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Environmental Emissions and Health Spending in Sub-Saharan Africa: Does the Quality of Institutions have a role to play?

გარემოსდაცვითი ემისიები და ჯანდაცვის ხარჯები სუბსაჰარის აფრიკაში: აქვს თუ არა ინსტიტუტების ხარისხს რაიმე როლი?

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Abstract

Introduction: This study investigates the direct and indirect effects of environmental and institutional quality on health expenditure in Sub-Saharan Africa between 2002 and 2021. It explores how various pollutants and climate factors influence different forms of health spending, and whether institutional quality moderates these relationships. **Methods:** Using panel data from Sub-Saharan African countries, the study employs a Fixed Effects estimation technique to analyze the impact of environmental indicators—including methane (NH_4), nitrous oxide (NO_2), greenhouse gas (GHG), and carbon dioxide (CO_2) emissions—alongside temperature trends and institutional quality indicators on total current health expenditure (CHE), public (PUHE), private (PrHE), external (EHE), and out-of-pocket (OHE) expenditures. **Results:** The findings reveal that NH_4, NO_2, and GHG emissions significantly increase all forms of health expenditure, though to varying degrees. CO_2 emissions are also positively associated with all forms of health spending except PUHE. Rising temperatures are particularly linked to increased PUHE. Institutional quality, especially government effectiveness, significantly moderates the effect of CO_2 on health expenditures across all models. Other institutional indicators—political stability, rule of law, regulatory quality, and voice and accountability—also moderate the relationship between pollution and health expenditure. Additionally, non-linear effects of environmental indicators are observed in specific models: NO_2 and GHG in PUHE; NH_4 and GHG in PrHE; NH_4 in OHE; and GHG in CHE. **Discussion:** The results underscore the multifaceted and context-dependent nature of environmental and institutional influences on health spending. Strong institutional frameworks can buffer or amplify the effects of environmental stressors on healthcare costs. **Conclusion:** Environmental degradation significantly drives health expenditures in Sub-Saharan Africa, and institutional quality plays a critical moderating role. Policymakers should integrate climate resilience strategies with governance reforms to manage the health-related costs of environmental change.

Keywords: Environmental quality; Institutional quality; Health expenditure; Sub-Saharan Africa region (SSA); Fixed effects estimator.

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აბსტრაქტი

შესავალი: კვლევის მიზანია გარემოსდაცვითი და ინსტიტუციური ხარისხის პირდაპირი და არაპირდაპირი გავლენის შესწავლა ჯანმრთელობის დანახარჯებზე სუბსაჰარელი აფრიკის ქვეყნებში 2002–2021 წლებში. სამუშაო განიხილავს, როგორ მოქმედებს სხვადასხვა დაბინძურების წყარო და კლიმატური ფაქტორი ჯანდაცვის ხარჯვის სხვადასხვა ფორმაზე, და არის თუ არა ინსტიტუციური ხარისხი ამ ურთიერთობების მოდერატორი. **მეთოდები:** კვლევისთვის გამოყენებულია სუბსაჰარელი აფრიკის ქვეყნების პანელური მონაცემები და გამოყენებულია ფიქსირებული ეფექტების შეფასების ტექნიკა. ანალიზის ობიექტია გარემოსდაცვითი მაჩვენებლები — მეთანის (NH_4), აზოტის ოქსიდის (NO_2), სათბურის გაზების (GHG) და ნახშირორჟანგის (CO_2) ემისიები — ასევე ტემპერატურის დინამიკა და ინსტიტუციური ხარისხის ინდიკატორები, და მათი გავლენა საერთო ჯანმრთელობის მიმდინარე ხარჯებზე (CHE), საჯარო (PUHE), კერძო (PrHE), საგარეო (EHE) და საკუთარი ჯიბიდან გადახდილი (OHE) ხარჯების ფორმებზე. **შედეგები:** კვლევამ აჩვენა, რომ NH_4, NO_2 და GHG ემისიები მნიშვნელოვნად ზრდის ყველა ტიპის ჯანმრთელობის ხარჯებს, თუმცა განსხვავებული ინტენსივობით. CO_2 ემისიებსაც აქვს დადებითი გავლენა ყველა ხარჯვით მოდელზე, გარდა PUHE-ისა. ტემპერატურის მატება განსაკუთრებით აისახება საჯარო ხარჯებზე. ინსტიტუციური ხარისხი, განსაკუთრებით მთავრობის ეფექტიანობა, მნიშვნელოვნად ასუსტებს ან აძლიერებს CO_2-ის გავლენას ჯანდაცვაზე ყველა მოდელში. ასევე, პოლიტიკური სტაბილურობა, სამართლის უზენაესობა, რეგულირების ხარისხი და ხმა და ანგარიშვალდებულება ასრულებენ მოდერატორის როლს დაბინძურებასა და ჯანმრთელობის დანახარჯებს შორის. ხმასა და ანგარიშვალდებულებას კი ერთადერთი გავლენა აქვს კლიმატის ცვლილებასა და საერთო ხარჯებს შორის კავშირზე. გარდა ამისა, გამოვლინდა გარემოსდაცვითი ფაქტორების არალინარული ეფექტები: NO_2 და GHG PUHE მოდელში, NH_4 და GHG PrHE მოდელში, NH_4 OHE მოდელში და GHG CHE მოდელში. **დისკუსია**: კვლევის შედეგები ადასტურებენ, რომ გარემოსა და ინსტიტუციურ ფაქტორებს ჯანდაცვის ხარჯებზე კომპლექსური და კონტექსტზე დამოკიდებული გავლენა აქვთ. ძლიერი ინსტიტუციური სტრუქტურები შესაძლოა შეამცირონ ან გააძლიერონ გარემოსდაცვითი სტრესორების ზემოქმედება ჯანდაცვის სისტემებზე. **დასკვნა:** გარემოს დაბინძურებას სუბსაჰარელი აფრიკის რეგიონში მნიშვნელოვანი გავლენა აქვს ჯანმრთელობის ხარჯებზე, ხოლო ინსტიტუციური ხარისხი ამ პროცესში გადამწყვეტ მოდერატორ როლს ასრულებს. პოლიტიკურმა გადაწყვეტილებებმა კლიმატის მიმართ მდგრადობის სტრატეგიები ინსტიტუციური რეფორმებით უნდა გააერთიანოს, რათა შეამციროს გარემოს ცვლილებებით გამოწვეული ჯანდაცვის ხარჯები.

საკვანძო სიტყვები: გარემოს ხარისხი; ინსტიტუციური ხარისხი; ჯანმრთელობის ხარჯები; სუბსაჰარელი აფრიკის რეგიონი (SSA); ფიქსირებული ეფექტების შეფასების მეთოდი.

ციტატა: ჯონ ბოსკო ნიანზი. გარემოსდაცვითი ემისიები და ჯანდაცვის ხარჯები სუბსაჰარის აფრიკაში: აქვს თუ არა ინსტიტუტების ხარისხს რაიმე როლი?. ჯანდაცვის პოლიტიკა, ეკონომიკა და სოციოლოგია. ჯანდაცვის პოლიტიკა, ეკონომიკა და სოციოლოგია, 2025; 9 (1). https://doi.org/10.52340/healthecosoc.2025.09.01.09.

Introduction

The World Bank (2022) report estimates the global health burden attributed to carbon dioxide (CO2) emissions and particulate matter (PM10) to reach over $8.1 trillion in health expenses, but with the poorest populations suffering the most relative to wealthier countries that are expected to experience lower levels of pollution-induced illnesses and deaths. According to the United Nations (2023) report, both man-made emissions and pollutants are a cause of a “global boiling”, with at least 95 per cent of the world’s population believed to be breathing polluted air (Liu & Ao, 2021). The consequences of deteriorating environmental quality can be catastrophic by increasing the incidence and severity of respiratory and other killer diseases, which in turn would increase the pressure on budgets due to increased hospitalization. Intuitively, besides the traditional well-known household and macroeconomic determinants of healthcare expenditure, environmental factors and climate change require particular attention in the explanation of health spending dynamics. For Sub-Saharan Africa (SSA) in particular, there are observed increasing droughts, extreme weather conditions, rising temperatures, as well as high pollution levels that threaten not only food security, livelihoods, and biodiversity, but also appear to be exacerbating existing vulnerabilities. What this implies for health financing mechanisms in SSA with enumerable welfare challenges is a subject that continues to attract the attention of scholars and policymakers alike. The United Nations Environment Program (2024) report adds that although Africa contributes minimally to the global pollution, with just about 2 to 3 percent of global emissions, it stands out disproportionately as the most vulnerable region to climate change impacts basically due to its reliance on rain-fed agriculture, weak infrastructure, and limited adaptive capacity. Indicative vulnerabilities encompass inter alia water and food systems, livelihoods, as well as health. In many developing countries and regions, however, the quantitative environmental impact, particularly on the latter, remains debatable.

In a bid to contribute to the ongoing discussion, with focus on SSA, we undertake to examine the relationship between the environment and health economics, through the lenses of environmental factors (viz., air pollution, environmental degradation and climate change (henceforth PEC)) and health expenditure (HE) in a bid to strengthen policy integration. The theoretical underpinning focusing on the hypothesized linkage between environmental quality and health expenditure goes in either direction. That is, while an improvement in environmental quality could lead to increased healthcare costs, possibly due to better health outcomes and longer lifespans, the possibility of poorer environmental quality translating into skyrocketing healthcare costs is not an unusual argument, pointing to the adverse impact a deteriorating environment can have on the health of individuals, requiring them to see medical attention.

In the empirical arena too, a number of researchers have certainly contributed to the debate albeit producing mixed and overly inconclusive findings, suggestive of the differential importance of PEC in the health spending behavior of countries. For example, in one school of thought, it is documented that environmental deterioration boosts health spending (e.g. Ullah et al., 2020; Yazdi & Khanalizadeh, 2017; Chaabouni, Zghidi & Mbarek, 2016; Chaabouni & Saidi, 2017; Wang et al., 2019). The central aspect of this cluster of studies is that countries with higher environmental expenditures have lower healthcare expenditures. On the other hand, a revelation that poor environmental quality is detrimental to health costs is registered in various works (e.g., Nyika, 2024; Barwick et al., 2018; Shen et al., 2021; Yaku & Danaa, 2024). Still, there is a third school that reveals no correlation between the two variables of interest. The last school of thought reports an asymmetric effect of environmental quality on healthcare expenditure (e.g., Demir et al., 2023). These conflicting revelations rejuvenate the need for a deeper analysis of the environment-health nexus. One fundamental observation, however, is that the existing variations in the relationship between the environmental quality and healthcare spending in the literature appear to stem from differences in context, the types of environmental factors considered, and the methods employed in the research.

The current paper expands the analysis of the direct environment-health nexus and establishes the possibility of other interventions in the observed relationship. Practically, in addition to expounding on the direct effect of selected environmental factors, earlier abbreviated as PEC on the multifaceted form of health expenditure, we show the extent to which this relationship would be moderated by the institutional factors. Note that the choice of the latter is based on the argument emphasizing the growing importance of institutional variables in the achievements of environmental outcomes via the implementation and enforcement of environmental regulations and policies. In other words, it has been argued that strong institutions such as government effectiveness, the rule of law and regulatory quality inter alia are better equipped to enforce environmental laws and regulations, by say, deterring polluters and ensuring compliance (Saboori, Madhavian & Radmehr, 2024). However, the latter can only happen when countries uphold the rule of law, which is a critical condition for ensuring that environmental regulations are fairly and consistently enforced in order to ensure a level playing field for businesses and individuals. Similarly, it can theoretically be averred that countries with improved control of corruption can promote environmental protection efforts by disallowing illegal activities and orchestrating the implementation of environmental policies. Amidst growing concerns that the institutional quality encompassing various aspects including rule of law, accountability and transparency, corruption, regulatory quality and political stability as well as government effectiveness, is relatively low in SSA countries (Hussein, 2023), we argue that institutions could potentially play a moderating role in the relationship between environmental quality and health expenditure. Recent works have similarly included intermediating factors in the relationship between environmental quality and health expenditure (e.g. Demir et al., 2023 – with focus on natural resources; Rahman, Dyuti & Tareque, 2025 – with focus on globalization). Its importance notwithstanding, the institutional quality has received less attention as a moderating variable.

Building on this foundation, our study provides an opportunity to relate not just the environment and health but also to determine how institutions could influence or not influence the observed nexus. This is a nuance of the current study. We are motivated by the argument that climate change is not just an environmental, social and economic threat, it is also a grave risk to public health. Therefore, a study to ascertain the quantitative impact of PEC on a multifaceted form of health expenditure is fundamental for ensuring the achievement of Sustainable Development Goal (SDG) 3, which focuses on good health and well-being. Sustainable health spending aims at ensuring healthy lives as well as the promotion of well-being for all at all ages. A model of health spending that takes into consideration the environmental and institutional factors would likely spur relevant policies to achieve the SDG goal just mentioned. Relatedly, the study aligns well with SDGs 11, 12, and especially 13, to support the advancement of sustainable development policies by examining the role of institutional quality in mitigating the PEC-HE relationship in SSA. Besides galvanizing the evidence-based policy implications, the study outcomes could be deemed an important contribution to the existing literature on the subject. Intuitively, the study may offer valuable insights for policymakers grappling with the triple challenge of environmental deterioration, institutional quality and health spending. Figure 1 demonstrates the health expenditure trends in SSA over the past decades.

Review of Literature

Several studies have examined the role of various factors on health expenditure in different countries and regions, and provided findings that sometimes appear conflicting and divergent, perhaps due to the context, methodology and the indicators employed in the analysis. We identify four schools of thought culminating from our review of existing literature. In the first school, the health expenditure is found to react adversely to environmental quality. For example, focusing on data from the Caucasus region and Russia during the period 2000 to 2020, Nyika, et al. (2024) employ the Autoregressive Distributed Lag (ARDL) model to show that in Armenia, Azerbaijan, Georgia, and Russia, carbon dioxide and methane emissions possess a significant and lasting impact of on healthcare expenditures, as opposed to greenhouse gas emissions and quality of life indicators where the results are found insignificant. The short-run relationship however, is found to support a significantly negative role of carbon dioxide emissions in healthcare expenditure in the studied countries. Nevertheless, the long-run positive effect is similarly reported in Ibukun & Osinubi (2020) for the 47 African countries based on the data covering the period 2000 to 2018. Specifically, the authors, employing a variety of panel estimation procedures, viz. pooled OLS, fixed effects, random effects and the system GMM, find that of the three proxies of environmental quality, only carbon dioxide emission had the highest effect on healthcare expenditure across the five African regions (i.e. North Africa, East Africa, Central Africa, West Africa and Southern Africa). A related study demonstrating similar findings is by Yazdi & Khanalizadeh (2017), carried out using data on countries from the Middle East and North Africa for the period 1995-2014. Here, the results based on the ARDL technique show that income and CO2, and air pollution (proxied by PM10) have statistically significant positive effects on health expenditure in the MENA region.

Alimi, Ajide & Isola (2020) add to the existing literature by estimating regressions based on data for 15 ECOWAS countries over the period 1995–2014, using the pooled OLS, fixed effects, and system GMM. In the study, it was found that carbon emission exerts a positive, statistically significant effect on both public and national healthcare expenditure. However, data reveal no evidence of any relationship between environmental pollution and private healthcare expenditure. Hamid & Wibowo (2022) elucidate the findings in their study on the 5 ASEAN countries, using the Panel Data Regression consisting of the Common Effect Model, Fixed Effect Model, and Random Effect Model to show that increasing CO2 carbon emissions lead to an increase in health expenditures. Moreover, at a micro level, Chen & Chen (2021), using a sample of the China Health and Nutrition Survey in 2015 document air pollution (PM2.5) as the leading upscale driver of health expenditure, with males, high-income individuals, highly educated individuals as well as people with health insurance and older people found to be more sensitive to air pollution. other notable finding from the study is that air pollution nonlinearly affects health expenditure.

The other school of thought reveals an asymmetric relationship between environmental quality and health spending. For example, a study by Demir et al. (2023) estimates a non-linear ARDL (NARDL) model based on Turkish data for the period 1975–2019 to show how positive environmental pollution shocks affect health expenditures positively in the long run, while negative environmental pollution shocks exhibit no statistically significant effect on health expenditures. Additionally, it was found that while positive and negative natural resource shocks affect health expenditures negatively in the long run, variations appear for trade. Specifically, the authors show that positive trade openness shocks have a negative effect on health expenditures, whereas negative trade openness shocks have a positive effect. Musa (2025) likewise stresses the asymmetric nature of the relationship between climate change and health expenditure in a study carried out based on data from Nigeria over the period spanning from 1990 to 2023. The results obtained by using non-linear autoregressive distributed lag (NARDL) approach in conjunction with Granger causality test show that while the positive temperature and CO2 shocks significantly increase costs in both short and long terms, negative CO2 shocks yield long-term health expenditure reductions, showcasing the potential of mitigations to curb the detrimental climate change outcome.

On their part, Yadav, Aneja, and Ahmed (2023) focus on 22 emerging economies for the period of 2000–2019 to reveal similar findings. Specifically, the Fully Modified Ordinary Least Squares (FMOLS) results that are confirmed robust to the use of an alternative Dynamic Ordinary Least Squares (DOLS) techniques, indicate that the aging population, natural resources depletion, and CO2 emissions positively influence health spending in the selected countries. However, an improvement in energy efficiency and renewable energy use is found to reduce health expenditure. A later study on Africa by Yakubu, Musah & Danaa (2024) confirms this catalyst role, by revealing that carbon dioxide (CO2) emissions and renewable energy consumption are positively related to health expenditure, just as education is in Africa during the period 2000–2021. On the other hand, the study finds a significant negative effect of economic growth, urbanization and industrialization on health expenditure.

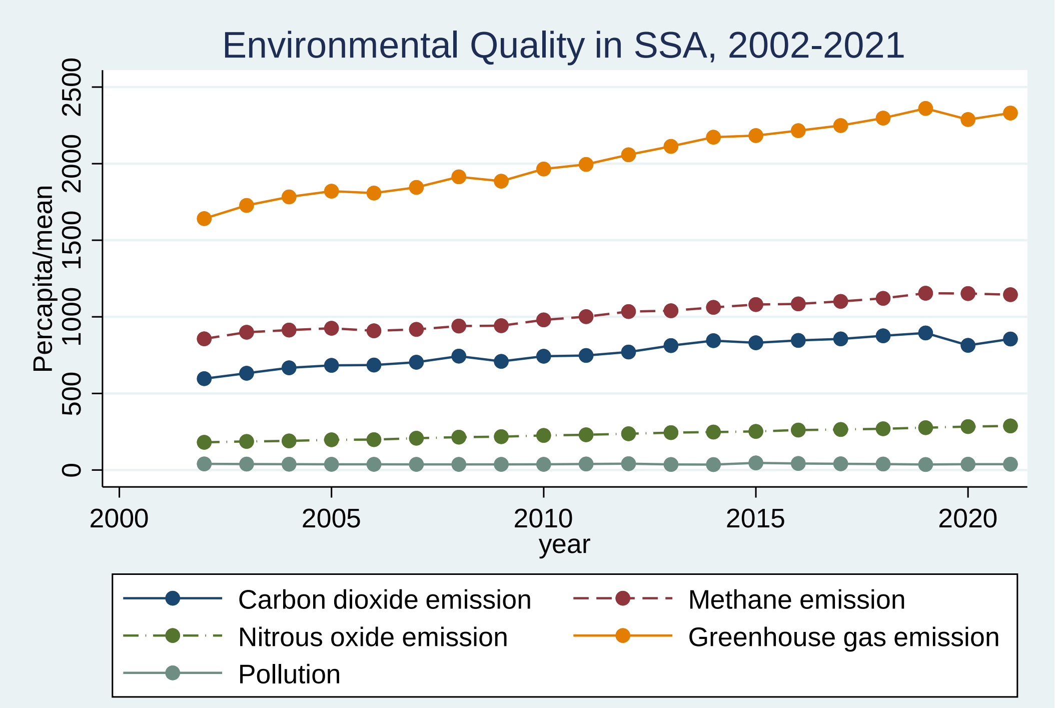
A similar study by Fonchamnyo et al. (2022) employs data from 1995 to 2019 for 115 countries to contribute to the subject under discussion. The results obtained using the Driscoll-Kraay technique add an extra layer that focuses on globalization. Specifically, while economic globalization and financial globalisation were found to significantly reduce health expenditure, social globalisation, environmental pollution and interpersonal globalisation were found to significantly increase health expenditure in the selected countries. Additionally, the author reveals that whereas the manufacturing output significantly increased health expenditure in low middle-income and middle-income countries and in the different sub-regional groupings, the agricultural production adversely affected health expenditure in low-middle-income countries and in Latin American countries. Similarly, the service sector output was found to reduce health expenditure in East Asian, the Pacific, and South Asia and to increase health expenditure in the Middle East and North Africa. The use of the Driscoll-Kraay technique is, however, questionable as it is normally applied to situations where the number of time periods is greater than the cross-sectional dimension (Driscoll & Kraay, 1998), which appears not to be the case in the study here reviewed. Nevertheless, a later study by Rahman, Dyuti & Tareque (2025) focuses on data for the BRICS nations from 2000 to 2023 to analyze good health. The results based on the fixed effects model reveal that whereas the current health and out-of-pocket costs significantly lead to good health outcomes, globalization exerts a detrimental moderating influence on the correlation between health expenditures and positive health outcomes.

Similarly, a study by Li, Du & Zhang (2020) however, considering 3,546 patients in the Respiratory and Critical Care Department of a tertiary hospital in Beijing between 2013 and 2015 as examples, combining daily air-quality data using a generalized linear regression-analysis model, reports that air pollution (PM2.5) has a significant positive impact on health-care expenditure directed towards respiratory diseases, drugs, and antibiotics. Additionally, it was found that as the air-pollution index increased, health care expenditure burden of respiratory diseases also gradually rose, suggesting heterogeneity in the expenditure burden. A similar finding using the alternative measure of air pollution, viz. PM10 is likewise reported in the data, as well as the length of stay in a hospital for treatment. Relatedly, Orset (2024) basing on data from 15 European Union countries from 1992 to 2020 and a panel co-integration approach, shows that whereas ammonia and cadmium emissions exert a statistically significant positive effect on health expenditure in the short run, a similar effect is observable in the longrun but only for the arsenic emissions.

Bayraktar et al. (2024) uses the system GMM estimation on data for the top 25 countries with the highest ecological footprint for the period 2000 to 2021 to argue that whereas economic growth and ecological footprint had a positive impact on health expenditures in the selected countries, information and communication technologies was found to exhibit a statistically significant but negative effect on health expenditures. The Covid-19 pandemic in particular was observed to have significantly increased health expenditures, similar to the environmental degradation, including carbon footprint, fishing grounds, cropland, grazing land, and built-up land. A previous study by Wei, Rahim & Wang (2022) includes the institutional quality variables in the health expenditure model for seven selected Emerging economies covering the period from 2000Q1 to 2018Q1. The results therefrom, based on the co-integration approach and the panel quantile regression, show that greenhouse gas emissions and regulatory quality are significantly and positively correlated to human health issues in emerging economies just as economic growth, government health expenditure, and human capital are found to significantly reduce human health disasters like malaria incidences and cases.

In summary, the available literature, though informative, provides mixed findings and is silent on the role of institutional quality in the relationship between PEC and the disaggregated forms of health expenditure. Moreover, SSA appears less represented in the various existing analyses so far carried out, at least to our knowledge. The need to integrate policies that consider the environment, health and institutions is the driving motivating force behind the current study.

Figure 1. Environmental Quality in SSA, 2002-2021



Source: Author computations based on WDI (2025) data

Methodology

Data and variables

In order to work with a complete balanced panel data, in this study our analysis period is 2002-2021 for a selected group of 44 SSA countries (see Appendix A2). The dependent variable is the health expenditure (HE). We disaggregate this into indicator by distinguishing between public health expenditure (PuHE), private health expenditure (PrHE), and external health expenditure (EHE), in order to capture the specific effects on each. Figure 2 shows the relevant trends of the various types of expenditure including out-of-pocket and current health expenditure. One of most outstanding observations is that while the external HE is the lowest and has been growing at a slow rate, the private health expenditure has over the period of analysis taken the top position relative to EHE and PuBHE. Nevertheless, all the expenditure indicators exhibit on average an increasing trend. The relevant data for these variables is sourced from the World Bank World Development

Indicators (World Bank, 2025). On the other hand, the main independent variable is environmental quality here captured by several proxies. As earlier suggested, and on basis of their contribution to environmental deterioration and the falling health standards, these include carbon dioxide (CO2), nitrous oxide emission (NO2), methane emissions (METH) and the greenhouse gas emissions (GHG) as well as air pollution (POLL). Figure 1 demonstrates the trending performance of these indicators over time in SSA. Here, the greenhouse gas emissions take a lion's share, followed by methane emissions, CO2, NO2 and at the lower end is POLL. Climate change, partially driven by these emissions is further captured by annual temperature changes. Data on the latter is sourced from Food and Agricultural Organization (FAO, 2024) database, while the World Bank World Development Indicators (WB, 2025) provides data for all the environmental proxies.

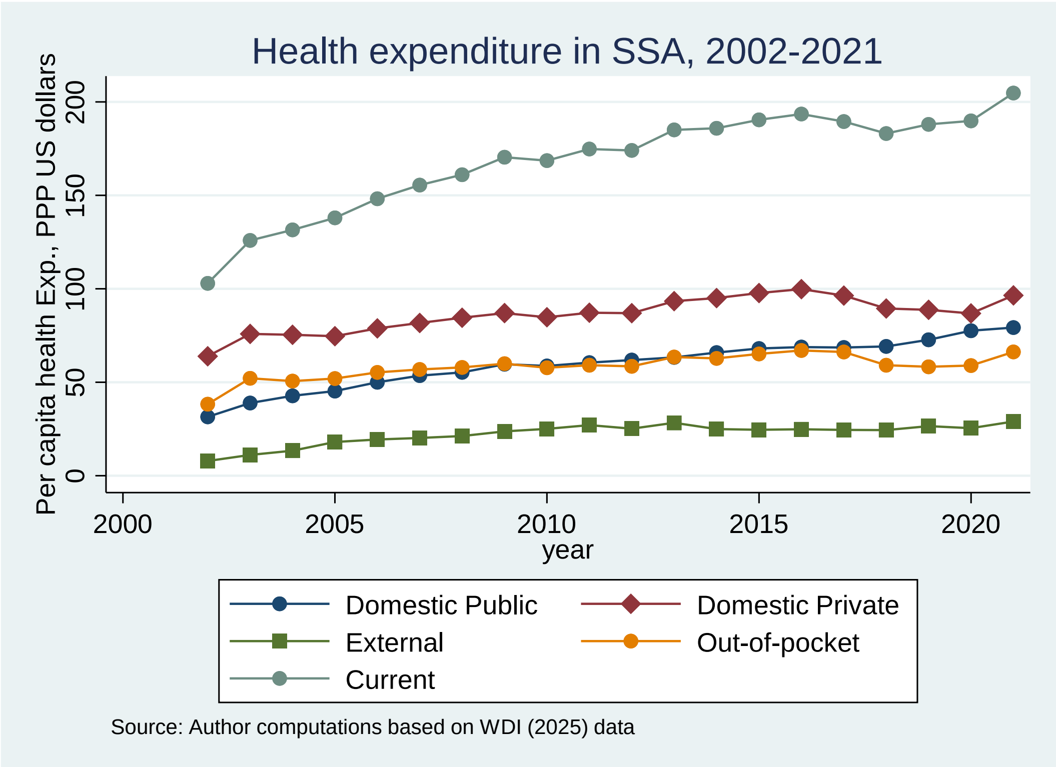


Figure 2. Health Expenditure in Sub-Saharan Africa, 2002-2021

To account for potential confounding variables, the study controls for per capita GDP growth, maternal mortality rate, population, age dependency of old people, the Covid-19 period, immunization, as well as control of corruption and political stability. Specifically, as used in Yakubu & Danaa (2024), economic growth is measured by gross domestic product (GDP) per capita growth (annual %). As in Farai et al. (2024) population is measured by annual population growth (%). As in Ibukun & Osinubi (2020), the maternal mortality ratio (modeled estimate, per 100,000 live births). This indicator is selected because of the four mortality rates prevalent in SSA, viz., infant mortality rate, under-five mortality rate, neonatal mortality rate, and maternal mortality rates, Sub-Saharan Africa (SSA) experiences the highest maternal mortality rates globally having for example accounted 70 per cent of the global maternal deaths in 2020. Immunization is measured as the sum of immunization against measles and DPT (% of children ages 12-23 months); and, CC, RL, GE, VA, RQ, PS are all estimates of the World Governance Indicators (WGI) of the World Bank to capture the extent to which a country performs in terms of control of corruption, rule of law, government effectiveness, voice and accountability, regulatory quality and political stability respectively, with scores running from as low as -2.5 to the highest score of +2.5, where higher scores represent better institutional quality of the relevant indicator just as low scores are indicative of low performance. The data pertaining to these institutional indicators is sourced from WGI (2025). Additionally, a dummy variable (Covid19) was used to consider the effect of the COVID-19 pandemic in SSA, where Covid19=0 for the year 2019 and before and Covid19=1 for the following years after 2019.

Table 1a. Descriptive Statistics – untransformed data

VARIABLES	N	mean	Std.	min	max	skewness	kurtosis
Carbon dioxide emissions (CO2)	880	1.071	2.114	0.0242	12.86	3.377	14.51
Methane emissions (NH4)	880	22.10	39.40	0.0505	267.4	3.819	19.81
Nitrous oxide emissions (NO2)	880	5.080	7.393	0.0096	38.83	2.215	7.471
Public health expenditure (PUHE)	880	98.89	170.2	0.444	1,352	2.974	13.41
External health expenditure (EHE)	879	30.55	33.74	0	228.0	2.483	10.48
Current health expenditure (CHE)	880	227.2	274.6	10.95	1,730	2.322	8.261
Private health expenditure (PrHE)	880	97.81	115.7	3.924	763.8	2.442	9.575
Out-of-pocket health expenditure (OHE)	880	69.21	84.26	3.064	663.0	3.524	18.12
Population growth (POP)	880	2.484	0.986	-2.629	6.220	-0.743	5.203
Urbanization (URB)	880	7.718e +06	1.375e +07	42,320	1.153e +08	4.335	26.35
Renewable energy consumption (REN)	880	64.82	26.59	0.700	98.30	-0.905	2.699
Political stability (PS)	880	-0.495	0.877	-2.699	1.201	-0.336	2.363
Voice and accountability (VA)	880	-0.502	0.699	-1.999	0.975	0.114	2.163
Rule of law (RL)	880	-0.647	0.600	-1.851	1.024	0.437	2.769
Control of corruption (CC)	880	-0.599	0.633	-1.646	1.600	0.738	3.014
Government effectiveness (GE)	880	-0.739	0.601	-1.881	1.150	0.718	3.243
Regulatory quality (RQ)	880	-0.632	0.553	-1.856	1.197	0.629	3.482
Per capita GDP growth (GDP)	880	1.611	4.629	-36.82	30.02	-1.106	15.47
Age dependency, old (AGED)	880	5.918	1.598	3.262	16.48	2.080	10.29
Pollution (PM2.5) (POLL)	880	36.63	18.16	1	107.1	0.746	3.167
Immunization, DPT (IMM-dpt)	880	77.46	17.28	19	99	-0.942	3.212
Immunization, measles (IMM-me)	880	74.61	16.96	16	99	-0.608	2.721
Immunization (IMM)	880	152.1	33.68	37	198	-0.772	2.921
Temperature (^{0}C) (TEMP)	880	0.999	0.364	-0.356	2.267	0.0764	3.373
Greenhouse gas emissions (GHG)	880	2.714	3.173	0.408	21.82	2.682	10.71
Countries	44	44	44	44	44	44	44

Note: All variables are untransformed data; Obs., Std., Min. and Max. respectively stand for observations, standard deviation, minimum and maximum

Table 1b. Descriptive Statistics – Transformed data

VARIABLES	(1) N	(2) mean	(3) sd	(4) min	(5) max	(6) skewness	(7) kurtosis
POP	880	2.484	0.986	-2.629	6.220	-0.743	5.203
PS	880	-0.495	0.877	-2.699	1.201	-0.336	2.363
VA	880	-0.502	0.699	-1.999	0.975	0.114	2.163
RL	880	-0.647	0.600	-1.851	1.024	0.437	2.769
CC	880	-0.599	0.633	-1.646	1.600	0.738	3.014
GE	880	-0.739	0.601	-1.881	1.150	0.718	3.243
RQ	880	-0.632	0.553	-1.856	1.197	0.629	3.482
GDP	880	1.611	4.629	-36.82	30.02	-1.106	15.47
PUHE	880	3.613	1.350	-0.811	7.209	0.450	2.816
PrHE	880	4.078	0.991	1.367	6.638	0.194	2.849
EHE	877	2.929	1.040	-2.182	5.429	-0.356	3.912
OHE	880	3.803	0.909	1.120	6.497	0.0800	3.517
CHE	880	4.934	0.936	2.394	7.456	0.548	2.877
CO2	880	-0.984	1.356	-3.720	2.554	0.554	2.929
NH4	880	1.933	1.815	-2.986	5.589	-0.784	3.623
NO2	880	0.431	1.893	-4.646	3.659	-0.652	2.893
GHG	880	0.587	0.833	-0.896	3.083	0.775	3.122
POLL	880	3.468	0.544	0	4.674	-0.730	5.002
TEMP	877	-0.0798	0.461	-4.269	0.818	-2.329	15.54
URB	880	14.84	1.558	10.65	18.56	-0.353	2.958
REN	880	3.970	0.859	-0.357	4.588	-2.773	11.54
IMM	880	4.994	0.262	3.611	5.288	-1.488	5.693
EGED	880	1.748	0.237	1.182	2.802	0.836	4.711
Countries	44	44	44	44	44	44	44

Note: All variables are in logs except institutional indices, population and per capita GDP growth

The descriptive statistics and the correlation matrix of all the employed variables can be found in Tables 1 (a&b) and 2, respectively. From Table 1a, the means of various health expenditures, viz., PuHE, PrHE, EHE, OPE and CHE, are respectively 98.9, 97.8, 30.5, 69.2 and 227, with corresponding standard deviations of 170.2, 115.7, 33.7, 84.3 and 274.6, implying that the values vary in their closeness to the mean, with large deviations noticed for PuHE and PrHE. Regarding the environmental proxies, the emissions from CO2, Methane, nitrous oxide, and greenhouse, exhibit means of 1.1, 22.1, 5.1, and 2.7, with corresponding standard deviations of 2.1, 39.4, 7.4 and 3.2, meaning that methane emissions appear outstanding with the largest deviation. In Table 2, however, the correlation analysis shows that NO2 should not be in the same model as METH, just as GHG should not be modeled with CO2. Also, with the exception of CC with PS, all the other institutional indicators are highly correlated with each other.

Table 2. Correlation Analysis

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(1) lnCO2	1.00						
(2) lnImmun	0.21	1.00					
(3) PS	0.55	0.47	1.00				
(4) CC	0.45	0.55	0.69	1.00			
(5) gdppcgrowth	-0.04	0.02	0.07	0.12	1.00		
(6) POPGR	-0.34	-0.34	-0.32	-0.57	0.03	1.00	
(7) lnAgedep_old	0.57	0.20	0.46	0.48	0.04	-0.47	1.00
(1) lnMETH	1.00						
(2) lnImmun	-0.43	1.00					
(3) PS	-0.55	0.47	1.00				
(4) CC	-0.49	0.55	0.69	1.00			
(5) gdppcgrowth	0.01	0.02	0.07	0.12	1.00		
(6) POPGR	0.46	-0.34	-0.32	-0.57	0.03	1.00	
(7) lnAgedep_old	-0.48	0.20	0.46	0.48	0.04	-0.47	1.00
(1) lnNO2	1.00						
(2) lnImmun	-0.28	1.00					
(3) PS	-0.52	0.47	1.00				
(4) CC	-0.32	0.55	0.69	1.00			
(5) gdppcgrowth	0.05	0.02	0.07	0.12	1.00		
(6) POPGR	0.29	-0.34	-0.32	-0.57	0.03	1.00	
(7) lnAgedep_old	-0.52	0.20	0.46	0.48	0.04	-0.47	1.00
(1) lnNO2	1.00						
(2) lnImmun	-0.28	1.00					
(3) PS	-0.52	0.47	1.00				
(4) CC	-0.32	0.55	0.69	1.00			
(5) gdppcgrowth	0.05	0.02	0.07	0.12	1.00		
(6) POPGR	0.29	-0.34	-0.32	-0.57	0.03	1.00	
(7) lnAgedep_old	-0.52	0.20	0.46	0.48	0.04	-0.47	1.00
(1) lnGHG	1.00						
(2) lnImmun	-0.16	1.00					
(3) PS	0.27	0.47	1.00				
(4) CC	0.19	0.55	0.69	1.00			
(5) gdppcgrowth	-0.06	0.02	0.07	0.12	1.00		
(6) POPGR	-0.16	-0.34	-0.32	-0.57	0.03	1.00	
(7) lnAgedep_old	0.34	0.20	0.46	0.48	0.04	-0.47	1.00
(1) lnPOLL	1.00						
(2) lnImmun	-0.25	1.00					
(3) PS	-0.36	0.47	1.00				
(4) CC	-0.32	0.55	0.69	1.00			
(5) gdppcgrowth	-0.02	0.02	0.07	0.12	1.00		
(6) POPGR	0.38	-0.34	-0.32	-0.57	0.03	1.00	
(7) lnAgedep_old	-0.37	0.20	0.46	0.48	0.04	-0.47	1.00
(1) lnTemp	1.00						
(2) lnImmun	-0.07	1.00					

(3) PS	-0.18	0.47	1.00				
(4) CC	-0.19	0.55	0.69	1.00			
(5) gdppcgrowth	-0.10	0.02	0.07	0.12	1.00		
(6) POPGR	0.20	-0.34	-0.32	-0.57	0.03	1.00	
(7) lnAgedep_old	-0.14	0.20	0.46	0.48	0.04	-0.47	1.00

Note: All variables are in logs except institutional indices, population growth and per capita GDP growth

Estimation Procedure

Given the panel nature of our study, we write the basic empirical model as follows:

$$Y_{it} = \beta + \phi' Z_{it} + \varepsilon_{it} \tag{1}$$

Here, Y represents the dependent variable, which changes according to the type considered; Z are the independent variables; β and ϕ denote regression coefficients; ε is the error term; i and t are the cross-sections and time periods, respectively. We then expand equation (1) to capture the variables of interest in examining the effect of environmental quality, institutional quality on the disaggregated form of health expenditure as follows:

$$\begin{aligned}\ln HE_{it} &= \beta + \phi_1 \ln EQ_{it} + \phi_2 GDPPCG + \phi_3 \ln REN_{it} + \phi_4 \ln URB_{it} + \phi_5 POPG_{it} \\ &+ \phi_6 INS_{it} + \phi_7 \ln AGE_{it} + \phi_8 \ln IMMUN_{it} + \phi_9 Covid19_{it} + \varepsilon_{it}\end{aligned} \tag{2}$$

Here, in equation (2) HE (health expenditure) is the dependent variable while the main independent variables are denoted as EQ (environmental variables) and INS (institutional quality indicators). We control for $POPG$ (population growth), $AGED$ (age dependency of old), $IMMUN$ (immunization against measles and DPT), $Covid19$ (COVID-19 shock), $GDPPCG$ (per capita GDP growth), REN (renewable resources) and URB (urbanization).

Basically, we estimate three equations and their variants taking into consideration the different selected environmental quality proxies capturing environmental degradation, pollution and climate change. The health expenditure variable has five categories considered here independently, viz., current, private, public, external and out-of-pocket respectively.

In order to capture the moderating effect of institutional quality on the relationship between environmental indicators and health expenditure, the following model will be estimated:

$$\begin{aligned}\ln HE_{it} &= \beta + \phi_1 \ln EQ_{it} + \phi_2 GDPPCG + \phi_3 \ln REN_{it} + \phi_4 \ln URB_{it} + \phi_5 POPG_{it} \\ &+ \phi_6 INS_{it} + \phi_7 \ln AGE_{it} + \phi_8 \ln IMMUN_{it} + \phi_9 Covid19_{it} + \delta_k \ln EQ_{it} * INS_{it} + \varepsilon_{it}\end{aligned}$$

(3)

Thus, the effect of environmental quality on each of the health expenditure indicator selected is from equation (3) captured via the institutional quality.

$$\frac{\partial HE_{it}}{\partial EQ_{it}} = \phi_1 + \delta_k \overline{INS}_{it} \tag{4}$$

The interpretation of ϕ_1 is the partial derivative of HE with respect to EQ when $INS = 0$. Equation (4) produces estimates for the effect of a change in EQ on HE when INS increases. Note that our interactions provide us the ability to enrich our understanding of economic relationships between environmental quality and health spending by establishing the conditions under which such relationships apply, or are stronger or weaker. As such, and as argued by Andersson, Cuervo-Cazurra & Nielsen (2014) interactions enable not only the extension of well-known relationships to contexts that the original research did not consider, but they also help provide more detailed predictions about the relationships, going beyond the simplistic argument “it depends”. For ease of interpretation, in equation (4), if both ϕ_1 and δ_k are positive, then EQ can be said to catalyze HE and INS is a complement to this effect by strengthening the positive effect. However, if ϕ_1 is positive and δ_k is negative, this would imply that EQ drives HE and INS turns to weaken this impact. Also, if ϕ_1 is negative and δ_k is positive, it means that the negative impact of EQ on HE is weakened by INS. Similarly, for cases where ϕ_1 and δ_k both exhibit a negative sign, it means that EQ reduces HE and INS plays a complimentary role.

According to Musa (2025) and Demir et al. (2023) *inter alia*, the possibility of a non-linear relationship between environmental quality and health expenditure exists. On this basis, we assume that environmental quality would influence health expenditure up to a certain threshold and once this threshold is surpassed, it will start to be behave differently. Therefore, we examine the possibility of this turning point, by introducing a nonlinear relationship between environmental quality and health expenditure. Intuitively, nonlinearity implies that the environmental quality effect on health expenditure is conditioned by the level of environmental quality. Hence, the following model is additionally run:

$$HE_{it} = \beta_0 + \beta_1 EQ_{it} + \beta_2 EQ_{it}^2 \tag{5}$$

Where EQ_{it}^2 is the environmental quality squared. The inclusion of this squared term enables us to examine the non-linearity effect of environmental quality on health expenditure, as well as analyzing the values of environmental quality thresholds. As theory avers, we calculate the thresholds only when both coefficients of EQ_{it} and EQ_{it}^2 are statistically significant. Taking the first order conditions, we get equation (6) from (5) as below:

$$\begin{aligned} \frac{\partial HE_{it}}{\partial EQ_{it}} &= \frac{\partial\left(\beta_0 + \beta_1 EQ_{it} + \beta_2 EQ_{it}^2\right)}{\partial EQ_{it}} \\ &= \beta_1 + 2\beta_2 EQ_{it} = 0 \\ &\Rightarrow EQ_{it}(\text{threshold}) = \frac{-\beta_1}{2\beta_2} \end{aligned} \tag{6}$$

Equation (6) is the environmental quality turning point or the threshold level of environmental quality, where, β_1 is the coefficient of the linear term and β_2 is the coefficient of the quadratic term.

The estimation of equations (2) and (3) takes into consideration the fact that the number of cross-sections (N) are larger than the time periods (T), but also the need of controlling for unobserved time-invariant characteristics, such that we ensure unbiased estimates when these characteristics are correlated with the included variables. The fixed effects estimator performs very well under such circumstances particularly for static models. For as, alluded to in Verbeek (2021), in addition to controlling for unobserved time-invariant heterogeneity that can lead to biased estimates in other models, the technique focuses on the within-group variation and reduces omitted variable bias. The latter are within the focus of the current paper rather than endogeneity. However, in adopting the fixed effects approach, we are in no way underrating the usual critique attributed to the approach (e.g. those summarized recently in Collischon & Eberl, 2020). However, as the same authors stress, there is no perfect estimation technique and that the fixed effects method is still a viable approach worth adopting under appropriate circumstances. Nevertheless, the proper pre-diagnostic tests are conducted to ensure the appropriateness of the FE, including the Hausman (1978) test that provides a criterion for choosing between random effects and fixed effects estimator. The results from the Hausman test and other tests are presented in the results tables shortly given.

According to Dickey & Fuller (1981), when T is less than 25, the need to test for unit root becomes less important. Nevertheless, before the implementation of the fixed effects estimation technique we carry out the unit root tests based on the nature of our data where time periods, T, is small relative to the number of cross-sectional units (N), suggesting that the risk of spurious regressions is not negligible. Therefore, to ensure an avoidance of the latter type of regressions, and to ensure the validity of our results, we perform the panel unit roots, viz., the IPS test by Im, Pesaran & Shin (2003), the LLC test by Levin, Lin & Chu (2002), and ADF test by Dickey & Fuller (1981) typically known as the Augmented Dickey-Fuller test. The corresponding results are not presented here to spare space but are available on request.

Empirical Results and Discussion

As pointed earlier, we use fixed-effects (FE) since we are only interested in analyzing the impact of variables that vary over time and the time-invariant characteristics are unique. Nevertheless, the Hausman test was employed to choose between the random effect and the fixed effect estimators. The latter was found preferable, as evident from the test results provided in the tables presented, where the Hausman chi-square p-value is less than 0.05. Also, note that the F-statistic p-value is less than 0.05 throughout, implying the all the coefficients in the models are different than zero.

The results in Table 3 models 1-12 show that methane (NH4) emissions, nitrous oxide (NO2) emissions and greenhouse gas (GHG) emissions drive up public health expenditure, with a 1 per cent increase in each translating into 0.370 per cent, 0.259 per cent and 0.400 per cent respective increase in domestic government health spending. By implication, an increase in these emissions is associated with an increase in public expenditure. This is possible because the emissions can contribute to climate change, which can lead to health effects because of the resultant health hazards such as heat-related illnesses, air pollution, as well as infectious disease outbreaks and mental health challenges *inter alia*. In SSA where resources are limited, the resultant increased health costs that arise from treating these conditions but also from the broader societal costs of climate change adaptation and mitigation efforts, the possibility of catalyzing public health expenditure is not farfetched. Our findings are consistent with Ibukun & Osinubi (2020) albeit contradicting Dritsaki et al. (2024) who reveal that per capita emissions of greenhouse gases have a negative effect on per capita health expenditure, except for the case of Greece, Lithuania, Luxembourg and Latvia.

Table 3. Effect of environmental quality on public and private health expenditure in SSA

	Public health expenditure						Private health expenditure					
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
VARIABLES	CO2	NH4	NO2	GHG	POLL	TEMP	CO2	NH4	NO2	GHG	POLL	TEMP
GDP	0.004	0.002	0.003	0.002	0.004	0.004	0.001	-0.001	0.001	-0.001	0.002	0.002
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
REN	-0.522***	-0.568***	-0.560***	-0.490***	-0.538***	-0.533***	0.008	-0.066	-0.054	0.040	-0.022	-0.020
	(0.101)	(0.098)	(0.100)	(0.099)	(0.099)	(0.099)	(0.089)	(0.086)	(0.088)	(0.086)	(0.088)	(0.088)
URB	0.940***	0.740***	0.814***	0.933***	0.974***	0.934***	0.485***	0.236***	0.351***	0.500***	0.547***	0.527***
	(0.079)	(0.087)	(0.100)	(0.072)	(0.072)	(0.074)	(0.070)	(0.076)	(0.088)	(0.062)	(0.064)	(0.066)
POP	0.032	0.024	0.039*	0.026	0.033	0.036	-0.005	-0.013	0.007	-0.011	0.001	0.001
	(0.024)	(0.023)	(0.024)	(0.023)	(0.024)	(0.024)	(0.021)	(0.020)	(0.021)	(0.020)	(0.021)	(0.021)
CC	0.286***	0.259***	0.260***	0.253***	0.293***	0.285***	0.161***	0.125**	0.128**	0.116**	0.154***	0.160***
	(0.060)	(0.059)	(0.061)	(0.059)	(0.060)	(0.060)	(0.053)	(0.052)	(0.054)	(0.052)	(0.053)	(0.053)
PS	0.160***	0.158***	0.152***	0.159***	0.157***	0.156***	0.029	0.023	0.015	0.024	0.021	0.021
	(0.032)	(0.032)	(0.032)	(0.032)	(0.032)	(0.032)	(0.028)	(0.027)	(0.028)	(0.028)	(0.028)	(0.028)
AGED	0.600***	0.646***	0.669***	0.576***	0.590***	0.571***	0.570***	0.637***	0.663***	0.541***	0.598***	0.556***
	(0.171)	(0.169)	(0.173)	(0.169)	(0.172)	(0.172)	(0.152)	(0.148)	(0.153)	(0.148)	(0.152)	(0.153)
lMM	0.008	0.017	-0.043	0.040	0.008	0.024	0.214**	0.229**	0.152	0.261***	0.228**	0.230**
	(0.105)	(0.104)	(0.108)	(0.104)	(0.105)	(0.105)	(0.093)	(0.091)	(0.095)	(0.091)	(0.094)	(0.094)
COV19	0.130***	0.140***	0.134***	0.139***	0.122***	0.130***	0.046	0.059	0.050	0.057	0.051	0.044
	(0.044)	(0.044)	(0.044)	(0.044)	(0.045)	(0.044)	(0.039)	(0.038)	(0.039)	(0.038)	(0.040)	(0.039)
CO2	0.052						0.114**					
	(0.059)						(0.052)					
NH4		0.370***						0.507**				
		(0.081)						(0.070)				
NO2			0.259**						0.332**			
			(0.115)						(0.102)			
GHG				0.400***						0.549***		
				(0.089)						(0.077)		
POLL					-0.067						0.089	
					(0.072)						(0.064)	
TEMP						0.062**						0.040
						(0.029)						(0.026)
Constant	-9.155***	-6.888***	-7.197***	-9.579***	-9.400***	-9.118***	-4.997***	-2.284*	-2.918*	-5.967***	-6.345***	-5.691***
	(1.423)	(1.433)	(1.704)	(1.304)	(1.342)	(1.342)	(1.259)	(1.249)	(1.507)	(1.137)	(1.190)	(1.192)
Observations	880	880	880	880	880	877	880	880	880	880	880	880
R-squared	0.429	0.443	0.432	0.442	0.429	0.432	0.213	0.255	0.218	0.253	0.210	0.210
F-Stat	62.12	65.68	62.87	65.53	62.13	62.48	22.29	28.26	23.02	28.03	21.92	21.84
Prob > F	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Year FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Wooldridge test	27.98***	28.19***	28.65***	28.29***	27.99***	27.97***	113.43***	114.1***	111.4***	111.6***	118.3***	114.6***

Hausman test	111.11***	122.98***	99.73***	4476.9***	124.68***	54.25***	45.1***	64.5***	56.31***	33.3***	36.5***	36.76***

Note: The dependent variables in models (1) to (6) and (7) to (12) are the public health expenditure, and, private health expenditure respectively. All variables – CO2 (carbon dioxide emissions), NH4 (methane emissions), NO2 (nitro oxide emissions), GHG (greenhouse gas emissions), POLL (air pollution), TEMP (Temperature), AGED (age dependency, old), REN (renewable resource), URB (urbanization), IMM (Immunization) are in log form except GDP (per capita GDP growth), POP (population growth), CC (control of corruption), PS (political stability) and the COV19 (COVID-19 dummy); Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1
Source: Author computations

Note that data does not provide sufficient evidence of the role of the carbon oxide (CO2) emissions in the latter health costs. Likewise, Eckelman et al. (2020) find that there is no obvious relationship between CO2 emissions and public expenditures in the USA. Air pollution too is insignificantly important. However, the effect of climate change with temperature as proxy is found to significantly orchestrate public health expenditure, with a 1 per cent increase in temperature is expected to lead to about 0.062 per cent increase in public health expenditure. The relevant coefficient (0.062) is statistically significant at 5 per cent. This means that as temperatures increase, public health expenditure increases, perhaps because the increase in the former can lead to an increase in heat-related illnesses, which lead to more emergency room visits as well as hospital admissions, and ultimately, higher healthcare costs, especially in the SSA contexts, where the majority focus on survival. Li, Smyth & Yao (2023) document a similar finding for China with regard to the temperature indicator.

Table 4. Effect of environmental quality on external and out-of-pocket health expenditure in SSA

	External health expenditure						Out-of-Pocket health expenditure					
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Variables	CO2	NH4	NO2	GHG	POLL	TEMP	CO2	NH4	NO2	GHG	POLL	TEMP
GDP	0.006	0.006	0.008*	0.003	0.010**	0.010**	0.001	-0.000	0.001	-0.001	0.002	0.002
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
REN	-0.182	-0.443**	-0.430**	-0.195	-0.366**	-0.372**	0.015	-0.050	-0.042	0.044	-0.012	-0.012
	(0.181)	(0.179)	(0.183)	(0.176)	(0.183)	(0.183)	(0.089)	(0.086)	(0.088)	(0.086)	(0.087)	(0.088)
URB	0.697***	0.509***	0.621***	0.949***	1.078***	1.089***	0.309***	0.106	0.185**	0.322***	0.364***	0.359***
	(0.142)	(0.157)	(0.181)	(0.126)	(0.132)	(0.135)	(0.070)	(0.076)	(0.088)	(0.062)	(0.063)	(0.065)
POP	-0.003	-0.001	0.039	-0.006	0.024	0.030	-0.008	-0.015	0.003	-0.014	-0.003	-0.003
	(0.042)	(0.042)	(0.043)	(0.041)	(0.043)	(0.043)	(0.021)	(0.020)	(0.021)	(0.020)	(0.021)	(0.021)
CC	0.344***	0.287***	0.279**	0.238**	0.350***	0.360***	0.131**	0.101*	0.100*	0.090*	0.124**	0.131**
	(0.108)	(0.108)	(0.112)	(0.106)	(0.111)	(0.110)	(0.052)	(0.052)	(0.053)	(0.052)	(0.053)	(0.053)
PS	0.128**	0.088	0.070	0.092*	0.085	0.084	-0.004	-0.009	-0.017	-0.008	-0.011	-0.011
	(0.057)	(0.057)	(0.058)	(0.056)	(0.058)	(0.058)	(0.028)	(0.028)	(0.028)	(0.027)	(0.028)	(0.028)
AGED	0.359	0.517*	0.608*	0.314	0.424	0.432	0.387**	0.443***	0.472***	0.359**	0.415***	0.386**
	(0.305)	(0.306)	(0.315)	(0.298)	(0.314)	(0.314)	(0.151)	(0.148)	(0.152)	(0.147)	(0.151)	(0.152)
IMM	0.391**	0.445**	0.268	0.531***	0.436**	0.436**	0.253***	0.266***	0.195**	0.296***	0.266***	0.264***
	(0.189)	(0.189)	(0.197)	(0.184)	(0.193)	(0.193)	(0.093)	(0.091)	(0.095)	(0.091)	(0.093)	(0.093)
COV19	0.071	0.080	0.069	0.089	0.056	0.049	0.048	0.058	0.052	0.058	0.054	0.046
	(0.079)	(0.079)	(0.081)	(0.077)	(0.082)	(0.081)	(0.039)	(0.038)	(0.039)	(0.038)	(0.039)	(0.039)
CO2	0.661***						0.105**					
	(0.104)						(0.051)					
NH4		0.920***						0.423***				
		(0.145)						(0.070)				
NO2			0.766***						0.306***			
			(0.209)						(0.101)			
GHG				1.426***						0.503***		
				(0.156)						(0.077)		
POLL					0.059						0.096	
					(0.132)						(0.064)	
TEMP						0.004						0.018
						(0.053)						(0.026)
Constant	-8.368***	-7.57***	-7.22**	-14.23***	-14.58***	-14.54***	-2.585**	-0.404	-0.663	-3.474***	-3.870***	-3.396***
	(2.546)	(2.595)	(3.095)	(2.305)	(2.460)	(2.460)	(1.251)	(1.252)	(1.498)	(1.134)	(1.182)	(1.184)
Observations	877	877	877	877	877	874	880	880	880	880	880	877
R-squared	0.247	0.247	0.223	0.283	0.210	0.213	0.134	0.166	0.139	0.172	0.132	0.130
F-Stat	26.93	26.95	23.56	32.41	21.89	22.17	12.76	16.44	13.33	17.16	12.54	12.33
Prob > F	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Year FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Wooldridge test	49.8***	49.09***	48.99***	48.8***	49.9***	51.23***	114.5***	117.61***	117.2***	112.5***	120.8***	120.0***
Hausman Chi-sq.	111.8***	138.0***	107.3***	180.58***	94.05***	88.87***	53.44***	18.01**	12.72**	33.03***	108.3***	78.9***

Note: The dependent variables are External health expenditure in models (1) to (6); and Out-of-Pocket health expenditure in (7) to (12). All variables – CO2 (carbon dioxide emissions), NH4 (methane emissions), NO2 (nitro oxide emissions), GHG (greenhouse gas emissions), POLL (air pollution), TEMP

(Temperature), AGED (age dependency, old), REN (renewable resource), URB (urbanization), IMM (Immunization) are in log form except GDP (per capita GDP growth), POP (population growth), CC (control of corruption), PS (political stability) and the COV19 (COVID-19 dummy); Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1
Source: Author computations

On the other hand, in Table 3 Columns 7-12, all the emissions, viz., CO2, NH4, NO2 and GHG emissions, are observed positively associated with private health expenditure. This means that as the emissions increase, private health expenditure increases, perhaps because the increase in the former can lead to several health problems such as respiratory diseases, cardiovascular complications and cancer, leading to increased health costs and expenditure. Yakubu & Danaa (2024) have previously recorded similar results, particularly for the CO2 indicator in Africa. The findings are also consistent with an earlier study by Apergis et al. (2020) who used data from 178 countries from 1995 to 2017, as well as Hamid & Wibowo (2022) with focus on 5 ASEAN countries. Although Ibukun & Osinubi (2020) find that of the three proxies of environmental quality (i.e. carbon dioxide, nitrous oxide and methane emission) it is carbon dioxide emission that had the highest effect on healthcare expenditure for 47 African countries during the period 2000 to 2018, our study distinguishes the effect according to the type of health expenditure where in the current case, greenhouse gas appears to dominate in all the four types of health expenditures (PrHE, PUHE, OHE, EHE and CHE), as evident in Tables 3-5. However, CO2 has the lowest quantitative effect in all except for public health expenditure where no substantial evidence exists to pin its relevance. Specifically, in Table 4 for example, a 1 per cent increase in the methane emissions tantamount to about 0.920 per cent increase in the external health expenditure, whereas a similar increase would lead to 0.766 per cent,0.661 per cent and 1.426 per cent increase in the latter expenditure.

Furthermore, an increase of 1 per cent in CO2, NH4, NO2 and GHG emissions is likely to lead to drive up out-of-pocket expenditure by 0.105 per cent, 0.423 per cent, 0.306 per cent and 0.503 per cent respectively, other factors constant. This means that the when the SSA countries experience a poor environmental quality in the indicators here considered, the repercussions will be felt through increased external and out-of-pocket health expenditure. This is probably because of the health risk and dangers the poor environmental quality can insinuate, leading to increased health costs and spending. In particular, we note the importance of foreign aid directed towards health during times when environmental quality is deteriorating. An increase in the out-of-pocket spending attributed to these environmental hazards would not only mean foregoing other essential needs like food, housing and education, but also leading to a sale of assets or incurring debts to pay for increasing health costs. Note that data provides no evidence of the significant effect of air pollution, nor climate change as measured by the temperature proxy, on the EHE or on OHE expenditure categories in Table 4. In Table 5 however, the effect of temperature on the current health expenditure is positive, albeit weakly significant at 10 per cent statistical level. Nevertheless, this positivity is consistent with Socol, Iuga & Socol (2023) who observe that during the period 2000 to 2020, the rising temperature and CO2 emissions were directly increasing the health burden on individuals' health and forced governments to enhance health spending in the European Union member states. In SSA, where the common talk is that the region is experiencing a disproportionate burden from the effects of climate change, it is likely that rising temperatures would lead to a higher burden of health issues like infectious diseases and malnutrition and lead to an increase in the current health spending. Overall, Table 5 confirms further the dangers of poor environmental quality to total current health expenditure, with greenhouse gas emissions and carbon dioxide emissions possessing the largest and smallest impact respectively in terms of magnitude. Still here, we fail to observe any significant effect of air pollution on the current health expenditure.

Introducing institutional quality as interactions in Tables 6 and 7 produces additional interesting findings. In Table 6, for example, we observe that whereas CO2 drives the private HE, EHE, OHE and CHE, as previously noted, an increase in the control of corruption can be said to catalyze only the EHE and OHE expenditure types, implying that corruption control is a complement to this effect by strengthening the observed positive effect. For example, when there is an improvement in the control of corruption, the total effect of CO2 on EHE would now be 0.654 (i.e. 0.784+0.216[-0.599]) instead of 0.661 (Table 4, Column1). Note that the -0.599 is the mean value of CC from Table 1. Similarly, while without the interaction the direct effect of CO2 on OHE is 0.105, the presence of an improving control of corruption reduces this effect to a total marginal effect of about 0.0995 (i.e. 0.169+0.116[-0.599]). A related argument holds when we have better institutional quality in terms of regulatory quality, government effectiveness and political stability as earlier noted. The importance of latter for example in boosting the total reduction in the effect of CO2 on external health financing from 0.661 to about 0.64368 is notable. Intuitively, countries with weak institutions, are much more likely to experience higher health costs associated with environmental degradation, including say, an increase in spending on disaster relief and health hazards linked to poor inhaling CO2 emissions.

Regulatory quality for example is found to positively moderate the relationship between CO2 and EHE on one side and between CO2 and OHE on the other. Specifically, countries with better regulatory quality are likely to reduce the effect of CO2 on EHE from 0.661 to about 0.502, just as a similar OHE effect of CO2 would be reduced from 0.105 to about 0.053, following a similar argument. An improvement in the government effectiveness too acts as a strong catalyst in the relationship between CO2 and each of the health expenditure forms, viz., PrHE, EHE and OHE. Countries with better government effectiveness are found to exhibit lower detriment of poor environmental quality on private health expenditure, out-of-pocket health expenditure, and external health expenditure, from as high as 0.114, 0.105, and 0.661 respectively to 0.079, 0.071 and 0.518 in that order, effectively implying in the latter case a reduction of about 30.1 per cent, 32.4 per cent and 21.6 per cent. Also, it is only in the external health expenditure model that political stability is found to strengthen the observed role of CO2. The importance of the four institutional quality indicators, viz., corruption control, regulatory quality and government effectiveness and political stability in the CO2 relationship with the observed spending types means that an improvement in each of these would moderate the health expenditure effect of CO2 in SSA.

In Table 7, we observe further that improvements in voice and accountability would reduce the detrimental effect of climate change on the current health expenditure. Perhaps this is because with better accountability resources are utilized rightly to mitigate the climate change effects on total health spending. Specifically, as evident from Column 9, the reduction is noticeably high, from 0.041 without VA intervention (Table 5, Column 6) to 0.0189 when VA is allowed to moderate the observed effect. This represents almost 53 percentage reduction. Similarly, better political stability is likely to provide support to the relationship between pollution and private HE, pollution and OHE. Also, better government effectiveness is found to reduce the effect of pollution on OHE from about 0.096 to about 0.052. The importance of institutional quality is likewise documented in an earlier study by Wei, Rahim & Wang (2022) focusing on seven selected Emerging economies covering the period from 2000Q1 to 2018Q1.

Table 5. Effect of environmental quality on current health expenditure in SSA

VARIABLES	(1) CO2	(2) NH4	(3) NO2	(4) GHG	(5) POLL	(6) TEMP
GDP	0.001	0.001	0.002	-0.000	0.003	0.003
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
REN	-0.059	-0.144*	-0.143*	-0.045	-0.108	-0.107
	(0.076)	(0.074)	(0.075)	(0.073)	(0.076)	(0.076)
URB	0.725***	0.577***	0.607***	0.778***	0.827***	0.806***
	(0.060)	(0.065)	(0.075)	(0.053)	(0.055)	(0.056)
POP	0.019	0.015	0.034*	0.015	0.026	0.028
	(0.018)	(0.018)	(0.018)	(0.017)	(0.018)	(0.018)
CC	0.175***	0.148***	0.139***	0.131***	0.174***	0.177***
	(0.045)	(0.044)	(0.046)	(0.044)	(0.046)	(0.045)
PS	0.084***	0.073***	0.065***	0.075***	0.071***	0.071***
	(0.024)	(0.024)	(0.024)	(0.023)	(0.024)	(0.024)
AGED	0.517***	0.577***	0.624***	0.492***	0.541***	0.510***
	(0.129)	(0.127)	(0.131)	(0.125)	(0.131)	(0.131)
IMM	0.209***	0.228***	0.144*	0.261***	0.225***	0.231***
	(0.079)	(0.078)	(0.081)	(0.077)	(0.080)	(0.080)
COV19	0.073**	0.081**	0.076**	0.082**	0.072**	0.069**
	(0.033)	(0.033)	(0.033)	(0.032)	(0.034)	(0.034)
CO2	0.181***					
	(0.044)					
NH4		0.406***				
		(0.060)				
NO2			0.369***			
			(0.087)			
GHG				0.556***		
				(0.066)		

POLL					0.048	
					(0.055)	
TEMP						0.041*
						(0.022)
Constant	-7.267***	-5.911***	-5.450***	-8.850***	-9.088***	-8.594***
	(1.072)	(1.075)	(1.286)	(0.962)	(1.021)	(1.021)
Observations	880	880	880	880	880	877
R-squared	0.447	0.465	0.448	0.481	0.436	0.438
F-Stat	66.72	71.74	66.92	76.48	63.86	64.18
Prob > F	0.000	0.000	0.000	0.000	0.000	0.000
Wooldridge chi-sq.	106.9***	108.8***	109.8***	105.9***	110.98***	108.5***
Hausman test	122.05***	235.87***	166.4***	135.48***	135.06***	133.2***

Note: The dependent variable is the current health expenditure. All variables – CO2 (carbon dioxide emissions), NH4 (methane emissions), NO2 (nitro oxide emissions), GHG (greenhouse gas emissions), POLL (air pollution), TEMP (Temperature), AGED (age dependency, old), REN (renewable resource), URB (urbanization), IMM (Immunization) are in log form except GDP (per capita GDP growth), POP (population growth), CC (control of corruption), PS (political stability) and the COV19 (COVID-19 dummy); Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Source: Author computations

Table 6. Moderating effect of institutional quality on relationship between environmental degradation and health expenditure in SSA

	PrHE			EHE				OHE			CHE
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Variables	CO2*CC	CO2*RQ	CO2*GE	CO2*GE	CO2*PS	CO2*RQ	CO2*GE	CO2*CC	CO2*RQ	CO2*GE	CO2*GE
CO2	0.145***	0.106**	0.178***	0.784***	.711***	0.638***	0.749***	0.169***	0.152***	0.237***	0.173***
	(0.055)	(0.054)	(0.058)	(0.111)	(0.106)	(0.106)	(0.116)	(0.054)	(0.053)	(0.057)	(0.050)
CC	0.208***			0.551***	0.328***			0.231***			
	(0.060)			(0.127)	(0.108)			(0.059)			
PS	0.033			0.143**	0.344***			0.005			
	(0.029)			(0.057)	(0.099)			(0.028)			
CO2*CC	0.055*			0.216***				0.116***			
	(0.033)			(0.071)				(0.033)			
CO2*RQ		0.059*				0.215***			0.157***		
		(0.033)				(0.066)			(0.033)		
RQ		0.320***	0.210***			1.047***	0.887***		0.374***	0.206***	0.290***
		(0.064)	(0.068)			(0.127)	(0.134)		(0.063)	(0.066)	(0.058)
CO2*GE			0.133***				0.312***			0.224***	0.057*
			(0.040)				(0.080)			(0.039)	(0.034)
GE			0.268***				0.322*			0.334***	0.170**
			(0.082)				(0.165)			(0.081)	(0.070)
CO2*PS					0.136***						
					(0.051)						
Observations	880	880	880	877	877	877	877	880	880	880	880
R-squared	0.215	0.224	0.234	0.255	0.253	0.289	0.293	0.147	0.170	0.180	0.459
Year FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
F-Stat	20.56	23.91	22.93	25.58	25.32	33.39	30.92	12.90	16.92	16.51	63.74
Prob > F	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Wooldridge chi-sq.											
Hausman test											

Note: The dependent variable is the private health expenditure (Models 1-3), external health expenditure (Models 4-7), out-of-pocket health expenditure (Models 8-10) and current health expenditure (Model 11). All models include (but not shown here) CO2 (carbon dioxide emissions), AGED (age dependency, old), REN (renewable resource), URB (urbanization), IMM (Immunization) in log form and unlogged GDP (per capita GDP growth), POP (population growth), CC (control of corruption), PS (political stability) and the COV19 (COVID-19 dummy); As in previous Tables, all the diagnostic tests and a constant are included (but not shown here). Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Source: Author computations

Additional findings point to the importance of renewable resources in reducing public health expenditure, while urbanization, age dependency (old), corruption control, political stability and Covid-19 in driving upwards public health expenditure. On the other hand, other factors constant, going by Model (7) in Table 3, an increase in urbanization by 1 per cent would enhance private health expenditure by about 0.485 per cent, whereas a unit increase in the control of corruption is associated with 17.5 per cent change in PrHE (i.e. $100[e^{\beta_i}-1]=100[e^{0.161}-1]\approx 17.5$). Similarly, a unit increase in CC and PS would respectively lead to about 33.1 per cent and 17.4 per cent change in public HE, while a similar unit increase in the same institutional quality indicators would respectively translate into about 41.1 per cent and 13.7 per cent in EHE, as well as 19.1 per cent and 8.8 per cent in CHE. Likewise, a unit increase in CC is likely to produce about 14 per cent change in OHE. We also find that GDP, urbanization, CC, PS and immunization are positively associated with the external health expenditure, whereas renewable resources are adversely related to it (Table 4). Likewise, urbanization, CC, age dependency (old) and immunization propel out-of-pocket health expenditure. These results are further tested on the total health expenditure in Table 5 where still renewable resources reduce CHE whereas urbanization, population, CC, PS, age dependency (old), immunization and Covid-19 dummy. In the latter case for example, the period of COVID-19 led to increased health expenditure relative to the period before COVID-19. Bayraktar et al. (2024) documents similar finding on latter pandemic for the top 25 countries with the highest ecological footprint for the period 2000 to 2021. Our findings on the institutional quality effect are also consistent with Wei, Rahim & Wang (2022).

Table 7. Effect of institutional quality on the relationship between pollution, temperature and health expenditure

	PrHE		EHE		OHE			CHE	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
VARIABLES	POLL*PS	POLL*RL	POLL*RL	POLL*RQ	POLL*PS	POLL*RL	POLL*GE	POLL*RL	TEMP*VA
POLL	0.139**	0.264***	0.308*	-0.425**	0.139**	0.215**	-0.199**	0.204***	
	(0.065)	(0.091)	(0.183)	(0.184)	(0.065)	(0.090)	(0.096)	(0.077)	
PS	-0.679***				-0.609***				
	(0.196)				(0.195)				
CC	0.172***				0.139***				
	(0.053)				(0.053)				
POLL*PS	0.189***				0.162***				
	(0.053)				(0.052)				
POLL*RL		0.229**	0.311*			0.156*		0.196**	
		(0.092)	(0.185)			(0.091)		(0.078)	
RL		-0.742**	-1.222*			-0.558*		-0.630**	
		(0.328)	(0.662)			(0.326)		(0.280)	
RQ		0.267***	1.029***	3.152***		0.276***	0.255***	0.345***	
		(0.065)	(0.131)	(0.588)		(0.065)	(0.066)	(0.055)	
POLL*RQ				-0.642***					
				(0.168)					
POLL*GE							-0.339***		
							(0.083)		
GE							1.193***		
							(0.291)		
TEMP									0.044**
									(0.022)
TEMP*VA									0.050*
									(0.027)
VA									0.292***
									(0.044)
Constant	-6.92***	-6.52***	-14.8***	-12.6***	-4.36***	-4.186***	-2.79**	-8.99***	-8.117***
	(1.192)	(1.216)	(2.465)	(2.376)	(1.187)	(1.209)	(1.180)	(1.037)	(1.017)

Note: The dependent variable is the private health expenditure (Models 1-2), external health expenditure (Models 3-4), out-of-pocket health expenditure (Models 5-7) and current health expenditure (Model 8-9). All models include (but not shown here) CO2 (carbon dioxide emissions), AGED (age dependency, old), REN (renewable resource), URB (urbanization), IMM (Immunization) in log form

and unlogged GDP (per capita GDP growth), POP (population growth), CC (control of corruption), PS (political stability) and the COV19 (COVID-19 dummy); As in previous Tables, all the diagnostic tests are included (but not shown here). Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1
Source: Author computations

Finally, we investigate the non-linearity issue with regard to environmental quality effect on health expenditure as earlier indicated. As the results in Tables 8 and 9 show, there is evidence of non-linearity in some health expenditure models but not all. This means that the observed relationship between these environmental quality indicators and health spending is non-linear. The change of sign from a significantly positive to negative on the associated coefficients of the unsquared and squared EQ variables respectively affords us the conclusion of a U-shaped curve. In Table 8 for example, it is observable that only nitrous oxide (NO2) and greenhouse gas (GHG) emissions exhibit non-linearity in the public expenditure (PUHE) model, whereas it is the methane (NH4) and greenhouse gas (GHG) emissions that present a non-linearity relationship in the private health expenditure (PrHE) model. On other hand, in the out-of-pocket health (OHE) expenditure model, we find only the methane (NH4) emissions portraying this U-shaped relationship, while GHG is non-linear in the current health expenditure (CHE) model. The non-linearity finding here observed is consistent with what is revealed in the earlier studies by Musa (2025) and Demir et al. (2023). Notable however, is that linearity is proved for the NO2 in the PrHE model, CO2, NO2 and GHG in the external health expenditure (EHE) model, and, NO2 in the OHE model. As evident in Tables 8 & 9, all relevant coefficients, both unsquared and unsquared, are all significantly positive.

Table 8. Environmental quality on health expenditure in SSA – Threshold effect

Panel A	**Public health expenditure**						**Private health expenditure**					
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
VARIABLES	CO2	NH4	NO2	GHG	POLL	TEMP	CO2	NH4	NO2	GHG	POLL	TEMP
CO2	0.079						0.103					
	(0.080)						(0.068)					
CO2_Squared	0.020						0.006					
	(0.022)						(0.018)					
NH4		0.382**						**0.704*** **				
		(0.156)						**(0.130)**				
NH4_Squared		-0.012						**-0.049** **				
		(0.027)						**(0.022)**				
NO2			**0.220* **						0.189*			
			(0.115)						(0.098)			
NO2_Squared			**-0.058*** **						0.032*			
			(0.019)						(0.017)			
GHG				**0.793*** **						**0.588*** **		
				(0.139)						**(0.118)**		
GHG_Squared				**-0.211** **						**-0.073* **		
				(0.045)						**(0.039)**		
POLL					0.181						-0.219	
					(0.205)						(0.174)	
POLL_Squared					-0.053						0.085**	
					(0.045						(0.038)	
TEMP						0.092*						0.005
						(0.048)						(0.041)
TEMP_Squared						0.029						0.009
						(0.020)						(0.017)
Threshold	NA	NA	**1.897**	**1.879**	NA	NA	NA	**7.184**	NA	**4.027**	NA	NA
Panel B	**External health expenditure**						**Out-of-pocket health expenditure**					
Variable	CO2	NH4	NO2	GHG	POLL	TEMP	CO2	NH4	NO2	GHG	POLL	TEMP
CO2	0.846***						0.143**					
	(0.134)						(0.068)					
CO2_Squared	0.070*						0.025					
	(0.036)						(0.019)					
NH4		0.363						**0.616*** **				
		(0.269)						**(0.133)**				

NH4_Squared		0.088*						**-0.046****				
		(0.046)						**(0.023)**				
NO2			0.388*						0.179*			
			(0.198)						(0.099)			
NO2_Squared			0.137***						0.037**			
			(0.034)						(0.017)			
GHG				0.815***						0.387***		
				(0.236)						(0.120)		
GHG_Squared				0.144*						0.002		
				(0.077)						(0.039)		
POLL					0.053						-0.216	
					(0.354)						(0.175)	
POLL_Squared					0.039						0.088**	
					(0.077)						(0.038)	
TEMP						-0.105						-0.014
						(0.082)						(0.041)
TEMP_Squared						-0.055						0.013
						(0.035)						(0.017)
Threshold	NA	NA	NA	NA	NA	NA	NA	**6.696**	NA	NA	NA	NA

Note: All models include controls, a constant and diagnostic tests plus all the details as indicated in the other tables. NA means not applicable, either because the two coefficients are not significant or only one is significant or they are both positive. The calculation is based on Equation 6.

Additionally, we identify several threshold levels unique for each EQ of interest, but each threshold appears dependent on the type of health expenditure under consideration. For example, while in the PUHE model, the turning point for NO2 happens at about 1.897, that of GHG takes place at a threshold of 1.879 (see Columns (3) & (4). This means that the NO2 and GHG effects are expectedly positive until respective thresholds of about 1.897 and 1.879. Note that when we compare these values with the respective means during the period under study earlier presented in Table 1b, viz., 0.431 and 0.587 respectively for NO2 and GHG (in logs), it implies that the respective curves have not yet taken a U-turn. On the other hand, in the private health expenditure specification, it is the methane emissions (NH4) and greenhouse gas emissions (GHG) that demonstrate asymmetry. Specifically, while the NH4 has a turning point at about 7.184, the threshold for GHG happens at 4.027. Still here, relative to the average values of 1.933 and 0.587 of the respective variables, it is safe to conclude that the NH4 and GHG have not yet taken the U-turn to start affecting the relevant health expenditures negatively.

Table 9. Environmental quality on current health expenditure in SSA

VARIABLES	(1) CO2	(2) NH4	(3) NO2	(4) GHG	(5) POLL	(6) TEMP
CO2	0.169***					
	(0.055)					
CO2_Squared	0.003					
	(0.015)					
NH4		0.376***				
		(0.108)				
NH4_Squared		-0.006				
		(0.019)				
NO2			0.234***			
			(0.081)			
NO2_Squared			0.008			
			(0.014)			
GHG				**0.693*****		
				(0.096)		
GHG_Squared				**-0.121*****		
				(0.031)		
POLL					-0.123	
					(0.143)	
POLL_Squared					0.056*	

					(0.031)	
TEMP						0.019
						(0.034)
TEMP_Squared						0.006
						(0.014)
Threshold	NA	NA	NA	**2.864**	NA	NA

Note: All models include controls, a constant and diagnostic tests plus all the details as indicated in the other tables. NA means not applicable, either because the two coefficients are not significant or only one is significant or they are both positive. The calculation is based on Equation 6.

Conclusions

We set out to examine both the direct and indirect roles of environmental quality on health expenditure in SSA during the period 2002-2021. The health expenditure was disaggregated into the public, private, external, out-of-pocket health expenditure types whereas the environmental quality indicators captured included carbon dioxide emissions, methane emissions, nitrous oxide emissions, greenhouse gas emissions, as well as a proxy for climate change and air pollution. The analysis was carried out using the fixed effects approach selected on the basis of the data characteristic and the Hausman test.

The results obtained from the above estimation technique exhibit differential findings depending on the expenditure type and the environmental quality indicator considered. While methane (NH4) emissions, nitrous oxide (NO2) emissions, greenhouse gas (GHG) emissions are found to increase the overall current health expenditure (CHE) as well as the public, private, external and out-of-pocket health expenditures albeit at varying magnitudes, we fail to find evidence of the importance of carbon dioxide (CO2) emissions in the public health spending., but significantly a catalyst for the remaining expenditure forms. The climate change indicator employed (Temperature) is similarly found to steer upwards the public health spending but less important for the total current health expenditure. Data provides no significant evidence that climate change, as measured by temperature, influences the external and out-of-pocket health expenditures. Likewise, air pollution has not significant impact on any health expenditure type we considered in the study. Additionally, we find that the observed relationship between environmental quality (CO2) and health expenditure is moderated by institutional quality, specifically government effectiveness in all the expenditure models; regulatory quality in the PrHE, PUHE, EHE and OHE models; control of corruption in the PUHE, PrHE and OHE specification; and, political stability in the PUHE and EHE models. On the other hand, political stability and rule of law, regulatory quality and rule of law, voice and accountability and rule of law, political stability, rule of law and government effectiveness, respectively moderate the pollution-health-expenditure relationship, whereas only voice and accountability influence the association between climate change and the current health expenditure in SSA. The other important finding is that while it is NO2 and GHG that show non-linearity effect on PUHE model, just as NH4 and GHG do in the PrHE model, NH4 in the OHE model, and, GHG in the CHE model, the relationship between CO2, NO2, GHG and EHE is evidently linear, and only NO2 is linear in the PrHE model.

The above findings are indicative of the important need for policy-makers in SSA to focus on environment-friendly strategies in the health financing mechanisms while considering crucial the measures to improve institutional quality. Without considering these issues, by equally investing in them, health expenditure might keep increasing as the poor environmental quality related diseases increase amidst poor institutions. Quite important is the observation that while some environmental indicators exhibit non-linearity in the different expenditure functions, others are evidently linear, suggesting that this ought to be considered in the future design of policies as it demonstrates partly the existence of a U-shaped curve and a threshold level at which some indicators would turn to benefit health spending downwards. The presence of non-linearity in some environmental quality indicators for specific health expenditures also implies that a one-size-fits-all policy may be inadequate. Future studies would look extensively at the empirical application of the observed non-linearity here documented.

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