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RESEARCH ARTICLE

An empirical investigation of the effects of poverty and urbanization on environmental degradation: the case of sub-Saharan Africa

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Abstract
This study empirically investigates the effects of poverty and urbanization on environmental degradation for a sample of 43 sub-Saharan African (SSA) economies from 1995 to 2018. The major contribution of the study lies in examining the existence of non-linear effects of poverty and urbanization on environmental degradation. We considered a set of institutional and demographic factors to explain the dynamics among poverty, urbanization, and environmental degradation. Findings suggest that an increase in the poverty gap significantly contributes towards intensifying environmental degradation in SSA countries. Results also show the existence of a non-linear relationship between poverty and environmental degradation. The findings purpose several crucial policy recommendations which necessitate the participation of different stakeholders such as government, institutions, researchers, non-profit organizations and citizens for the effective implementations of environment-friendly policies. A battery of robustness tests confirms the validity of the main findings of the study.

Keywords Poverty · Urbanization · Environmental degradation · Sub-Saharan Africa

Introduction

The primary objective of this study is to examine the main drivers of environmental degradation in sub-Saharan Africa (SSA) countries. Although the region's contribution to per capita energy consumption is minimal, accounting for only 4.8% globally, the notable increase in economic growth and accelerating urbanization have resulted in higher energy demand (Deichmann et al. 2011; Wang and Dong 2019; Yameogo et al. 2021a, b; Byaro et al. 2022; Haldar and Sethi 2022). The SSA region has witnessed a reasonable growth in annual energy consumption from 2000 to 2017 (World Bank 2017. Climate Change Vulnerability Index (2015) reveals that countries susceptible to a higher risk of climate change are mostly from the SSA region such as Sierra Leone, South Sudan, Chad, Nigeria, Ethiopia, Eritrea, and Central African Republic. SSA countries are bestowed with abundant potential for renewable energy, despite that use of non-renewable energy has outpacedrenewable energy consumption (Outlook 2017). Additionally, energy shortage and environmental degradation are increasingly becoming a matter of policy concern across countries in SSA as the region is characterized by energy grid systems, which are among the poorest performing in the world (Asongu and Odhiambo 2021; Asiedu et al. 2022).

During the transition period between millennium development goals (MDGs) and sustainable development goals (SDGs), the incidence of extreme poverty has declined worldwide with minuscule positive changes in the SSA region (Nwani and Osuji 2020). The slowdown in global extreme poverty reduction is caused by the slow economic progress in SSA (Schoch and Lakner 2020). As per World Bank, the number of people living on $1.9 a day or less has decreased from 1.9 billion in 1990 to 736 million in 2015 (World Bank 2017) and by 2030, nearly 9 out of 10 extremely poor people will live in SSA (Fig. 1). The United Nations classifies the SSA region as one of the world's poorest regions, with 31 countries classified as "least developed countries." Although urban economic

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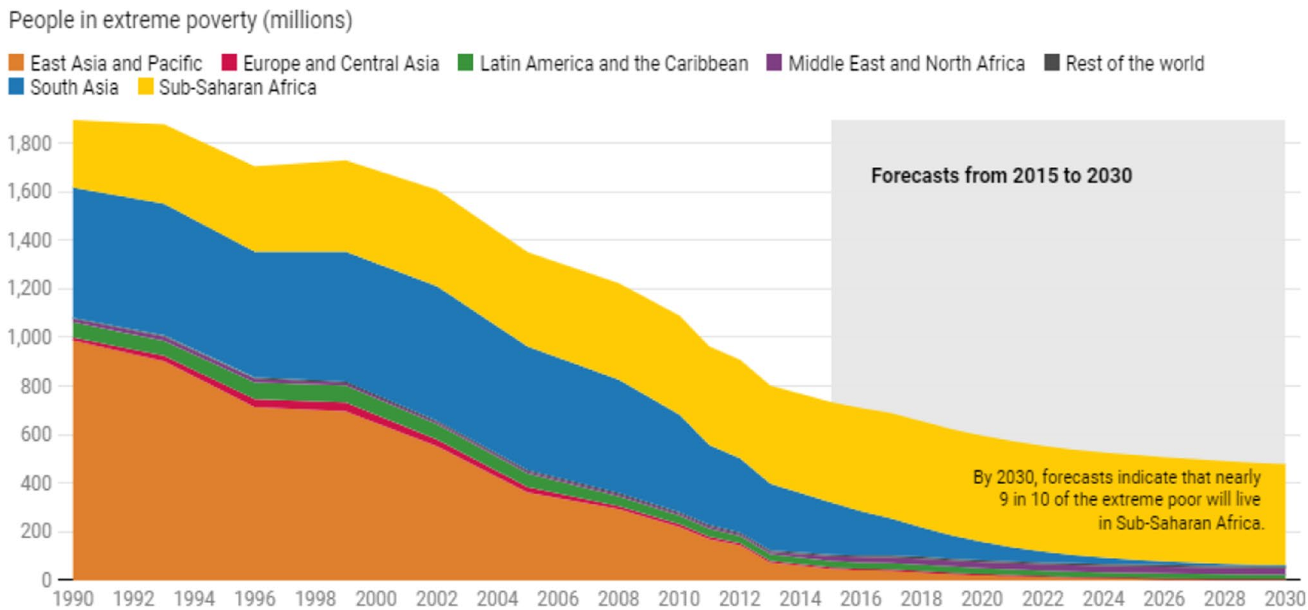

Fig. 1 Poverty forecast from 2015 to 2030

development helps alleviate poverty, it comes with the risk of environmental deterioration (Li et al. 2022; Behera and Sethi 2022). Though a flourishing body of literature documents the interconnectedness between poverty and environmental degradation, the effect of poverty on environmental degradation is theoretically conflicting and empirically inconclusive (Cheng et al. 2018; Khan 2021; Kousar and Shabbir 2021; Rao et al. 2020; Awad and Warsame 2022; Kocak and Celik 2022). The nexus between environmental degradation and poverty has been viewed in such a manner that the poor people are regarded as both victims as well as causes of the environmental pollution in the SSA region.

SSA is one of the fastest urbanizing regions in the world. The region is experiencing an annual urban population growth of 4%, compared with global growth of 2.0% (World Bank 2017). A report published by the Department of Economic and Social Affairs of the United Nations (United Nations 2019) showed that between 1950 and 2018, the urban population grew fourfold worldwide, from 800 to 4220 million, which is expected to increase further to 6700 million by 2050. The global share of African urban residents has been projected to grow from 8.7% in 1990 to 22.3% by 2050 (Saghir and Santoro 2018). Due to rapid urbanization, big cities and their inhabitants come across several economic, social, and human losses due to environmental degradation (Salahuddin et al. 2019). The growing urban centers in the region experience environmental degradation due to inadequate infrastructure and institutional capacity (Douglas et al. 2008; Diagne 2007; Brown et al. 2014). Owing to accelerated urbanization and increased economic activities, the region's energy consumption has grown annually by 3.8% between 2000 and 2007 (Outlook 2019).

Over the years, a slew of human activities ranging from industrialization, urbanization, population growth, and deforestation largely contributed to environmental degradation in SSA countries (Maurya et al. 2020). Furthermore, factors such as economic policy uncertainty, energy poverty, the outbreak of the coronavirus pandemic, and poor and ineffective implementation of environmental reforms have further resulted in the deterioration of the region's environmental quality (Basupi et al. 2017; Anser et al. 2021; Adedoyin et al. 2021; Dash et al. 2022). Moreover, the enormous strain on natural resources caused by floods, typhoons, droughts, and rising temperatures has further damaged the quality of the environment (Fenta et al. 2020; Adedoyin et al. 2021). Kenny (2020) and Lee et al. (2020) extensively discussed the impact of Official Development Assistance (ODA) on environmental degradation. A detailed analysis of whether ODA reduces environmental degradation is scant in the literature.

Given the background, this study raises a series of important questions: Does urbanization deteriorate or improve the quality of the environment? Does poverty influence environmental degradation? What is the joint effect of urbanization and poverty on the environment? Does ODA affect environmental degradation in SSA countries?

This study extends an analytical framework to explore the inter-linkages between urbanization, poverty, and environmental degradation in the SSA region. We identify the gaps in the existing literature on the poverty-environment nexus and discuss the implications of the joint effects of urbanization and poverty on environmental degradation in the SSA region. We also analyze the mediating role of institutional and demographic factors in the discourse of poverty-environmental connection. Lastly, we identify the channels through which development assistance, a crucial source of international funding to SSA countries, is conducive to environmental sustainability.

We apply the static and dynamic panel data models to examine the effects of poverty and urbanization on environmental degradation. The results obtained reveal that an increase in the poverty gap significantly contributes to the growing problem of environmental degradation in SSA. The results further reveal the existence of a non-linear relationship between poverty and environmental degradation. An increase in poverty coupled with rapid urbanization affects the quality of environment in the region. Additionally, institutional and demographic factors seem to have significant effects on the environmental degradation in SSA region.

The major contributions of this study to the existing literature can be outlined as follows. First, there is a lack of empirical understanding about how the incidence of poverty along with unregulated and unchecked urbanization is affecting the environment in SSA. To the best of our knowledge, this is the first study investigating the joint effects of poverty and urbanization on environmental degradation in SSA. Second, there are several studies that have investigated the impact of macroeconomic indicators on environmental degradation by applying linear models (Arouri et al. 2012; Sadorsky 2014; Shahbaz et al. 2016; Wang et al. 2018a, b, Ahmad et al. 2019; Sahoo and Sethi 2021). Our study shows that the relationship between poverty-environment and urbanization-environment is non-linear in SSA; therefore, policies must be country-specific, and no single policy can be enacted in the region that can work equally well for all countries. Third, unlike previous studies on environmental degradation, this study considers the role of development aid in mitigating environmental degradation. One previous study (Wang et al. 2021) investigated the impact of ODA on renewable energy development in 34 SSA countries. Our study differs from Wang et al. (2021) on the ground that it considers the role of ODA in environmental degradation for a wider set of 43 SSA countries. Finally, we employ several alternative indicators of poverty and environmental degradation to derive conclusions about the effect of poverty on the environment.

The remainder of the paper is structured as follows. The "Theoretical literature" section discusses the theoretical considerations of urbanization, poverty, and environmental degradation. The "Empirical literature" section provides an overview of empirical literature. The "Data and empirical framework" section provides the methodological background of the study. The "Results and discussion" section discusses the findings and the "Conclusion and policy implications" section concludes the paper with several policy implications, limitations, and the future scope of research.

Theoretical literature

Poverty and environmental degradation

Masron and Subramaniam (2019) view that poverty alleviation and environmental sustainability are like "killing two birds with one stone." The poverty-environment hypothesis states that the poor people disproportionately rely on natural resources, focus on current benefits rather than future developments, and have restricted access to financial resources; therefore, their activities can have damaging effects on the environment. It is vehemently argued that environmental degradation also impacts the lives of the poor and they are also the victims of harmful consequences of environmental pollution. Duraiappah (1998) argues that the association between poverty and environmental degradation is multidimensional, and poverty is not the root cause of environmental degradation. On one hand, the conventional school of thought maintains that poverty and environmental degradation can feed each other, and poverty is the leading cause of the vicious circle; therefore, it is imperative to tackle poverty first to reduce environmental degradation (Yusuf 2002). On the contrary, another school of thought suggests that quality institutions and population growth mediate the bi-directional relationship between poverty and environmental degradation (Yusuf 2002). Quality institutions along with well-defined property rights create an enabling environment for the poor to adopt sustainable activities that help in preventing environmental degradation (Adler 2000; Aron 2000; Subramanian 2007; Khan 2021; Esquivias et al. 2022). In addition to institutional quality, Dasgupta (2000) suggested that large family size is associated with poverty, which further generates negative environmental externalities through pressure on common natural resources. The practical relevance of conventional theory, according to which, poverty leads to environmental degradation has been put into question by contrasting empirical evidence (Duraiappah 1998).

Urbanization and environmental degradation

Poumanyvong and Kaneko (2010) extended three underlying theories that potentially explain urbanization and environmental degradation relationship. *First*, *ecological modernization theory* states that urbanization increases environmental degradation during the transition from low to medium development as nations prioritize economic growth over sustainable development. However, post the middle stage of development, urbanization reduces environmental degradation through technological advancement, innovation, and environmentally sustainable policies. *Second*, *the urban environmental theory argues* that as societies undergo a transition to a more manufacturing and industry-led economy, the level of atmospheric pressures increases along with society's wealth and progress. It has been further maintained that as the cities start flourishing and become wealthier, the pollution levels can be significantly reduced with the help of environmental regulatory policies and structural changes in the economy. Finally, *the compact city theory* exhibits that there are advantages of urbanization with the view that higher urban density ensures economies of scale for public infrastructure, thereby lowering the environmental pollution (Burgess and Jenks 2002; Effiong 2016). These theories maintain that urbanization has varying environmental impacts across different stages of development; first, it propels environmental degradation, and later, it supports environment-friendly activities (Effiong 2016). Various empirical studies support these theories in the context of developing countries (Ehrhardt-Martinez et al. 2002; Martínez-Zarzoso and Maruotti 2011).

Dynamics between poverty, urbanization, and environmental degradation

Cobbinah et al. (2015) argue that rural poverty and the resultant migration to urban areas put excessive pressure on urban resources, which leads to the development of informal settlements with dismal state of sanitation and essential services. Furthermore, the lack of financial and technical resources, and institutional capacity in developing countries reduce their ability to plan and guide the urbanization process sustainably. Poor migrants in urban areas are less well-acquainted with several urban environmental problems and therefore face difficulty adapting to the urban lifestyle. Weak institutional provisions for the urban poor by local and national governments in many developing countries further aggravate the issue and make them dependent on common natural resources. Migration and forced settlement in urban areas make the poor both the cause and victim of environmental degradation (Yusuf 2002). Liddle (2017) also showed similar projections and revealed that cities have a strong migratory pull in countries with lower per capita income. Based on these arguments, we argue that urbanization spurs the negative effect of poverty on environmental degradation. Moreover, existing studies have not examined the interactive effect of urbanization and poverty to the best of our knowledge (Awad and Warsame 2022; Hussain et al. 2022; Kocak and Çelik 2022).

Linkage between demographic, institutions, and environmental degradation

IPAT model (IPAT), first proposed by Ehrlich and Holdern (1971), suggests that environmental degradation (I) is the multiple function of population size (P), per capita of economic activity (A), and technology (T). The framework emphasizes the role of population and economic growth in accelerating environmental degradation by using more natural resources and waste generation beyond the assimilation capacity of nature (Dasgupta 2000; Effiong 2016). Besides these demographic factors, good quality institutions enable governments to devise and implement pro-environment and poverty alleviation policies (Rizk and Slimane 2018; Khan 2021; Chandio et al. 2021b). Adams et al. (2016), Amuakwa-Mensah and Adom (2017) , and Adekunle (2021) unveiled that quality institutions are critical for environmental sustainability in African countries, which are undergoing rapid urbanization. Moreover, African countries are bound by conflict, bad policy environments, and poor-performing institutions, thereby limiting the effectiveness of private investments in the region (Fosu 2015).

Under this scenario, development assistance from developed nations could assist African countries in building institutional capacity to tackle environmental issues and poverty simultaneously by enhancing financial and technical ability to take care of natural resources, protect the environment, and create a more inclusive society through stimulating economic growth and technological development (Huang and Quibira 2018). A rise in per capita income and technological innovation increases the demand for a clean environment and enhances the capacity to provide environmental protection. In this context, Dodman et al. (2017) argue that due to lack of absorptive capacity in African countries, large-scale investments in social and economic projects through concessional funding might not be effective in tackling environmental issues.

Empirical literature

Several studies have investigated the factors that cause environmental degradation in a set of developing countries (Yahaya et al. 2020; Tenaw and Beyene 2021; Ali et al. 2021; Dagar et al. 2022; Usman et al. 2022). However, these studies did not consider the aspect of poverty while explaining the causes of environmental degradation. Few studies explored the intricacies between poverty and environmental degradation in the context of individual countries and cross-country context (Azizi et al. 2022; Ehigiamusoe et al. 2022; Khan et al. 2022; Meher 2022) and findings reveal that the relationship between poverty and environment is mostly inconclusive and other macroeconomic, institutional, and country-specific factors affect the poverty-environment linkage.

Masron and Subramaniam (2019) affirmed that poverty is the leading cause of environmental degradation in developing countries and suggest that poverty alleviation can significantly improve the quality of the environment. By contrast, Rizk and Slimane (2018) and Kousar and Shabbir (2021) revealed that environmental degradation significantly contributes to poverty; therefore, focus must be on improving environmental quality, which might lead to poverty reduction. Khan (2021) showed that poverty and environmental degradation can be reduced simultaneously by improving institutional quality. Baloch et al. (2020) showed that poverty degrades ecological footprints and asserted that excessive use of natural resources in the form of food, water, and energy to sustain livelihood might lead to environmental degradation in SSA. Asongu (2018) showed that increasing CO_2 emissions negatively impacts inclusive human development and hinders poverty and inequality reduction. As existing studies provide inconclusive evidence on the poverty-environmental degradation linkage, we attempt to contribute to the literature by investigating the poverty-environmental degradation nexus by accounting for non-linearity, mediating factors, and endogeneity concerns.

Past studies examined the nexus between energy, poverty, and ecological footprint across countries. Using the autoregressive distributed lag model, Amin et al. (2020) investigated the impact of energy poverty on economic growth in South Asian countries from 1995 to 2017 and showed that energy poverty adversely affects economic growth both in the short and long run. Ansari et al. (2022) examined the impact of energy poverty on macroeconomic variables in SSA countries from 1995 to 2018 and find that energy poverty significantly reduces the ecological footprint in the region. The relationship between poverty and environment is empirically an unsettled research agenda. This is primarily because policies directed towards poverty eradication may get reflected in poor quality of the environment and some policy measures to preserve the environment may lead to the expansion of poverty (Ahmed et al. 2009; Barbier 2010; Watmough et al. 2016; Bhujabal et al. 2021; Ehsanullah et al. 2021; Awad and Warsame 2022; Amin et al. 2022; Chandio et al. 2022a, b). In light of previous studies, we propose our first hypothesis as follows:

- Hypothesis 1: The incidence of poverty has no effect on environmental degradation in SSA countries.

Since environmental degradation is closely associated with human activities, the relationship between urbanization and the environment has been considered in this study. Although a flourishing body of literature investigated the linkage between urbanization and environmental degradation across countries, literature is limited in the context of SSA region (Cole and Neumayer 2004; Sadorsky 2014; Shahbaz et al. 2014; Azam and Khan 2016; Wang et al. 2018b; Yasin et al. 2021; Wang et al. 2022). The accelerating pace of urban economic development has resulted in reduction in poverty at the expense of higher environmental risk (Li et al. 2022). Esso and Keho (2016) argued that lack of advanced technology has impeded the tapping of green energy potential and increased the consumption of energy from fossil fuels in the process of urbanization. Urbanization also influences the quality of the environment through traffic congestion, excessive use of personal vehicles, and unhygienic water and sanitation (Sahoo and Sethi 2020, 2021).

In terms of population growth, the percentage of urban population is rapidly increasing, and parts of the SSA and Asia are the most rapidly urbanized regions in the world (Sulemana et al. 2019). Kasman and Duman (2015) found that there exists unidirectional short-run causality from urbanization to CO_2 emissions in EU countries from 1992 to 2010. Unplanned urbanization, imperfect government planning of urban constructions, and economic development exert a serious burden on environmental sustainability including land degradation, ecological depletion, and greenhouse gas emissions (Ali and Kaur 2021; Kassouri 2021). Nathaniel and Khan (2020) investigated the association between urbanization and ecological footprint in ASEAN economies from 1990 to 2016. Their findings reveal that the rapid pace of urbanization dilutes ecological footprint across countries. A large volume of studies also found an inverse relationship between urbanization and ecological footprint (Ahmed et al. 2020a, b; Bhujabal et al. 2021; Haldar and Sethi 2021; Sahoo and Sethi 2021).

In the African context, existing empirical studies provide inconclusive and mixed evidence on the relationship between urbanization and environmental degradation. On the one hand, Effiong (2016) and Nathaniel et al. (2019) showed that urbanization reduces environmental pollution through economies of scale in providing adequate and efficient public infrastructure. However, most empirical studies found negative effect of urbanization on environmental quality (Adams et al. 2016; Wang and Dong 2019; Jena and Sethi 2019; Salahuddin et al. 2019; Iheonu et al. 2021; Malik 2021). While segregating African countries into carbon exporters and importers, Mensah et al. (2021) observe that urbanization improves environmental quality in net exporters and degrades environmental quality in net importer countries. However, none of the existing studies incorporated the non-linear effects of urbanization on environmental degradation as elucidated by these theoretical underpinnings. Based on the previous literature reviewed, we formulate our second hypothesis as follows:

- Hypothesis 2: Urbanization has no effect on the environmental degradation in the SSA countries.

Recently, a great deal of attention has been paid towards exploring the dynamics between development assistance and climate change, as the role of ODA in mitigating environmental degradation has remained a debated issue (Park 2016; Barasa et al. 2018; Lee et al. 2020; Kenny 2020). Lee et al. (2020) suggest that ODA exerts both positive and negative effects on the carbon emissions of recipient countries. Few studies have found that ODA does not directly affect the development of renewable energy and environmental quality (Barasa et al. 2018; Dagar et al. 2022; Mehmood 2022). Wang et al. (2022) found that ODA helps in alleviating the environmental pressures during the process of urbanization in SSA countries. Though a good volume of empirical studies have been published to investigate the effect of ODA on economic growth, health, and trade openness, very little attention has been paid towards exploring the relationship between ODA and environmental degradation (Herzer and Nunnenkamp 2012; Martínez-Zarzoso et al. 2017; Lessmann and Seidel 2017; Herzer 2019; Gnangnon 2019; Park and Jung 2020; Boateng et al. 2021). ODA for the effective implementation of renewable energy projects is very crucial as ODA for renewable energy increases the amount of electricity generated from renewable sources in SSA economies (Gozgor 2018; Wang et al. 2022). Given the crucial role of ODA in SSA countries, it seems reasonable to explore the association between development assistance and environmental degradation as per the following null hypothesis.

- Hypothesis 3: ODA has no effect on environmental degradation in SSA countries.

Data and empirical framework

Data and variable sources

The present study explores the dynamics among poverty, urbanization, ODA, and environmental degradation for a panel of 43 SSA countries from 1995 to 2018. We collected information from different sources such as African Development Indicators (ADI) of the World Bank, World Governance Indicators (WGI), World Development Indicators (WDI), PovcalNet, World Bank and Organization for Economic Cooperation and Development (OECD) and Development Assistance Committee (DAC) database. We use two alternative indicators of poverty, namely the headcount ratio and the poverty gap (Figs. 2 and 3 in the Appendix). To measure environmental degradation (ED), we use two indicators: CO_2 emission from fossil fuels and deforestation. Urbanization is defined as the urban population as a percentage of the total population. Additionally, we use a set of demographic, institutional, and macroeconomic factors as control variables. The description of the variables along with data sources is presented in Table 1. The selection of the time period is strictly based on availability of the data. Since information on some variables such as poverty gap and headcount ratio were not available for few countries for recent years, we restricted the time period up to 2018.

Empirical framework

Two empirical specifications are employed in this study. First, we use a static panel data model with fixed-effects regression to address the possible unobserved heterogeneity. Second, we apply the GMM model that accounts for simultaneity using instruments and also tackles the issues of endogeneity, reverse causality, and omitted variables bias. Following Asongu and Odhiambo (2018), we specify the panel fixed-effects model as below.

$$\ln \mathrm{ED}_{i,t} = \alpha_0 + \alpha_1 \ln \mathrm{POV}_{i,t} + \alpha_2 \ln \mathrm{POV}^2_{i,t} + \alpha_3 \ln \mathrm{URB}_{i,t} + \alpha_4 \ln \mathrm{URB}^2_{i,t} + \alpha_5 \ln \mathrm{Controls}_{i,t} + u_{i,t} \quad (1)$$

In Eq. (1), i denotes cross-section (SSA country) and t denotes time (years from 1995 to 2018). We use two proxy variables for ED, namely CO_2 emission and deforestation. Emissions are those stemming from the burning of fossil fuels and manufacture of cement apart from other activities. Another proxy used for ED is deforestation, defined as the net forest depletion and is calculated as the product of unit resource rents and the excess of round wood harvest over natural growth. POV and POV^2 denote poverty measure in the linear and quadratic forms. We use the poverty gap and headcount ratio to measure poverty. The poverty gap is defined as the average shortfall of the total population from the poverty line. This indicator shows the intensity of poverty in a country. The poverty headcount ratio at \$1.90 a day is the percentage of the population living on less than \$1.90 a day at 2011 international prices. URB and URB^2 denote urbanization and urbanization-squared, which is defined as the urban population as a percentage of the total population. Controls represent the set of control variables such as population growth, development assistance, government effectiveness, and the rule of law. We consider two macroeconomic indicators, namely economic growth and inflation as control variables. To overcome the problem of endogeneity of some regressors, we also estimate Eq. (1) by applying a dynamic panel data model, i.e., system GMM. The application of GMM mitigates the potential small sample biases arising from the difference estimator (Asongu 2013). As in our study, the system GMM technique is well-suited in those cases where the number of cross-sections is higher than the number of periods. Table 2 presents the descriptive statistics of the variables.

Table 1 Definitions of the variables

Variables	Definitions	Symbols	Source	Expected sign
Dependent variables				
CO_2 emission	Carbon dioxide emissions are those stemming from the burning of fossil fuels and the manufacture of cement. They include carbon dioxide produced during the consumption of solid, liquid, and gas fuels and gas flaring	CO_2	IEA	
Deforestation	It is defined as the net forest depletion, calculated as the product of unit resource rents and the excess of round wood harvest over natural growth	DEF	WDI	
Independent variables				
Poverty gap	The poverty gap is defined as the average shortfall of the total population from the poverty line. This indicator shows the intensity of poverty in a country	POV	WDI	positive
Headcount ratio	Poverty headcount ratio at $1.90 a day is the percentage of the population living on less than $1.90 a day at 2011 international prices	HCR	WDI	positive
Urbanization	Urban population as a percentage of the total population	URB	WDI	positive
Population growth	Population growth is the increase in the number of individuals in a population of a country	PG	WDI	positive
Development assistance	Official development assistance (ODA) is defined as government aid designed to promote the economic development and welfare of developing countries. The aid includes grants, "soft" loans, and the provision of technical assistance	ODA	WDI	Negative
Government effectiveness	It measures the quality of public services, civil service, policy formulation, policy implementation, and credibility of the government's commitment to raise these qualities or keeping them high	GE	WGI	Negative
Rule of law	This index captures the perceptions of the extent to which agents abide by enforcement of contracts, property rights, police, and the court	LAW	WDI	Negative
Economic growth	Gross Domestic Product per capita (constant USD)	EG	WDI	Inconclusive
Inflation	Inflation is measured by the consumer price index, which reflects the annual percentage change in the cost to the average consumer for acquiring a basket of goods and services	INF	WDI	Inconclusive

IEA International Energy Agency, *WDI* World Development Indicators, *WGI* World Governance Indicator

Table 2 Descriptive statistics

Variables	No. of Observations	Mean	Standard deviation	Minimum	Maximum
CO_2	1032	0.834	1.652	0.015	9.979
DEF	1032	3.912	5.721	0	40.815
URB	1032	37.301	15.606	7.211	89.370
HCR	1032	43.830	23.650	0.140	96.420
PG	1032	18.316	13.240	0.020	66.040
ODA	938	678.956	764.971	− 18.410	7017.770
GE	1032	− 0.703	0.605	− 1.884	1.056
LAW	1032	− 0.652	0.638	− 2.130	1.07713
PG	1029	18.310	13.210	0.020	50.440
INF	973	0.183	1.617	− 0.096	41.451

Author's calculation

In this study, the Roodman (2009a, b) extension of Arellano and Bover (1995) is expressed, which is used to restrict the over-identification and limit the proliferation of instruments (Baltagi and Baltagi 2008; Tchamyou 2017). The two-step model is preferred to the one-step procedure because the latter is homoscedasticity-consistent while the former also controls for heteroscedasticity. For GMM estimation, following Arellano and Bond (1991), we provide the following specification of the empirical model.

$$\ln \mathrm{ED}_{i,t} = \alpha_0 + \alpha_1 lnED_{i,t-1} + \alpha_2 \ln \mathrm{POV}_{i,t} + \alpha_3 \ln \mathrm{POV}^2_{i,t} + \alpha_4 \ln\mathrm{URB}_{\,i,t} + \alpha_5 \ln\mathrm{URB}^2_{i,t} + \alpha_6 \ln \mathrm{Controls}_{\,i,t} + \delta_i + \gamma_t + u_{i,t} \quad (2)$$

where δ_i captures the unobserved country-specific effects, and γ_t is the time-specific effect.

Results and discussion

First, we present the correlation matrix and then we present results of static as well as dynamic panel regression models. Finally, we examine the robustness of our findings by applying alternative econometric techniques. In our robustness analysis, we also consider deforestation as an alternative indicator of environmental degradation.

Table 3 shows the correlation matrix of all the variables considered in this study. Most importantly, we notice that there exists a positive correlation between poverty and CO_2 emissions, and between urbanization and CO_2 emissions at a 5% significance level. We note a negative correlation between ODA and CO_2 emissions. Government effectiveness and rule of law have been found to be negatively correlated with environmental degradation. There is negative correlation between economic growth and CO_2 emissions and a positive but insignificant correlation between inflation and environmental degradation. Finally, population growth is positively correlated with CO_2 emissions.

Table 4 presents panel fixed effect estimation results, showing the effect of poverty and urbanization on environmental degradation using CO_2 emissions as the dependent variable. Considering the impact of poverty on ED, we find that the coefficient of the poverty gap is positive and statistically significant at 1% level, implying that an increase in the poverty gap significantly contributes to environmental degradation. The results show that 1% increase in the poverty gap is associated with a 2% increase in CO_2 emissions. Our findings are in line with a previous study(Baloch et al. 2020), which found that an increase in income inequality and poverty contributes to environmental degradation in the region. The consumption of non-renewable energy in the region has far overweighs renewable energy consumption as, since 2000, most new electricty access has come from fossil fuels (Outlook 2017). Thus, over-exploitation of non-renewable sources of energy by the poor might be the leading cause of environmental degradation in the region. This finding implies that the null hypothesis 1 has been rejected in the SSA region implying that poverty might be exacerbating environmental degradation in the region. The finding of our study corroborates the results obtained by Rizk and Slimane (2018) and Masron and Subramaniam (2019), who found poverty to be adversely affecting the quality of the environment.

The negative and statistically significant coefficient of the POV^2 across all the models justifies the existence of non-linear relationships between poverty and environmental degradation. After a certain threshold level of poverty, the increase in the poverty gap might not be detrimental to the environment. It indicates that poverty might be the cause of environmental degradation and not an outcome of it. Therefore, the first step must be to reduce poverty to improve ecological quality in the region in close agreement with Rizk and Slimane (2018), who also noted a non-linear relationship between poverty and environment. Regarding the effects of urbanization on environmental degradation, we find that higher urbanization levels significantly increase environmental degradation. The coefficients of urbanization across all the estimated models are positive and statistically significant at 5% in majority of models, which might be attributed to the gradual shift of rural population to urban areas, the use of personal vehicles for transport, traffic congestion, and unhygienic water and sanitation. This finding is in line with previous studies of Jaysawal and Saha (2014) and Sahoo and Sethi (2020, 2021). Contrary to our findings, Nathaniel and Khan (2020) found that urbanization diluted the ecological footprint of a panel of selected ASEAN economies. Based on our findings, we reject the second hypothesis of no relationship between urbanization and CO_2 emissions and conclude that urbanization is positively associated with higher CO_2 emissions in the SSA countries.

Table 3 Correlation matrix

Variables	*CO_2*	*POV*	*URB*	*ODA*	*GE*	*LAW*	*PG*	*EG*	*INF*
CO_2	1								
POV	0.549*	1							
URB	0.477*	−0.458*	1						
ODA	−0.156*	0.256*	0.267*	1.00					
GE	−0.547*	−0.508*	0.199*	−0.046	1				
LAW	−0.490*	0.435*	0.184*	−0.094*	0.894*	1			
PG	0.016	0.194*	0.104*	0.786*	−0.084*	−0.175*	1		
EG	0.669*	−0.726*	0.530*	−0.232*	0.525*	0.476*	0.111*	1	
INF	−0.013	0.024	0.015	−0.058	−0.011	−0.035	−0.085*	0.01	1

*denotes statistical significance at 5% level

Table 4 Impact of poverty and urbanization on environmental degradation

Dependent variable: CO_2 emission	Model 1	Model 2	Model 3	Model 4	Model 5
URB	0.197*** (0.0644)	0.206*** (0.0683)	0.208*** (0.0684)	0.129 (0.0869)	0.150* (0.0866)
PG	0.029*** (0.0063)	0.030*** (0.0065)	0.030*** (0.0065)	0.026*** (0.0068)	0.024*** (0.0068)
Square of PG	−0.027*** (0.0046)	−0.027*** (0.0048)	−0.027*** (0.0048)	−0.029*** (0.0048)	−0.027*** (0.0050)
ODA		−0.011 (0.0111)	−0.011 (0.0111)	−0.013 (0.0111)	−0.022 (0.0167)
LAW			−0.023 (0.0345)	−0.025 (0.0343)	−0.026 (0.0340)
*URB*PG*				0.0002** (0.0001)	0.0002** (0.0001)
*URB*ODA*					4.01*** (0.2300)
*POV*ODA*					−1.08** (0.5107)
PG	0.0157** (0.0085)	0.014* (0.0087)	0.014* (0.0087)	0.014* (0.0087)	0.012 (0.0086)
GE	−0.035* (0.0229)	−0.044** (0.0243)	−0.032 (0.0298)	−0.038 (0.0298)	−0.035 (0.0296)
EG	0.031** (0.0125)	0.040*** (0.0134)	0.041*** (0.0135)	0.040*** (0.0134)	0.042*** (0.0133)
INF	−0.011* (0.0058)	−0.011* (0.0059)	−0.011* (0.0060)	−0.010* (0.0060)	−0.009 (0.0059)
Constant	−1.279*** (0.2458)	−1.348*** (0.2707)	−1.369*** (0.2727)	−1.070*** (0.3077)	−1.12*** (0.3170)
R^2	0.6156	0.5984	0.6097	0.5607	0.5924
Observations	1032	1032	1032	1032	1032
Number of countries	43	43	43	43	43
F Statistic (p-value)	30.86 (0.00)	25.96 (0.00)	23.09 (0.00)	21.42 (0.00)	19.13 (0.00)

The dependent variable is CO_2 emission. Aid implies development assistance. Values in parentheses below coefficient estimates represent the standard error and values in parentheses for *F* statistics represent the *p*-value.

*, **, and *** denote the level of significance at 10%, 5%, and 1% respectively

The coefficient of development aid (ODA) is negative and but not statistically significant in any model (Table 4). ODA is very crucial for SSA countries as the region is bestowed with huge renewable energy potential and development assistance can play a very crucial role in promoting renewable energy development. However, we failed to reject the null hypothesis as the coefficient is not statistically significant in any model. It might be due to the fact that some of the ODA might be going towards environmentally sustainable and some of the ODA might be going towards projects which have detrimental effects on the environment. The finding is different from Wang et al. (2021) who found that development assistance promotes renewable energy development during the initial phases of technological progress and social structural changes. A detailed examination of the relationship between ODA, renewable energy and environment in the region can be an agenda of future research.

However, when we interacted ODA with poverty, the joint effect significantly reduces environmental degradation in the region. It implies that development assistance directed towards alleviating poverty can enhance environmental quality in the region as poverty is the main cause of environmental degradation. In comparison, aid projects and programs directed towards growth and development in urban centers might be detrimental to the environment, as indicated by the positive and significant coefficient on the interaction term of urbanization and development aid. In line with the theoretical explanations, the empirical findings indicate that the combined effect of poverty and urbanization aggravates environmental degradation. It suggests that poverty and the resultant migration to urban areas have affected the environment adversely in SSA countries. Therefore, urban poverty and dismal state of informal settlements caused by unregulated urbanization in SSA pose a severe threat to the region's environmental sustainability.

Turning attention to the effect of institutional, demographic, and macroeconomic factors, we mostly find negative but statistically insignificant effects of institutional factors such as government effectiveness and the rule of law on environmental degradation. As poor institutions characterize the SSA region, the marginal increase in the institutional quality is not enough to positively contribute towards environmental protection (Dodman et al. 2017). Concerning population growth, it has been noted that the explosion in population has an adverse effect on environmental sustainability. Finally, higher levels of economic growth in terms of the extension of industrial activities and the expansion of financial services have led to environmental degradation. Yameogo et al. (2021a, b) also found that higher economic growth coupled with government ineffectiveness and poor institutional qualities deteriorates the quality of the environment in the SSA region.

Table 5 shows the existence of the non-linear relationship between urbanization and environmental degradation.

Table 5 Effects of institutional variables on environmental degradation

Dependent variable: CO_2 emission	Model 1	Model 2	Model 3	Model 4	Model 5
URB	0.132** (0.0544)	0.149*** (0.0547)	0.136** (0.0654)	0.128* (0.0749)	0.170** (0.0755)
Square of URB	−0.0024*** (0.0008)	−0.0019*** (0.0001)	−0.0020*** (0.0004)	−0.0024 (0.0027)	−0.0021** (0.0009)
HCR	0.032*** (0.0025)	0.029** (0.0125)	0.024* (0.0145)	0.027*** (0.0078)	0.019 (0.0135)
Square of HCR	−0.016*** (0.0035)	−0.036*** (0.0057)	−0.016*** (0.0037)	−0.018*** (0.0028)	−0.017*** (0.0020)
*HCR*PG*		0.011*** (0.0011)	0.011*** (0.0001)	0.013 (0.0111)	0.022 (0.0167)
LAW HCR*			0.022 (0.0246)	0.026 (0.0247)	0.017 (0.0247)
*GE *HCR*				−0.0004*** (0.0001)	−0.0004*** (0.0001)
*PR * ODA*	−0.0214*** (0.0024)	−0.0147*** (0.0012)			−0.021 (0.0147)
*GE *ODA*			−1.057*** (0.2417)	−2.14*** (0.614)	−1.08** (0.5107)
EG	0.031** (0.0125)	0.040*** (0.0134)	0.041*** (0.0135)	0.040*** (0.0134)	0.042*** (0.0133)
INF	−0.001 (0.0008)	−0.001 (0.0009)	−0.011* (0.0060)	−0.010* (0.0060)	−0.009 (0.0059)
Constant	−1.168*** (0.2157)	−1.244*** (0.2608)	−1.647*** (0.2524)	−1.070*** (0.3077)	−1.12*** (0.3170)
R^2	0.6351	0.5283	0.6496	0.5748	0.5748
Observations	1032	1032	1032	1032	1032
Number of countries	43	43	43	43	43
F Statistics (p-value)	30.86 (0.00)	25.96 (0.00)	23.09 (0.000)	21.42 (0.0)	19.13 (0.00)

Values in parentheses below coefficient estimates represent the standard error and values in parentheses for *F* statistics represent the *p*-value. *, **, and *** denote the level of significance at 10%, 5%, and 1% respectively

The significant negative coefficients of the square terms of the urbanization across all the models shows the inverted U-shaped relationship between urbanization and CO_2 emissions in the SSA region. This finding ascribes the non-linear relationship to the effects of the urbanization and the growth of service-dominated urban economies. In Table 5, we replace the poverty variable with the poverty headcount ratio. The positive and significant coefficients of the headcount ratio show the positive impact of poverty on environmental degradation. The statistically significant coefficient on the square of the headcount ratio justifies the existence of the non-linear relationship between poverty and environmental degradation. This implies that though poverty causes environmental degradation initially, after a threshold level, an increase in poverty does not affect the region's environmental quality.

As argued theoretically, better institutional quality plays a major role in mediating the poverty-ED relationship (Duraiappah 1998; Yusuf 2002). Therefore, we interact poverty with institutional variables to examine the mediating role of the institutions in the poverty-ED relationship. We find that quality of institutions in the form of better governance effectiveness alters the negative effect of poverty on environmental degradation. It indicates that the quality of civil services and the policy formation ability of the government could impact those activities of poor people that are harmful to the environment. Estimated results further reveal that higher population growth and higher poverty incidence adversely affect the SSA region's environment. Regarding the interaction between development assistance and institutional factors, we find that foreign aid effectiveness for reducing environmental degradation depends on government effectiveness in the recipient country. As predicted, we notice that higher economic growth exerts a positive effect on environmental degradation.

We further check the robustness of the main findings using a two-step system GMM approach and replace the dependent variable with an alternate proxy of ED, i.e., deforestation. Table 6 shows that the estimated coefficients of the lagged dependent variable are positive and statistically significant across all the models implying the persistent effect of deforestation in the SSA countries. With respect to the effects of urbanization on deforestation, we find that urbanization positively contributes to deforestation in the region. Concerning the effects of poverty and other institutional variables, we find that the results obtained through the two-step system GMM are largely consistent with the fixed-effects model. However, turning to the effect of development aid on deforestation, we note that development aid positively and significantly gives rise to deforestation in the SSA region. The finding can be attributed to the event that development funds directed towards infrastructure and

Table 6 Robustness check

Dependent variable: deforestation	Model 1	Model 2	Model 3	Model 4	Model 5
DEF (t – 1)	0.967*** (0.0401)	0.982*** (0.0489)	0.990*** (0.0388)	0.912*** (0.0427)	0.936*** (0.0478)
URB	0.009*** (0.0007)	0.006*** (0.0006)	0.008*** (0.0008)	0.010 (0.0473)	0.008 (0.0595)
PG	0.005*** (0.0009)	0.003*** (0.0006)	0.003 (0.0107)	0.008 (0.0099)	0.005*** (0.0005)
ODA		0.013*** (0.0048)	0.011 (0.0068)	0.0009*** (0.0001)	−0.003*** (0.0006)
LAW			−0.03* (0.0164)	−0.009 (0.0415)	0.0006 (0.0498)
*URB*PG*				0.006*** (0.0016)	0.0006 (0.0004)
*URB*ODA*					0.0007*** (0.0001)
*POV*ODA*					−0.0003 (0.0011)
PG	−0.009*** (0.0003)	−0.007*** (0.0005)	−0.009*** (0.0030)	−0.003** (0.0010)	−0.001 (0.0072)
GE	−0.019 (0.0210)	−0.040 (0.0320)	−0.016 (0.0796)	0.004 (0.0560)	−0.002 (0.0422)
EG	0.006*** (0.0001)	0.002 (0.0135)	0.004 (0.0210)	0.021*** (0.0071)	0.023*** (0.0015)
INF	0.001 (0.0031)	0.001 (0.0064)	0.003 (0.0062)	−0.006*** (0.0009)	−0.005*** (0.0003)
Constant	−0.110** (0.0524)	−0.142** (0.0621)	−0.147*** (0.0545)	−0.243*** (0.0088)	−0.242** (0.1155)
Observations	1032	1032	1032	1032	1032
Number of countries	43	43	43	43	43
Number of instruments	42	43	43	43	43
Hansen Test (p-value)	0.50	0.549	0.600	0.576	0.91
AR (1) Test (p-value)	0.004	0.017	0.018	0.004	0.004
AR (2) Test (p-value)	0.102	0.278	0.332	0.119	0.139

Values in parentheses below coefficient estimates represent the standard error. *, **, and *** denote the level of significance at 10%, 5%, and 1% respectively

other economic projects necessitate the allotment of land that is covered by forest. Therefore, the implication of development aid on deforestation appears to be negative in the SSA region.[1]The results show the number of instruments is equal to the number of cross-sections in majority of models. Hansen test is used to check the validity of the instruments in all specifications. The higher *p*-values of the Hansen test show no over-identifying restrictions in the estimated models. Furthermore, the *p*-values of AR (1) confirm the presence of first-order autocorrelation in all models and the presence of second-order autocorrelation is rejected ($p > 0.05$). These diagnostics tests reveal that the estimated models are well-specified and are free from the issue of autocorrelation and instrument proliferations.

Table 7 presents the results of the sensitivity analysis. We replace the poverty variable with the headcount ratio and examine whether the relationship between poverty and environmental degradation holds true under the dynamic specification of panel model. We find that poverty proxied by headcount ratio has a significant effect on deforestation across most models implying that the incidence of poverty positively contributes to deforestation in SSA. With respect to the effects of urbanization and other demographic and institutional variables on environmental degradation, these results are largely consistent with the main findings. The application of system GMM technique along with static panel data model leads to similar conclusions in terms of the dynamics between poverty, urbanization, and environmental degradation in the SSA region.

Conclusion and policy implications

This study empirically investigates the dynamics among poverty, urbanization, ODA, and environmental degradation for a panel of 43 SSA countries from 1995 to 2018. While examining the dynamics, this paper considers a set of demographics, macroeconomic, and institutional variables to explain the poverty-environment nexus. A notable contribution of this study is to examine the non-linear effects of poverty and urbanization on environmental degradation in SSA.Results obtained through static as well as dynamic panel models (two-step system GMM) show that both urbanization and poverty positively contribute to environmental degradation in SSA.From the perspective of the relationship between ODA and environmental degradation,

[1] It is worthwhile to mention that in this study we considered the aggregate data on development aid. Disaggregated data on development aid could provide contrasting results. For example, development aid directed towards environment protection is likely to reduce deforestation in the region. Moreover, lack of longitudinal data for environmental specific aid reduces its scope of using it in this study.

Table 7 Sensitivity analysis

Dependent variable: deforestation	Model 1	Model 2	Model 3	Model 4	Model 5
DEF (t – 1)	0.850*** (0.0617)	0.890*** (0.0636)	0.890*** (0.0645)	0.839*** (0.0942)	0.844*** (0.0505)
URB	0.006*** (0.0012)	0.004 (0.0026)	0.004* (0.0023)	0.062** (0.0241)	0.337 (1.447)
HCR	0.295*** (0.1019)	0.099*** (0.0211)	0.101 (0.0934)	0.036 (0.2008)	0.065*** (0.0051)
ODA		0.312** (0.1221)	0.307*** (0.1189)	0.004*** (0.0011)	0.013*** (0.0018)
LAW			0.021 (0.9905)	0.389 (2.4847)	1.127 (1.0129)
*URB*HCR*				0.009*** (0.0033)	0.002 (0.0016)
*URB*ODA*					– 0.0002** (0.0001)
*PG*ODA*					– 0.236*** (0.0081)
PG	– 0.066*** (0.0011)	– 0.092** (0.0357)	– 0.091** (0.0374)	0.010 (0.1014)	– 0.006 (0.1165)
GE	– 0.164 (0.1041)	– 0.029** (0.0132)	– 0.047 (0.8922)	0.076 (2.8925)	– 1.473*** (0.4471)
EG	– 0.069 (0.1769)	– 0.329*** (0.1010)	– 0.322*** (0.1154)	– 0.471*** (0.1329)	– 0.708*** (0.1206)
INF	– 0.003 (0.0026)	0.027 (0.0178)	0.025 (0.0479)	0.357*** (0.1211)	0.143*** (0.0435)
Constant	– 0.694** (0.3367)	0.844** (0.4247)	0.800 (2.8933)	7.677*** (1.6273)	4.230*** (1.6138)
Observations	1032	1032	1032	1032	1032
Number of countries	43	43	43	43	43
Number of instruments	43	41	43	41	40
Hansen Test (p-value)	0.382	0.517	0.600	0.561	0.821
AR (1) Test (p-value)	0.021	0.021	0.210	0.200	0.021
AR (2) Test (p-value)	0.516	0.465	0.465	0.514	0.520

Values in parentheses below coefficient estimates represent the standard error. *, **, and *** denote the level of significance at 10%, 5%, and 1% respectively

we find no direct evidence about the effect of ODA on carbon emissions but when it was interacted with other variables such as poverty and urbanization, it had statistically significant influence on the environmental degradation in the region.The macroeconomic, demographic, and institutional factors played a significant role in explaining the intricate dynamics between poverty, urbanization, and environmental degradation.

The findings of the study recommend several policy implications, which necessitate the participation of different stakeholders such as the government, institutions, researchers, non-profit organizations, climate advocacy groups and citizens for the effective implementation of environmental policies. First, governments in the SSA countries should formulate an independent and robust regulatory mechanism to provide and facilitate energy use that does not contribute much to environmental degradation. Second, policymakers should formulate policies to alleviate poverty and control unguided urbanization, which has been on an alarming uptrend due to the region's unregulated rural-to urban-migration. Robust disaster-resilient infrastructure and sustainable housing facilities for the poor in urban centers need to be built by the government to reduce the impact of likely future environmental risks, which also helps manage the explosive population growth in urban areas. In addition, it is high time to unleash the renewable energy generation potential of the region and invest in energy-efficient infrastructure to fulfill the rising energy demand of the urban population to reduce pollution from conventional sources. Third, policymakers need to adopt robust governance protocols and strengthen local institutions that cater to the rural and urban poor needs in a cleaner and sustainable manner. Fourth, we also find that development assistance when interacted with variables such as poverty and urbanization have significant effect on the environmental sustainability in the region. It emphasizes the need to redefine the targets of aid, which should focus on poverty alleviation through localized programs rather than funding big infrastructure projects, which are generally beyond the institutional and geographical capacity of urban areas to manage them efficiently. It is of paramount importance that policymakers should tackle the adverse impact of poverty and urbanization on environmental degradation separately by adopting poverty alleviation and stringent environmental policies encompassing different sectors and administrative levels. National energy policy differs across countries in the SSA region. However, SSA countries are often considered homogeneous entity with similar socio-economic and environmental characteristics;therefore, it is crucial for the region to form a governmental-level environmental consortium to make a combined effort to deal with environmental degradation in the region.

Although the present study contributes to the empirical literature by exploring the dynamics among poverty, urbanization, ODC, and environmental degradation in SSA countries, the study has the following limitations. The findings evolved from the analysis may not be appropriate for worldwide applications as it deals with only the SSA region. A comparative analysis of the SSA region with other regions could be an important future research agenda. Second, the time period covered in this study can further be extended and application of improved econometric techniques could provide better insights in the future. Finally, this study is carried out from a macroeconomic perspective, and thus, it leaves the scope for a microlevel analysis of the poverty-environment nexus.

Appendix

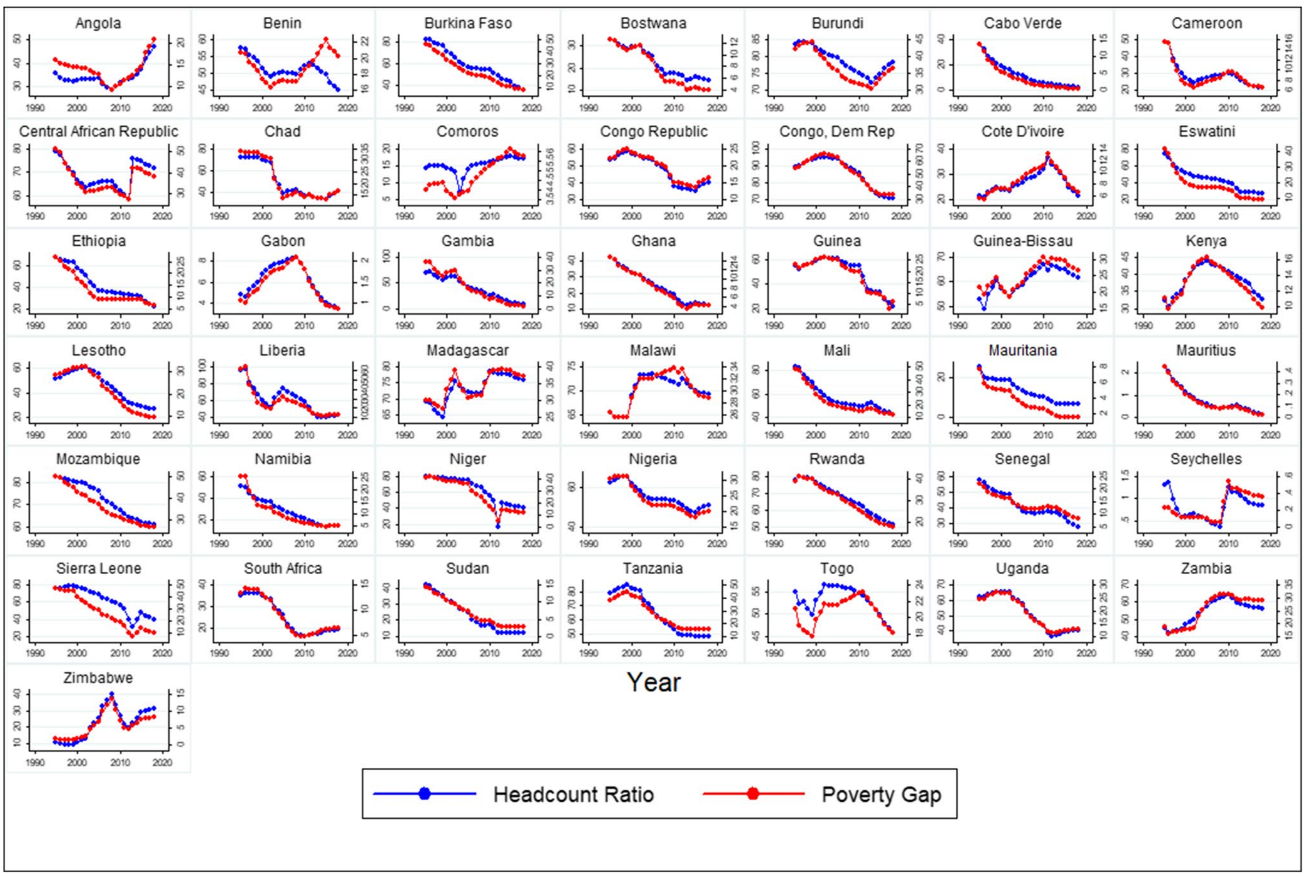

Fig. 2 Country-wise temporal patterns of poverty and headcount ratio. Left axis represents headcount ratio and right axis represents the poverty gap in countries

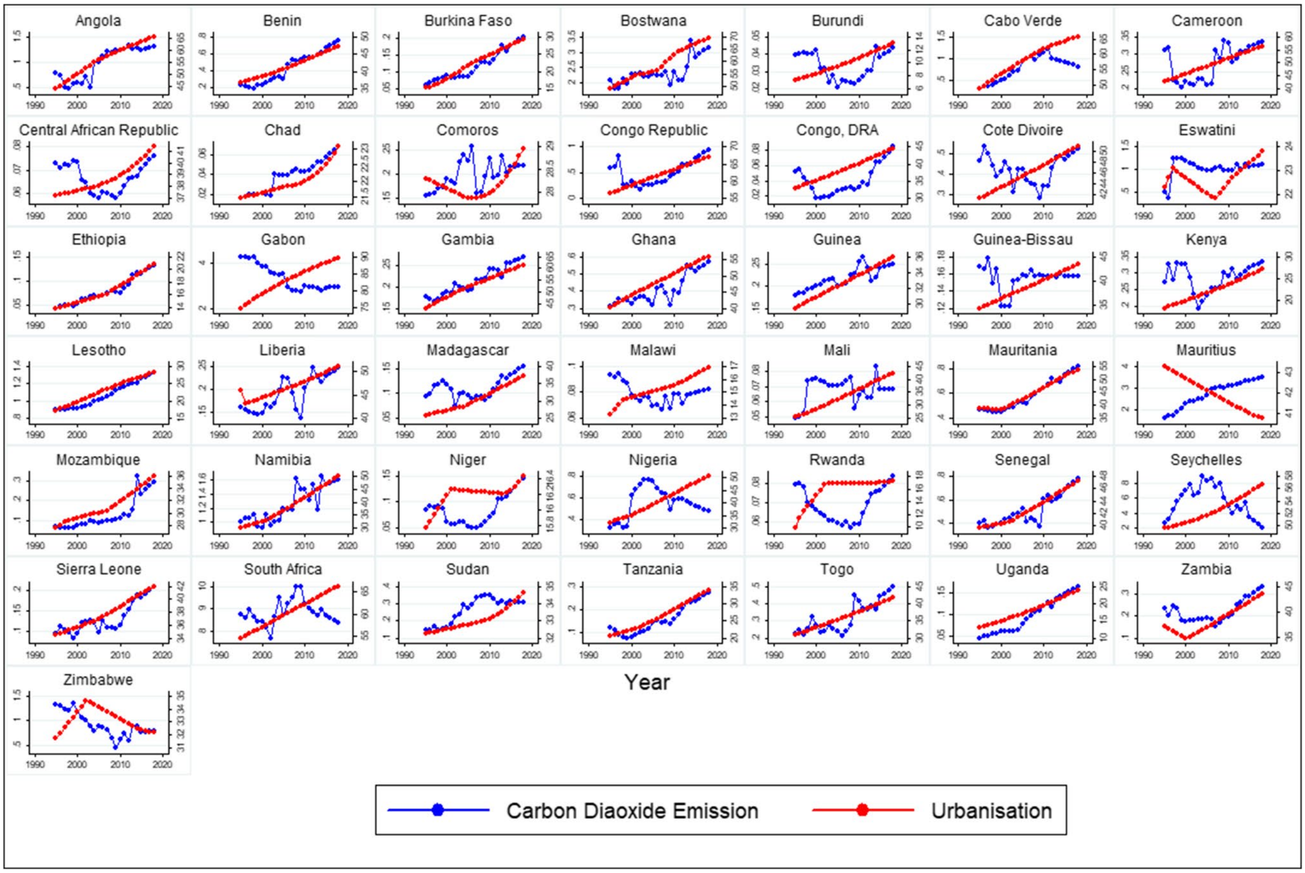

Fig. 3 Country-wise temporal patterns of CO_2 and urbanization. Left axis represents CO_2 levels and right axis represents the urbanization rate in countries

Author contribution Bijoy Rakshit: conceptualization, methodology, literature review, writing, editing, analysis.

Panika Jain: conceptualization, literature review, writing, editing, analysis.

Rajesh Sharma: writing, editing, analysis, supervision.

Samaresh Bardhan: supervision, editing.

Data availability All the data utilised in the study to arrive at our results using different specifications are listed in the data and methods section. All the data is available in the public domain.

Declarations

Ethics approval and consent to participate The research was conducted using data available in the public domain and did not include any human participants or animals. Therefore, no ethical approvals were required.

Consent for publication The authors of the study have consent and responsibility for submission to the journal.

Patient consent statement Not applicable.

Conflict of interest The authors declare no competing interests.

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