potentially resulting in an ecological deficit in Africa. In this study, it is anticipated that this variable will have a detrimental impact on the environment (i.e. >0). However, it is hypothesized that the magnitude of this influence is contingent upon the level of financial deepening in African economies.

The variable TRD_{it}_it represents trade openness as a percentage of GDP, calculated as the sum of exports and imports as a percentage of GDP. This variable captures the extent of a country's engagement in international trade. The impact of trade openness on the environmental deficit is subject to debate. Some experts, such as Shahzad et al. (2017), argue that trade openness can either dampen or improve the environmental deficit. On the other hand, experts like Rauf et al. (2018) have suggested that trade openness benefits the environment, while others believe that it may accelerate the rate of environmental degradation. Based on these differing viewpoints, we postulate that the effect of trade openness on the dependent variables can be positive or negative, depending on the context. This is reflected in the parameter estimate θ_3, where $\theta_3 > 0$ indicates a positive effect of trade openness on the dependent variables, while $\theta_3 < 0$ suggests a negative effect. The specific direction and magnitude of this effect will depend on the empirical analysis conducted in this study.

The variable URB_{it}_it represents urbanization, which refers to the number of people living in a specific area for a given period. The theoretical relationship between urban growth and environmental degradation is often discussed in the context of ecological modernization theory and urbanization transition theory. Ecological modernization theory suggests a positive relationship between population growth and environmental deficit, while urbanization transition theory proposes a neutral effect of population on the environment (A. Khan et al., 2020). Based on these theories, we anticipate that the URB_{it}_it variable will have a positive or neutral effect on the dependent variables. A positive effect is indicated by $\theta_3 > 0$, suggesting that urbanization contributes to environmental degradation. On the other hand, a neutral effect is represented by $\theta_3 = 0$, implying that urbanization has no significant impact on the dependent variables. The specific direction and magnitude of this effect will be determined through empirical analysis in this study.

3.3. Parameter estimations

In this section, we have undertaken the following stages:

Stage 1: We have addressed one of the main econometric challenges encountered in cross-country analysis by examining the issue of cross-sectional dependence (CSD)[2] in panel data sets. This examination is crucial because countries are deeply interconnected, and their economic variables may exhibit dependencies. The null hypothesis of this test is stated as follows: $H_o : \hat{p}_{ik} = corr(\varepsilon_{it}\varepsilon_{kt}) = 0 \quad i \neq k$. Additionally, the Pesaran (2004) cross-section dependent test is applied to assess the presence of cross-sectional dependence in the dataset

$$CSD = \sqrt{\frac{2T}{n(n-1)}\left(\sum_{i=1}^{n-1}\sum_{k=i+1}^{n}\hat{p}_{ik}\right)} \sim n(0,1)i,k \quad (5)$$

The time period of our analysis spans from 1971 to 2022. We have a total of n cross-sections, specifically nine ecological deficit African countries. In equation 5, the term $\hat{p}_{ik}$ introduces the Augmented Dickey–Fuller (ADF) test, which assesses the pairwise cross-sectional connection. To account for the interconnectedness among the countries in selected. We further subject our series to the slope heterogeneity test proposed by Pesaran (2007). This test acknowledges the potential issue of obtaining spurious results in the analysis due to the interdependencies among the SSA countries. It is considered reliable and takes into account cross-sectional dependence (CSD), making it more efficient in situations where the sample size is small and the time period is large (Pesaran et al., 2008).[3]

Step 2: In order to examine the statistical properties of the data series, the researcher employs the cross-sectional augmented Im, Pesaran, and Shin (CIPS) test and the truncated version of CIPS statistics proposed by Pesaran (2007). These tests are widely recognized in scholarly literature for their ability to handle heterogeneity and consider cross-sectional dependence. By utilizing these preliminary estimation methods, the researcher takes into account the presence of cross-sectional dependence among the units within the data series. The null hypothesis in these tests is that the variables are not stationary. The equations for the CIPS and truncated version of CIPS statistics are as follows:

$$\Delta Y_{it} = \omega_i + \rho_i^* Y_{i,t-1} + d_0 \bar{Y}_{t-1} + \sum_{j=0}^{p} d_{ij}\Delta\bar{Y}_{t-j} + \sum_{j=1}^{p} c_{ij}\Delta Y_{i,t-j} + \varepsilon_{it} \quad (6)$$

The difference operator is denoted by Δ. The target variable is represented by Y, and i = 1,. . .,n denotes the countries considered, while t = 1,. . .,T represents the time periods. The stochastic error term is denoted asε_{it}. The Cross-sectional augmented Im, Pesaran, and Shin (CIPS) statistics are derived from equation 5. The estimated equation for the CIPS test is expressed as follows:

$$CIPS = \frac{1}{N}\sum_{i=1}^{N} CADF_i \quad (7)$$

Following the work of Pesaran (2007), we introduce an additional test statistic known as the truncated version of CIPS statistics, denoted as CIPS-TR. This truncated version incorporates certain modifications to the original CIPS test.

$$CIPS - TR = \frac{1}{N}\sum_{i=1}^{N} CADF_i^* \quad (8)$$

Step 3: In this study, we adopt the Westerlund (2007) approach within the framework of the error correction method (ECM) to examine the presence of cointegration among the variables. The estimation procedure is presented as follows:

$$\Delta Y_{i,t} = \gamma_i' d_t + \alpha_i\left(Y_{i,t-1} - \beta_i' X_{i,t-1}\right) + \sum_{m=1}^{k} \partial_{im}\Delta Y_{i,t-m} + \sum_{m=1}^{k} \varphi_{im}\Delta X_{i,t-m} + \varepsilon_{it} \quad (9)$$

In Equation 9, $\alpha_i$represents the adjustment coefficient, which indicates the error coefficient term and the speed of correction towards equilibrium. $Y_{i,t}$ and $X_{i,t}$ denote the dependent and independent variables, respectively. The symbol Δ represents the difference operator. By estimating Equation 8, we anticipate obtaining four different tests to assess the presence of cointegration among the variables. These tests will provide insights into the long-term relationship and dynamics between the dependent and independent variables.

$$G_t = \frac{1}{N}\sum_{i=1}^{N}\frac{\hat{\alpha}_i}{se(\hat{\alpha}_i)} \tag{10}$$

$$G_a = \frac{1}{N}\sum_{i=1}^{N}\frac{T\hat{\alpha}_i}{1-\sum_{m=1}^{K}\alpha_{im}^{'}} \tag{11}$$

$$P_t = \frac{\hat{\alpha}}{se(\hat{\alpha})} \tag{12}$$

$$P_a = P\hat{\alpha} \tag{13}$$

The group statistics $G_t and G_a$ are utilized to test the null hypothesis of non-cointegration, which suggests that there is no long-term relationship in at least one of the cross-sections (H_0: $\alpha x_i = 0$ for all values of i). The alternative hypothesis (H_1: $\alpha x_i < 0$ for at least one i) indicates the presence of long-term relationship. In contrast, the panel statistics P_t and P_a aggregate information from all the cross-sectional units to assess the null hypothesis (H_0: $\alpha x_i = 0$ for all values of i) against the alternative (H_1: $\alpha x_i <$ 0 for all i). These panel statistics provide a means to identify the presence of cointegration for the entire panel, indicating a long-term relationship between the variables.

3.3.1. Step 5 estimation of technique

To obtain initial estimates for different specifications of Equations (4), we utilize the Fixed Effect Driscoll-Kraay (DK) regression method. This approach employs standard errors that are robust to both cross-sectional and temporal dependencies in a general form (Driscoll & Kraay, 1998). However, a notable limitation of the FE-DK regression technique is its focus solely on modeling the conditional mean of the dependent variable. To overcome this limitation and capture additional aspects of the conditional distribution of ecological deficit, our study adopts the method of moments quantile regression (MM-QR) proposed by Machado and Silva (2019) to handle fixed effects in panel quantile models. By employing the MM-QR estimator, we investigate the impact of finance, trade, and urbanization on the lower, median, and upper distributions of ecological deficit countries in Africa.

The estimation methodology for the conditional quantile $Q_y(\tau|X_{it})$ of the location-scale variant model is derived by modifying Equations 4 based on the methodologies proposed by Machado and Silva (2019). The broad specification is employed to adjust the equations.

$$Q_y(\tau|X_{it}) = \left(\beta_i + \delta_i qi\right) + X_{it}^{'}\beta + Z_{it}^{'}\gamma q(\tau) \tag{14}$$

where$Q_y(\tau|X_{it})$ depict the quantile distribution of the dependent variablelnY_{it}, conditional on the location and scale of explanatory variable $(X_{it}^{'})$. $X_{it}^{'}$ it is a vector of explanatory variables.$\alpha_i(\tau) = \alpha_i + \delta_i q(\tau)$ represents the distributional effect atτ or the scalar coefficient of the quantile-τ fixed effect for individual i. q(τ) is the τ -th quantile estimated through optimization function:

$$\min_q \sum_i \sum_t \rho_\tau(\hat{R}_{it} - (\hat{\delta}_i + Z_{it}^{'}\hat{\gamma})q) \tag{15}$$

Accordingly, this threshold $\rho_\tau(A) = (\tau-1)AI\{A \le 0\} + \tau AI\{A > 0\}$ offers a check-function. Drawing from Equation (15), we present the final modified baseline model stated in equ.4 for panel quantile calculation as thus

$$Q_{Y_{it},}(\tau|\beta_i, \varepsilon_{it}, X_{it}) = \beta_0 + \beta X_{it} + \gamma Z_{it} + \delta_{it} + \varepsilon_{it} \tag{16}$$

The quantile model presented in Equations (16) considers the distributional effects of explanatory variables on the explained variable, and also account for the impact of finance, trade, and urbanization in ecological deficit African region.

3.4. Descriptive statistics and correlation analysis

Table 1 presents a thorough summary of descriptive statistics for six variables—FOOD, SHEL, GDP, DCP, POP, and TRADE—using a sample of 468 observations. The mean ecological deficit with regard to food spending is approximately 17.9 million, demonstrating significant variation spanning from 532,411 to 141 million. The distribution displays a significant right-skewness (skewness = 2.7276), indicating a longer tail on the right side, and shows a high kurtosis (kurtosis = 10.7566), implying prominent tails and a peaked form. The JB statistic of 1753.5150, along with a low p-value (Prob = 0.000), clearly suggests that the data do not follow a normal distribution. Ecological deficit on Shelter, with a mean value of almost 8 million, exhibit comparable skewness and kurtosis properties to food spending. The JB Statistic of 560.6063 and a low p-value provide additional evidence of non-normality. The average GDP, which is around $2,068, has mild skewness and kurtosis. The JB Statistic of 58.5666 and a low p-value suggest a deviation from normalcy. The credit to domestic private sector, with an average of around $25.86, has a positively skewed distribution and moderate kurtosis. The JB Statistic of 58.1313, along with a low p-value, indicates the presence of non-normality. The population size, with a mean of approximately 27.9 million, demonstrates a significant positive skewness and a high kurtosis. The JB Statistic of 1511.4390, along with a low p-value, indicates the absence of normalcy. The TRADE has a mean of roughly 62.57, showing positive skewness and moderate kurtosis. The JB Statistic is 163.6483, and the low p-value suggests that the data is not normally distributed. In Panel B, the correlation matrix provides an in-depth understanding of the relationships between the variables. There are strong positive correlations between ecological deficit and population, as well as economic growth and finance. In contrast, there are negative correlations found between ecological deficit, finance and trade, and population and trade. Further, Figure 1 shows the distribution of the dependent variable, ecological deficit and the key variables, using histogram and Kernel density plots. From Figure 1a,b, it is clear that the distribution of the series is distinctly skewed and deviates from normal (symmetric) distribution. Thus, this study relies on the robustness of the MM-QR algorithm to identify the impact of Finance, Trade, and Urbanization across different conditional distributions of ecological deficits in Africa.

4. Empirical results and discussion

4.1. Preliminary tests

This study begins by evaluating the existence of multicollinearity among variables using the variance inflation factors (VIF) test, as described by Belsley et al. (2005). The results from Table 2, using two different model assumptions, show that both the computed VIF and their average values are lower than the commonly recognised thresholds of 10 and 5, respectively. These assessments confirm that there are no issues of multicollinearity among the variables in the provided models. Next, we do a test to determine if there is cross-sectional dependence (CSD) in the panel data, using Pesaran (2004) CSD test. The results, as shown in Tables 3, 4, present strong evidence of cross-sectional dependency in each variable at a significance level of 1%. Therefore, we utilise the second-generation panel unit root test known as the cross-sectionally augmented Im—Pesaran—Shin (CIPS) tests developed by Pesaran (2007) using Truncated CIPS. The results, which are included in the estimates, demonstrate that all variables exhibit stationarity when measured at the first difference. Based on these discoveries, we then conduct slope heterogeneity tests and long-term coevolution tests on the series. The results in Panel A of Table 3 reveal diverse characteristics across the analysed cross-sections. In order to examine the relationship between variables over a long period of time, the Westerlund (2007) cointegration test is utilised. Please refer to Panel B, Table 4 for the results. This rigorous phase guarantees the dependability and significance of our analyses. Both model specifications strongly reject the null hypothesis of no cointegration at a 1% significance level, providing confirmation of the presence of cointegration among the variables.

5. Empirical results and discussion

5.1. Urbanization and ecological deficit

Given the asymmetrical nature of the data series, as shown in Figures 1 and 2, the influence of GDP, GDPSQ, DCP, TRADE, and URB on ecological deficit (ECO) might be influenced by the distributional properties of these variables. This suggests that there may be considerable differences in the sizes of coefficient estimations in the case FE-DK estimation. We use the MMQR estimator considering the fact that FE-DK estimates are subject to a distributional bias as it precludes possible heterogeneous impact across the entire conditional distribution of the ecological deficit. Therefore, in this study we extended our analysis by incorporating MMQR with bootstrap variance to estimate the model parameters. Accordingly, we perform 1,000 replications with degree of freedom (DOF) modification for accuracy. The specification incorporates a variance option that produces resilient standard errors. Accordingly, the baseline model employs Driscoll—Kraay panel fixed-effects regression, with results presented in Column 1 and 7 of Table 5. Additionally, distributional impact analyses using the MM-QR panel quantile regression technique are reported in Column 2–6 and 8–12 of Tables 5. Estimates in Column 2–6 elucidate changes in the ecological deficit for Food, while those in Column 8–12 delineate the ecological deficit for Shelter. Table 5 provides insights across three quantile sections: the lower quantile (qtile_25th), the median quantile (qtile_50th), and the upper quantile (qtile_75th). Notably, the lower section of Table 5 underscores a U-shaped relationship between economic growth and ecological deficit, indicating that environmental concerns intensify or diminish only when a country surpasses a certain threshold of reliance.

The preliminary results suggest that population increase has a detrimental effect on the ecological footprint for food, mostly as a result of variations in population size. The impact is clearly observable in FE-DK and the distribution across different quantiles (please see columns 1–12). These findings emphasize that in African nations facing ecological deficits, population expansion poses a major barrier to attaining environmental sustainability which is in line with *ecological modernization theory*. This conclusion is consistent with previous studies conducted by Dimnwobi et al. (2021) in Africa and Opuala et al. (2023) in the West African sub-region. Hence, it is imperative for policymakers to give priority to awareness programmes that focus on educating the expanding

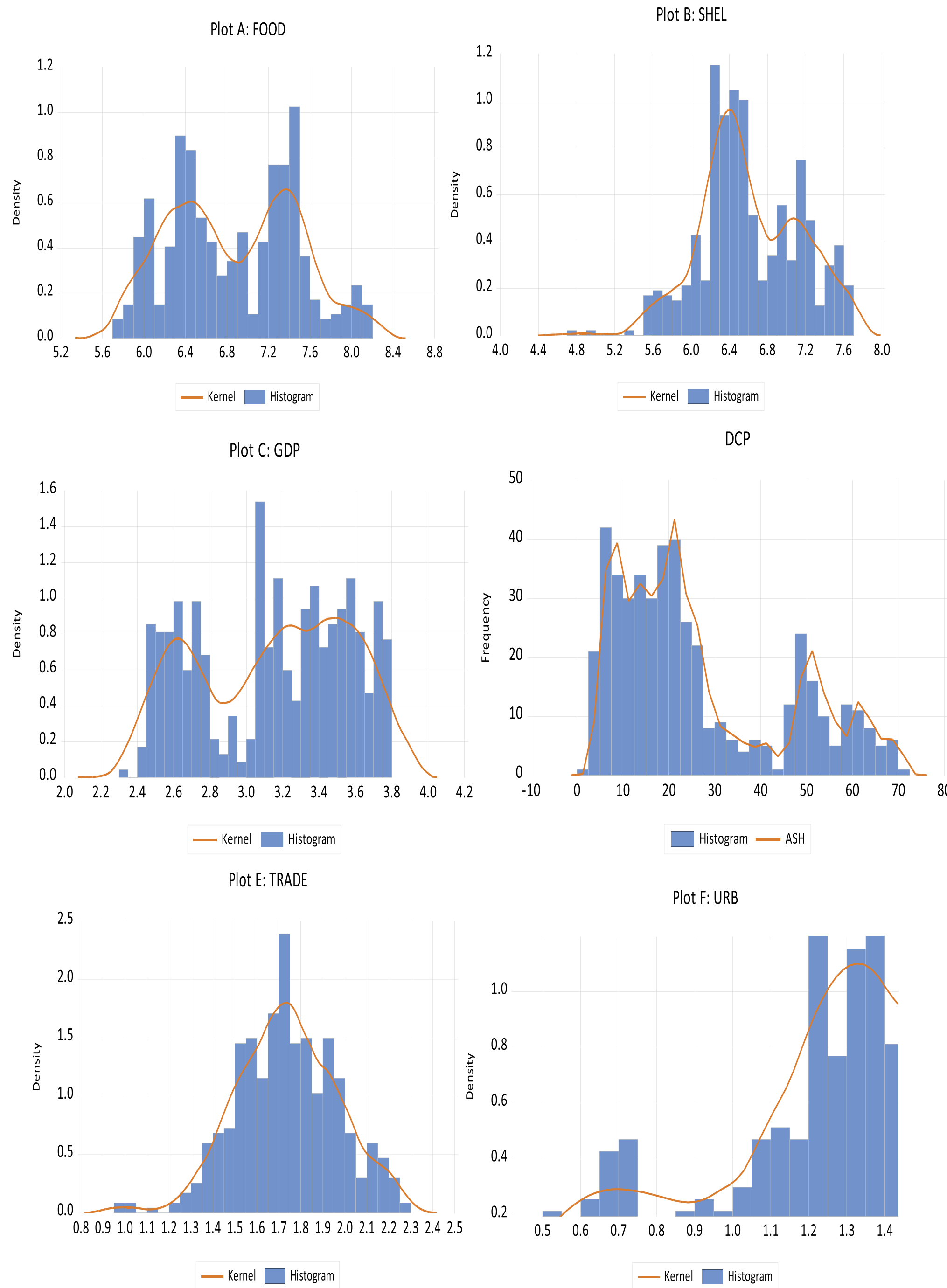

Figure 1. Distributional –kernel and normality plots of key variable.

Table 2. Variance inflation factors (VIF)

Variable	VIF	1/VIF	VIF	1/VIF
	Model 1		Model 2	
GDP	1.43	0.6993	1.43	0.6993
GDPSQ	3.49	0.2865	3.49	0.2865
TRADE	3.28	0.3046	3.28	0.3046
URB	2.85	0.3512	2.85	0.3512
DCP	1.8	0.5547	1.8	0.5547
Mean VIF	2.57		2.57	

Table 3. Cross-sectional dependence and unit root tests

Variable	Panel A Pesaran (2004) Cross-sectional dependence CD-test	Panel B Pesaran (2007) CD-adjusted (Second-generation) panel unit root tests At level form		At first difference form	
		CIPS	Truncated CIPS	CIPS	Truncated CIPS
FOOD	31.842***	−2.283	−2.283	−8.718***	−6.188***
SHEL	28.672***	−2.064	−2.064	−7.891***	−6.117***
GDP	15.363***	−1.344	−1.344	−6.86***	−6.053***
GDPSQ	15.631***	−1.36	−1.36	−6.755***	−6.076***
DCP	13.612***	−2.102	−2.102	−7.706***	−5.937***
URB	42.40***	−1.088	−2.143	−6.502***	−7.566***
TRADE	3.615***	−1.72	−1.72	−7.64***	−6.124***

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

Table 4. Slope homogeneity and cointegration tests

Test specification	Test of Specification	Algorithm	Model 1: FOOD	Model 2: SHELTER
Panel A	Slope homogeneity	Pesaran et al. (2008)		
		Delta tilde (Δ)	27.562	21.929
			0.000	0.000
		Adjusted delta tilde (Δ)	29.629	23.573
Panel B	Panel cointegration	Westerlund (2007) Error-correction-based test		
		Gt	−4.549	−3.374
			0.000	0.000
		Ga	−19.749	−16.562
			0.041	0.000
		Pt	−12.362	−14.97
			0.000	0.000
		Pa	−22.268	−35.887

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

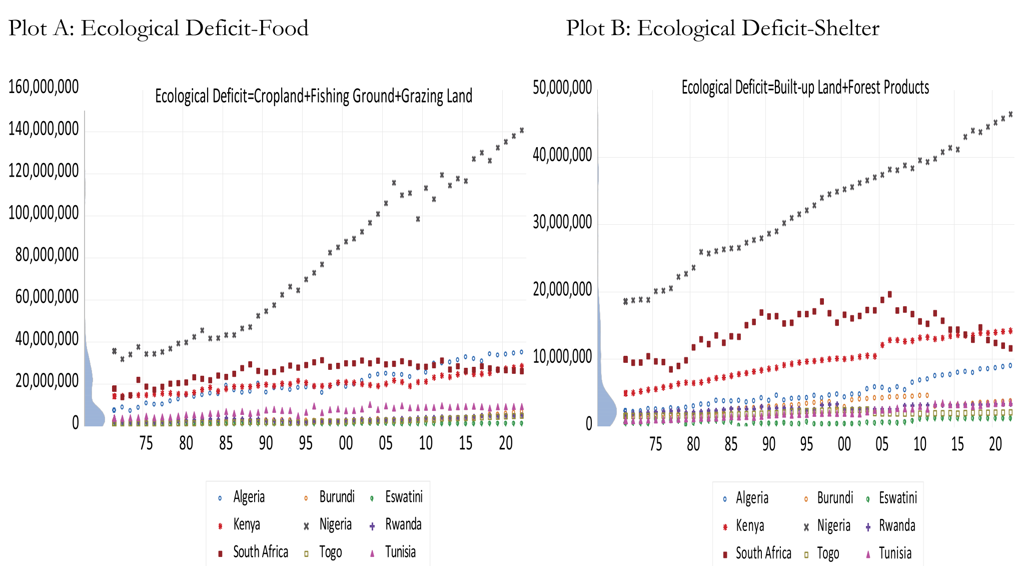

Figure 2. Distributional plots of key ecological Deficit.

population about the adverse repercussions linked to reduced environmental quality. Moreover, the adoption of strategic birth control techniques, as proposed by Dimnwobi et al. (2021), could effectively mitigate the identified ecological deficiencies.

5.2. Economic growth and ecological deficit (EKC hypothesis)

The findings from both the FE-DK and MMQR estimations (Column 1–6) in Table 5 support the existence of an inverted U-shaped curve in the relationship between

Table 5. FE-DK and Quantile-based distributional effects

	1	2	3`	4	5	6	7	8	9	10	11	12
Series	FE-DK	location	scale	qtile_25	qtile_50	qtile_75	FE-DK	location	scale	qtile_25	qtile_50	qtile_75
URB	0.819***	0.819***	−0.0118	0.830***	0.819***	0.809***	0.517***	0.517***	0.0470***	0.472***	0.527***	0.561***
	(0.041)	(0.033)	(0.017)	(0.039)	(0.033)	(0.034)	(0.072)	(0.032)	(0.018)	(0.044)	(0.031)	(0.026)
GDP	0.712*	0.712**	−0.451***	1.135***	0.696**	0.312***	−3.193***	−3.193***	0.209	−3.390***	−3.147***	−2.996***
	(0.369)	(0.318)	(0.163)	(0.363)	(0.320)	(0.345)	(0.368)	(0.374)	(0.208)	(0.493)	(0.355)	(0.331)
GDPSQ	−0.0992*	−0.0992**	0.0678***	−0.163***	−0.0968*	−0.039***	0.548***	0.548***	−0.0612	0.606***	0.534***	0.490***
	(0.056)	(0.049)	(0.025)	(0.057)	(0.050)	(0.053)	(0.071)	(0.065)	(0.038)	(0.086)	(0.062)	(0.057)
DCP	0.0536	−0.0536***	0.0226*	−0.0748***	−0.0528***	−0.0335*	0.0245	0.0245	0.0279***	0.0019	0.0307	0.0508**
	(0.034)	(0.020)	(0.012)	(0.025)	(0.020)	(0.019)	(0.020)	(0.022)	(0.010)	(0.027)	(0.021)	(0.020)
TRADE	0.121***	0.121***	−0.00684	0.128***	0.121***	0.115***	−0.0658*	−0.0658	0.0708***	−0.133**	−0.0502***	−0.0071**
	(0.033)	(0.030)	(0.016)	(0.035)	(0.030)	(0.032)	(0.052)	(0.041)	(0.025)	(0.057)	(0.038)	(0.032)
Threshold	3.5887	3.5887	3.326	3.4816	3.595	4–000	2.9133	2.9133	1.7075	2.797	2.9466	3.0571
Threshold (GDP per capita,US$	36.1874	36.1874	27.8257	32.5115	36.4172	54.5982	18.4179	18.4179	5.5152	16.3959	19.0417	21.2667
Ecological deficit hypothesis	*valid*	*valid*	*valid*	*valid*	*valid*	*valid*	*valid*	*valid*	*valid*	*valid*	*valid*	*valid*
Constant	−0.315	−0.315	0.860***	−1.123*	−0.285	0.448	7.563***	7.563***	−0.461	8.000***	7.462***	7.130***
	(0.555)	(0.529)	(0.274)	(0.596)	(0.535)	(0.585)	(0.777)	(0.618)	(0.376)	(0.871)	(0.574)	(0.494)
Obsv	468	468	468	468	468	468	468	468	468	468	468	468

Standard errors in parentheses.
***p<0.01, **p<0.05, *p<0.

per capita income and the ecological footprint for food. The coefficients of income per capita and its squared term display positive and negative values, respectively, and are statistically significant. This suggests that achieving environmental sustainability is possible by reducing the ecological deficit at higher levels of income or economic growth. The fixed effects estimate indicates that the threshold GDP per capita income falls within the range of $18.4179 to $36.1874 (refer to column 1 and 7), while the MMQR estimates show a range between $16.3959 and $21.2667. On the other hand, columns 7–12 demonstrate a U-shaped relationship between economic growth and the ecological footprint for Shelter, with a threshold falling between $32.5115 and $54.5982. The observed variances suggest that the level of evidence for the ecological deficit hypothesis is influenced by both the specific data sample and the estimating methodology employed. This is congruent with the discoveries made by Ben Jebli et al. (2022), who noted inconclusive evidence regarding the Environmental Kuznets Curve (EKC) theory in various nations due to variations in the size of the data sample and the econometric approach used.

5.3. Finance and ecological deficit

Regarding the impact of finance, the statistical analysis reveals the following findings: For the FE-DK estimates in Column 1 and 7, the results indicate that the effect of finance on the ecological deficit is statistically insignificant, albeit with a positive effect that is practically negligible. However, the MMQR estimates in Columns 2 to 6 present a noteworthy pattern. They suggest a significant and negative (mitigating) impact of finance on the ecological deficit across different quantiles. Regardless of a country's position in the distribution, a 1% increase in finance is associated with a decrease in the ecological deficit. Specifically, the coefficient is estimated to be 0.0748% at the 10th quantile and 0.0335% at the 75th quintile. These findings are supported by the quantile regression plots shown in Figure 1. Similarly, the MMQR estimates in Columns 8 to 12 reveal a varying relationship between finance and the ecological deficit concerning shelter. The quantile locations qtile_25 and qtile_50 do not yield statistically significant effects. However, a statistically significant relationship emerges at the upper quantile of qtile_75. Further details and visualization of these results can be found in the quantile regression plots displayed in Figure A1 (Appendix A). This discovery further contributes to the growing body of empirical evidence supporting the findings of Ahmed et al. (2021) and X. Liu et al. (2022), who independently demonstrated the negative impact of finance in ecological footprint of developed and developing nations, respectively. The findings of these estimates have important policy implications and suggest different approaches for addressing the ecological deficit in the areas of food and shelter (see, Chien et al., 2023). In the case of food, the results support the hypothesis that finance can play a positive role in mitigating the ecological deficit. This is achieved by promoting sustainable agricultural practices that prioritize ecological stewardship, such as organic farming, agroecology, and regenerative agriculture (Aydin & Turan, 2020). By providing support to these practices, the financial system can contribute to reducing the ecological deficit associated with food production. On the other hand, the estimates reveal that the financial system generates significant economic inefficiency and contributes to a higher ecological deficit in the area of shelter. This indicates that the financial systems tend to prioritize economic growth without considering ecological limits. As a result, there is an over-exploitation of natural resources and an exacerbation of ecological deficits in the shelter sector.

5.4. Trade and ecological deficit

The results indicate that trade openness has a positive and statistically significant relationship with the ecological footprint for food, implying an unfavorable environmental impact. This is apparent in both the FE-DK estimates (column 1) and the MMQR estimates (columns 4–6). The findings suggest that when policy decisions prioritise addressing agricultural needs through enhanced commerce, it might result in the proliferation of agricultural operations in various geographical areas. This expansion, in turn, can exacerbate ecological shortfalls by causing land conversion, water depletion, and heightened energy demand. These results align with previous research conducted by Opuala et al. (2023) in the West African region, Usman, Kousar, et al. (2020) in Asia, Ansari and Khan (2021), and Chien et al. (2023). These studies have consistently demonstrated that trade activities contribute to growing environmental concerns and provide evidence for the existence of a pollution-haven effect in certain African economies. This phenomenon suggests that increased trade openness can result in the relocation of environmentally detrimental activity from industrialised economies to regions with less stringent environmental regulations. Another aspect of this is revealed by the influx of multinational firms, especially those from wealthy countries who are looking for markets with lax environmental regulations.

This becomes significant when reevaluating trade policy in the region. It is crucial to acknowledge and tackle the potential adverse environmental impacts linked to the activities of these firms. This underscores the necessity for more robust environmental policy frameworks in countries experiencing ecological deficits in order to successfully address these environmental risks. However, the results indicate that the TRADE coefficient has a negative and statistically significant impact on the ecological footprint for shelter, as observed in both the FE-DK estimates (column 7) and the MMQR estimates (columns 10–12). These findings suggest that increased trade openness has a mitigating impact on the ecological footprint specifically related to shelter. This implies that commerce has the capacity to alleviate environmental deterioration in the shelter industry. This findings reinforce the emerging studies such as S. P. Nathaniel (2019) and Ali et al. (2016) Dauda et al. (2020) in the Africa.

5.5. Further discussion on threshold estimation

An intriguing discovery from Table 5 is the existence of a curvilinear association between economic growth and ecological footprint deficits, characterised by an inverted U-shaped pattern. This implies that economic expansion can effectively tackle environmental challenges, but its effectiveness diminishes beyond a certain degree of prosperity. The turning point, estimated within the ranges of \$18,4179 to \$36,1874 (column 1 and 7), \$16,3959 to \$21,2667 (column 4–6), and \$32,5115 to \$54,5982 (column 10–12) of GDP per capita, signifies the critical level at which additional economic growth begins to reverse the environmental trajectory in the countries. This empirical observation elucidates the reason behind the inconclusive findings and policy suggestions from prior studies (Ben Jebli et al., 2022) that investigated developing and developed nations with diverse degrees of economic growth and resource endowments. For countries that have exceeded the defined ranges of affluence (\$18,4179 to \$36,1874, \$16,3959 to \$21,2667, and \$32,5115 to \$54,5982 of GDP), economic growth continues to aid in achieving environmental sustainability by decreasing ecological deficits. However, if economic expansion advances beyond this threshold, the likelihood of ecological imprint grows, resulting in an ecological deficit. To address the *ecological deficit paradox*, governments must modify their ecological frameworks and adopt clean technology structures that are in line with finance, trade, and urbanization. Countries might aim to achieve a more sustainable equilibrium between economic growth and environmental preservation by taking into account the interaction of these elements.

5.6. Robustness test

To enhance the reliability of the empirical findings, the study utilizes the Half-Panel Jackknife (HPJ) Wald-type test introduced by Juodis et al. (2021). This method, as demonstrated in previous studies, offers improved size and power performance compared to other similar techniques available in the literature such as (Granger, 1980). Moreover, it is capable of estimating multivariate and heterogeneous panel data models. The HPJ Wald-type test employed in this study incorporates the bootstrap variance option, which effectively addresses cross-sectional dependence. The test algorithm utilizes the Wald test to assess the presence of Granger causality, a concept that explores the causal relationship between variables. To determine how the selected covariates influence the equation, the test algorithm employs the bias-corrected pooled estimator. Furthermore, it utilizes cross-sectional heteroskedasticity-robust standard errors to account for potential variations in the error term across different cross-sectional units. By employing the Half-Panel Jackknife (HPJ) Wald-type test with the bootstrap variance option, the study aims to ensure the robustness of the results and provide more reliable insights into the relationships between variables in the panel dataset.

The results are shown in Table 6, while Appendix A, Figures A1 & A2 gives a concise visualisation. Within Panel A specifications, Columns (1) to (6) and (7) to (12) investigate the potential causal relationship between variables including GDP, GDPSQ, DCP, TRADE, and URB and their influence on ECO, using the Granger causality test. The HPJ Wald statistic demonstrates statistical significance in these parameters, hence rejecting the null hypothesis that the covariates do not have a causal relationship with ECO in the ecological deficiency region. In addition, the regression output of the bias-corrected pooled estimator in Panel B indicates that the test result of the multivariate equation is affected by previous TRADE values in the context of ecological deficit for food. As a matter of policy concern, countries with an ecological deficit need to be incredibly careful about trade with other countries, especially those from areas with weak policies for reducing carbon emissions. It's important to note that the African

Table 6. JKS multivariate non-causality test

	1	2	3	4	5	6	7	8	9	10	11	12
VARIABLES	FOOD	GDP	GDPSQ	DCP	TRADE	URB	SHEL	GDP	GDPSQ	DCP	TRADE	URB
Panel A: Non-causality test												
	9.553*	150.261***	196.043***	40.398***	64.036***	100.489***	287.866***	1100.001***	180.111***	58.354***	138.037***	216.890***
	0.0889	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Panel B: -Panel Jackknife estimates of Selected covariates												
GDP	0.428		−20.31***	0.623	1.036	−0.0187	−1.991***		−23.69***	0.628	1.265*	−0.0385
	(0.452)		(4.143)	(0.688)	(0.725)	(0.024)	(0.703)		(3.411)	(0.615)	(0.709)	(0.030)
GDPSQ	−0.066	0.592***		−0.0843	−0.156	0.00305	0.367***	0.718***		−0.0811	−0.193*	0.00562
	(0.075)	(0.154)		(0.103)	(0.114)	(0.004)	(0.124)	(0.143)		(0.092)	(0.110)	(0.005)
DCP	−0.00475	−0.01	−0.0782*		−0.0195**	0.00442*	−0.00731	−0.0124*	−0.0984**		−0.0195*	0.00470*
	(0.012)	(0.008)	(0.042)		(0.009)	(0.002)	(0.029)	(0.007)	(0.038)		(0.011)	(0.002)
TRADE	0.0588**	0.0487**	0.244**	0.0874***		0.00354	−0.112***	0.0428**	0.216**	0.0977***		0.00304
	(0.029)	(0.022)	(0.101)	(0.028)		(0.003)	(0.035)	(0.019)	(0.088)	(0.023)		(0.004)
URB	0.0114	0.0566***	0.339***	0.168**	0.115*		0.153**	0.0946***	0.563***	0.112*	0.0994***	
	(0.046)	(0.014)	(0.075)	(0.079)	(0.060)		(0.075)	(0.014)	(0.072)	(0.061)	(0.029)	
FOOD/SHEL		0.0154	0.123**	−0.063	−0.0119	−0.0004		−0.0605***	−0.321***	−0.0089	0.0591**	−0.0052***
		(0.012)	(0.061)	(0.072)	(0.051)	(0.002)		(0.010)	(0.042)	(0.044)	(0.027)	(0.002)
Observations	9	9	9	9	9	9	9	9	9	9	9	9

Standard errors in parentheses.
$***p < 0.01$, $**p < 0.05$, $*p < 0.1$.

Continental Free Trade Area (AfCFTA) was just created, and its goal is to encourage economic integration and the benefits that come with it among African countries. However, the AfCFTA strategy might leave some African economies open to environmental problems caused by trade from other parts of the continent if it is not carefully planned. Column 3 demonstrates a unidirectional causal connection between the square of GDP and the ecological deficit for food. The test answer of the multivariate equation in Column 7 is considerably impacted by previous values of GDP, GDPSQ, TRADE, and URB in relation to the ecological deficit for shelter. A significant discovery is the bidirectional relationship identified between GDP, GDPSQ, TRADE, and URB in columns 8, 9, 11, and 12.

6. Summary and policy recommendation

This study investigates the relationship between finance, trade, and urbanization in the context of the Ecological Tapestry of African Economies, aligning with Sustainable Development Goal 15, which aims to promote the conservation and sustainable use of land and ecosystems for the long-term well-being of both human and non-human life. The analysis focuses on a sample of 9 African countries spanning from 1971 to 2022. The study examines two dependent variables of interest: (a) the ecological footprint in the area of built-up land forest product, and (b) the ecological footprint in the areas of cropland, fishing grounds, and grazing land. To explore the relationship, the study employs the FE-Driscoll and Kraay (1998) method, the Method of Moments quantile regression (MM-QR) proposed by Machado and Silva (2019), and the Half-Panel Jackknife (HPJ) Wald-type test introduced by Juodis et al. (2021). These methodologies are used to shed light on the interplay between finance, trade, and urbanization in the context of the Ecological Tapestry of African Economies.

The results as shown in Figure 3 indicate that population size has a significant increasing effect on ecological deficiency. The rising population generates unsustainable demand, stretching the ecological environment in the area of built-up land forest product, cropland, fishing grounds and grazing land, and beyond its capacity to supply productive resources, leading to deforestation, soil degradation, water pollution, and, ultimately, reduced capacity to face the future. As a result, tackling problems such as poverty, loss of biodiversity, and climate change in these regions requires slowing population growth. Short-, medium-, and long-term policies must indicate the obligation to future generations, and that includes, on the one hand, controlling the urge to reproduce and, on the other hand, sensitizing and educating the populace to adopt and use clean technologies.

There is an observed inverted U-shaped relationship between economic growth and the ecological deficit, indicating that economic expansion can initially address environmental challenges but loses effectiveness beyond a certain level of prosperity. The estimated turning points, ranging from \$18,4179 to \$36,1874 (column 1 and 7), \$16,3959 to \$21,2667 (column 4–6), and \$32,5115 to \$54,5982 (column 10–12) of GDP per capita, represent critical thresholds where further

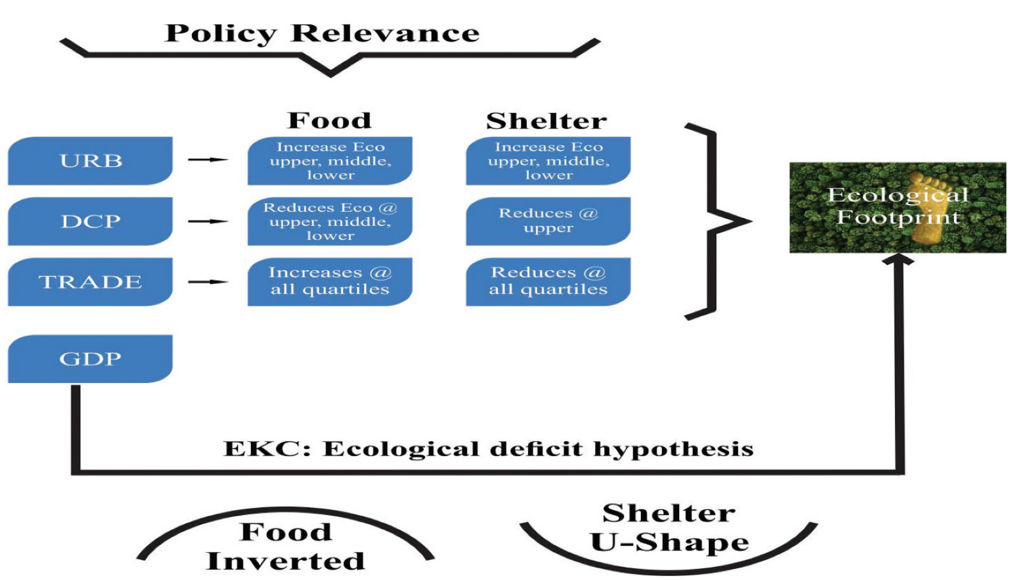

Figure 3. Summary of findings. Sustainability path in the Ecological Tapestry of deficit African countries

economic growth begins to reverse the environmental trajectory in the countries under study.

In terms of finance, it is found that there is a significant and mitigating impact on the ecological deficit related to food across various quantiles. This suggests that finance plays a mitigating role in reducing the ecological deficit for food. Meanwhile, the relationship becomes only statistically significant at the upper quantile (qtile_75) in the case of the ecological deficit for shelter. This indicates that finance is associated with higher levels of ecological deficit for shelter at the upper quantile. Furthermore, the analysis reveals that trade openness is associated with an exacerbation of the ecological deficit for food, meaning that higher levels of trade openness contribute to an increased ecological deficit in the food sector. On the other hand, trade openness has a mitigating effect on the ecological deficit for shelter, indicating that it helps reduce the ecological deficit in the shelter (see Figure 2). Moreover, the results indicate that, within a multivariate framework, the collective predictive ability of the impact model is notably influenced by GDP, GDPSQ, DCP, TRADE, and URB. The bias-corrected pooled estimator reaffirms that, on average, TRADE has a detrimental impact on ECO (ecological deficit) in the region. Additionally, a bidirectional causal relationship exists between ECO and higher GDP per capita, and the past values of GDP, GDPSQ, TRADE, and URB have an impact on the ecological deficit for shelter. Furthermore, a bidirectional relationship has been identified between GDP, GDPSQ, TRADE, URB, and the ecological footprint for shelter.

6.1. Policy options

Based on these findings, it is recommended that ecological-deficit nations adopt and implement the following policies to enhance ecological welfare: First, the ecological footprint in the selected African countries is threatened by population growth. The increasing urbanisation generates unsustainable demand that exceeds the ecological bio-capacity to provide necessary resources. This leads to detrimental effects such as deforestation, soil degradation, water pollution, and a diminished ability to address future challenges. Therefore, addressing issues like poverty, biodiversity loss, and climate change in these nations requires a focus on slowing down population growth. Effective policies should be greed towards controlling the urge to reproduce and raising awareness among the population about the adoption and use of clean technologies. Given the high rate of natural population increase in these countries, strategies for population stabilization, such as comprehensive sex education, access to contraception, and family planning, can be valuable tools in promoting ecological sustainability. By implementing these measures, the selected nations can work towards maintaining a balanced population that is better equipped to achieve long-term ecological sustainability. Other areas policy experts can explore in reducing the negative effect of urbanisation on the environment includes investment in upgrading infrastructural facilities beyond its dependence on fossil fuels so as to decrease the stock of its emission to overall greenhouse gases emissions, introduce energy-efficient buildings and create standards on energy-saving appliances (either local or foreign) and conserve more green spaces within urban clogged areas. Second, this study has uncovered a complex relationship between finance and ecological footprint of food and shelter. Considering the mixed findings, it is imperative to identify and overcome barriers that hinder the adoption of low-carbon energy sources. This can be achieved through offering financial support for technological upgrades. Additionally, innovation in the financial sector is necessary to improve access to credit, reducing ecological threats and helping nations dependent on natural resources achieve ecological surplus status. To promote eco-friendly practices, one effective approach is to scale up ecological funds allocations specifically designated for cleaner energies such as solar, wind, hydro, and geothermal power. However, it is important to note that simply increasing ecological fund availability is insufficient. The demand for these funds must also be stimulated. Therefore, stakeholders should work together to implement policy measures that enhance the efficiency of the financial sector that specializes in disbursing ecological funds. This is essential for addressing issues such as capital misallocation, lack of transparency, information gaps, and disclosure deficiencies. By doing so, excessive investments in projects with adverse environmental impacts can be mitigated.

Finally, the findings suggest that increased trade openness has a mitigating impact on the ecological footprint specifically related to shelter. This implies that commerce has the capacity to alleviate environmental deterioration in the case of shelter. Trade openness facilitates the sharing of sustainable building designs, technology, and breakthroughs. This facilitates the transmission of information and optimal methods in sustainable building, the incorporation of renewable energy, and the advancement of green infrastructure. Trade openness can help decrease ecological deficits in this region by encouraging the adoption of ecologically friendly and resource-efficient dwelling alternatives. It is crucial to steer cross-border inflows into the research and development of low-carbon technology. Approaches to accomplish this objective involve establishing agreements and engaging in negotiations with multinational firms, as well as implementing limitations on foreign investments in projects that generate high levels of carbon emissions. Prioritising a green transition is of utmost importance, and it is imperative to direct foreign investment towards the advancement of low-carbon technologies.

6.2. Limitations and area for further studies

The study investigated the symbiotic relationship between finance, trade, urbanization, and ecological footprint in selected ecological deficit African economies. The empirical investigation completed present solely an aggregate analysis of the described symbiotic relationship between finance, urbanization, trade, and their combined effects on the environmental quality in selected African economies. Aside from aggregate analysis, there is need to concentrate these studies at city-level, especially in commercial hotspots across Southern, Northern, Eastern and Western Africa. There are neighborhood effects and channels through which trade could induce urbanisation; these grey areas should be explored using tools of spatial econometrics which are beyond the scope of the current study.

Notes

1. The countries are: Algeria, Burundi, Eswatini, Kenya, Nigeria, Rwanda, South Africa, Togo, Tunisia.
2. To test for cross-sectional dependence, we have employed the CSD test proposed by Pesaran (2004).
3. The equation can be shown as thus.

$$\hat{\Delta}_{SH} = (N)^{\frac{1}{2}}(2k)^{-\frac{1}{2}}\left(\frac{1}{N}\bar{S} - k\right), \hat{\Delta}_{ASH} = (N)^{\frac{1}{2}}\left(\frac{2k(T-k-1)}{T+1}\right)^{-\frac{1}{2}}\left(\frac{1}{N}\bar{S} - 2k\right)$$

The null and alternative hypotheses are the delta and modified delta that is tandem with the homogeneous and heterogeneous slope coefficients.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Data availability statement

There is no additional data associated with this paper.

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Appendix

Appendix A

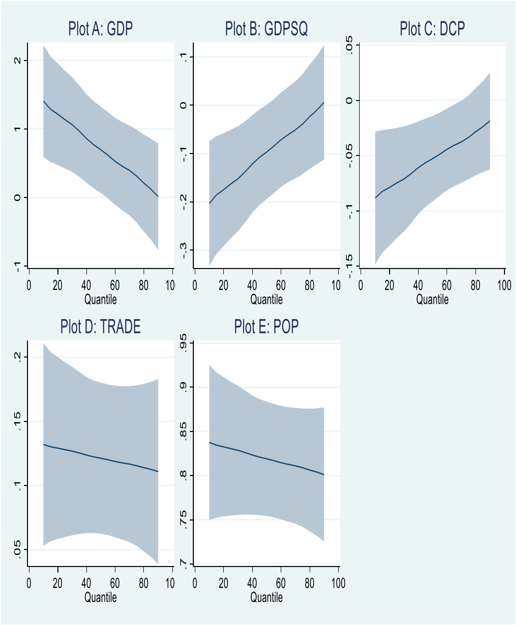

Figure A1. Quantile plots (food ecological deficit analysis).

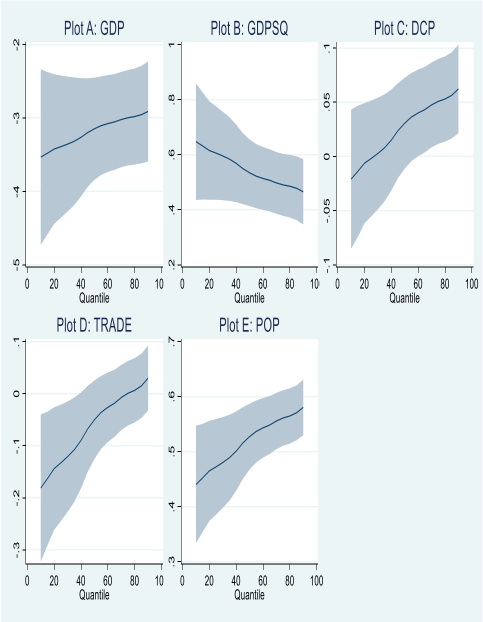

Figure A2. Quantile plots (shelter ecological deficit analysis).