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### Article

# Environmental quality and health outcomes in sub-Saharan Africa- A panel econometric approach on the role of forest investment

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*Suggested Citation:* Oyedele, Ovikuomagbe; Tella, Sheriffdeen A. (2023) : Environmental quality and health outcomes in sub-Saharan Africa- A panel econometric approach on the role of forest investment, Cogent Economics & Finance, ISSN 2332-2039, Taylor & Francis, Abingdon, Vol. 11, Iss. 2, pp. 1-14,

https://doi.org/10.1080/23322039.2023.2269806

This Version is available at: https://hdl.handle.net/10419/304247

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**Cogent Economics & Finance** 

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/oaef20

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**To cite this article:** Ovikuomagbe Oyedele & Sheriffdeen Adewale Tella (2023) Environmental quality and health outcomes in sub-Saharan Africa- A panel econometric approach on the role of forest investment, Cogent Economics & Finance, 11:2, 2269806, DOI: 10.1080/23322039.2023.2269806

To link to this article: https://doi.org/10.1080/23322039.2023.2269806

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Published online: 23 Oct 2023.

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Received: 22 May 2023 Accepted: 08 October 2023

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Reviewing editor: Goodness Aye, Agricultural Economics, University of Agriculture, Makurdi Benue State, Nigeria

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### **DEVELOPMENT ECONOMICS | RESEARCH ARTICLE**

# Environmental quality and health outcomes in sub-Saharan Africa- A panel econometric approach on the role of forest investment

Ovikuomagbe Oyedele<sup>1\*</sup> and Sheriffdeen Adewale Tella<sup>1,2</sup>

**Abstract:** Beyond the economic support in terms of food, fuelwood, charcoal, wood, and timber supplies that investment towards forest environments provides, its contribution to environmental quality could also provide health benefits. Using data from 16 selected sub-Saharan African countries from 2002 to 2016, this study examined the effect of environmental quality on health outcomes with specific consideration for forests. Employing different panel estimation methods for robustness and conducting a sub-sample estimation for sensitivity analysis, the results showed that forest expansion initially seemed to worsen health outcomes as shown by its reduction effect on under-five mortality and its increasing effect on life expectancy at birth. Policies towards improving population health should consider forest expansion and conservation reforms.

### Subjects: Political Economy; Environmental Economics; Economics

Keywords: environmental quality; health outcomes; forest investment; sub-Saharan Africa; under five mortality; life expectancy at birth

JEL Classification: Q2; Q5

### 1. Introduction

Sub-Saharan Africa remains one continent with poor population health status, characterized by a low life expectancy at birth and a high number of child deaths when compared with other continents. Despite the drop in the global under-5 mortality rate from 91 deaths per 1000 live births in 1990 to 43 in 2015, the reduction was insufficient to reach the MDG target of a two-thirds reduction of 1990 mortality levels by the year 2015 (World Health Organization, 2021). Children in sub-Saharan Africa are more than 14 times more likely to die before the age of 5 than children in developed regions (WHO, 2021). Some countries had as high as 150.7 deaths per 1,000 live births as in the case of Congo Democratic Republic with a life expectancy at birth of 51.4 years in 2002 although the death rate and life expectancy declined to 93.9 and 59.7, respectively, by 2016 (WDI, 2022). Despite the decline, this still shows a relatively poor population health when compared with developed countries. Other SSA countries, such as Nigeria, Cameroon, Chad, and Cote D'Ivoire had 125, 84.5, 125.6, and 88, under-five mortality rates and life expectancy at birth of 53.5, 58, 53, and 56.6, respectively, in 2016 (WDI, 2022).





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Climate change threatens the essential ingredients of good health, including clean air, safe drinking water, nutritious food supply, and safe shelter, and it has the potential to undermine decades of progress in global health (WHO, 2021). The importance of the environment for human health and survival informs the several concerns and efforts made by international organizations toward improving environmental quality. The first global forest goal is to reverse the loss of forest cover worldwide through sustainable forest management, including protection, afforestation, and increasing efforts to prevent forest degradation towards reducing climate change (United Nations, 2012). The third sustainable development goal is to ensure healthy lives and promote well-being. The fifteenth sustainable development goal focuses on protecting the environment, sustainably managing forests, and reversing degradation. There are several concerns in the literature about environmental hazards in developed countries as a result of the high level of industrialization as well as calls for reforms in energy use and production technologies to mitigate such consequential hazards. However, there is a growing level of industrialization in developing countries and a high poverty level which leaves a large proportion of the population opting for cheaper energy sources, mostly solid fuels that contribute immensely to greenhouse gas emissions and are usually obtained after deforestation. Therefore, developing regions including sub-Saharan Africa require more attention than it has received towards achieving global environmental pollution reduction success and better health outcomes.

A reduction in environmental quality is usually a result of pollution and hazards, which are in the form of air pollution, water pollution, land pollution, as well as deforestation. According to WHO (2021), policy reforms that improve the transport system and promote better food and energy choices (and at the same time do less harm to the environment) could help improve health. A forest is an area of land mostly consisting of trees. Forests are expected to provide important health benefits for all people directly or indirectly. These benefits are not only for those whose lives are closely intertwined with forest ecosystems but also for people who live far from forests, including the urban population (Food and Agricultural Organization of the United Nation FAO, 2020). The world has a total forest area of 4.06 billion hectares (ha), which is 31% of the total land area; however, the world has lost 178 million ha of forest since 1990 (FAO, 2020).

Forest depletion can be caused by deforestation, which is the cutting down of trees in order to erect infrastructure or carry out agricultural production. Huge areas of forests have been lost worldwide due to deforestation. It can also be due to natural disasters, which destroy the forest such that it cannot regrow naturally (FAO, 2010). Africa experienced the largest annual rate of net forest loss, followed by South America, with a loss of 3.9 million ha and 2.6 million ha, respectively, between 2010 and 2020 (FAO, 2020). The forest helps to store a lot of carbon because plants use them (FAO, 2010). Forests are important for reducing carbon dioxide that is already emitted, thereby contributing to improved environmental quality. The implication of this on population health needs more attention than it has gotten in the literature. This is especially important in Africa, where cutting down trees for firewood, coal, and other energy forms is a common practice. Subsistence farming and agricultural production also encourage deforestation as well as the need for wood supplies by timber and wood industries. However, there are costs associated with depleting the ecosystem and this includes health costs.

Between 2030 and 2050, climate change is expected to cause approximately 250,000 additional deaths per year, from malnutrition, malaria, diarrhoea, and heat stress alone, with a direct cost due to health damage estimated to be between 2 and 4 billion USD per year by 2030 (WHO, 2021).

There have been several calls at national and global levels towards protecting the environment by reducing emissions and conserving the environment through behavioral changes. Ninety percent of all SSA countries have emphasized health risks and food insecurity as consequences they face due to climate change (Crumpler et al., 2022). To show the level of interest by SSA countries, 46 out of 47 countries submitted their first Nationally Determined Contributions (NDC) to the United Nations Framework Convention on Climate Change (UNFCCC) in 2020. Several countries, including those in SSA, have proposed mitigation contributions. Majority of countries comprising 34 countries or 85% promote afforestation, reforestation, reduction of degradation, and sustainable forest management policies (Crumpler et al., 2022). For instance, one mitigation activity in Kenya was to plant trees to cover up to 10% of the land area (United Nations Framework Convention on Climate Change, 2020). Adaptation priorities of SSA countries cover areas such as livestock, forestry, and human health among others (Crumpler et al., 2022).

Other SSA countries have also made institutional arrangements and coordination mechanisms towards environmental quality improvement. For instance, several countries in the SSA region have established national committees comprising relevant ministries and government representatives to formulate the Nationally Determined Contributions (NDCs) (Crumpler et al., 2022). Many countries have also reported various initiatives under domestic implementation mechanisms and monitoring systems, such as institutional arrangements for monitoring and evaluating NDC implementation, tracking and reporting NDC progress, and developing NDC implementation plans (Crumpler et al., 2022).

Several concerns in the literature exist about the state of the environment and how to improve it. Studies such as Zhou et al. (2017) and Waheed et al. (2018) have shown that growing more trees and forests helps to reduce carbon emissions. Thus, the importance of forests cannot be overemphasized. Considering the ongoing increasing call for countries to work towards mitigating the consequential global warming and other health impacts by implementing necessary reforms to take care of the environment, this paper investigates the role of forests as a determinant of environmental quality and its effect on health outcomes including the under-five mortality rate and life expectancy at birth. The empirical evidence provided is for sub-Saharan Africa, a region characterized by poor levels of both health outcomes.

The various efforts of China (known as the largest emitter of greenhouse gases) to improve the level of forestry in order to mitigate climate change were presented by Zhou et al. (2017) while Waheed et al. (2018) showed that using renewable energy and increasing the forest area can in the long run reduce carbon emission.

Suk et al. (2016) emphasized the need for a global pollution control strategy based on a public realization of the increasing environmental pollution-related diseases in high income and low-income countries as well. These concerns are as a result of the negative implications of environmental hazards, one of which is negatively affecting human health and increasing the burden of disease. Even the frequent and common outbreak of cholera amongst other epidemics in Africa is caused by environmental pollution. Forests play an important role in mitigating environmental hazards such as air pollution. Thus, the need to examine the relationship between the forest and health status cannot be overemphasized especially in the case of Africa.

Despite the growing literature on the health effects of poor environmental quality, most studies have been limited to CO<sub>2</sub> emissions, and there is very little consideration for the forests. For instance, Majeed and Ozturk (2020) and Sirag et al. (2017) have shown that environmental degradation worsens health outcomes, such as infant mortality, life expectancy, liver and lung cancer mortality amongst others, but focused on other measures of environmental quality apart from the forest, including CO<sub>2</sub> emission, carbon monoxide and particulate matter amongst others. Few studies that considered the forests (such as Farooq et al. (2019), Jagger and Shively (2014), Pienkowski et al. (2017), and Twohig-Bennet and Jones (2018) conducted country-specific studies while some studies considered other regions besides sub-Sahara Africa. This study contributes to the literature by examining the effect of environmental quality on health outcomes with particular emphasis on the level of forestland area and considering the case for sub-Sahara Africa. This study also goes beyond the scope of previous studies to examine the applicability of the Kuznet curve hypothesis to the forest and health outcome relationship. The Kuznet (1955) theory of an inverted U-shape curve relationship exists between income and inequality so that despite the initial

increasing effect of income on inequality, after a turning point or threshold, a reduction effect on inequality begins and is sustained. Therefore, this study also investigated whether an inverted U-shape curve relationship exists between the level of forest area and health outcomes in SSA.

### 2. Literature review

The Grossman (1972) theory of the demand for health posits that the health status of individuals depends on factors among which are income, education, as well as the environmental status or conditions faced by the individual. Individuals produce their health by the level of investment they make in increasing their health stock. These investments include those made in medical care or health expenditures, diet, exercise, and improving the level of sanitation and hygiene. The maintenance of sanitation and hygiene shows the importance of environmental quality in determining health outcomes. The Mosley and Chen (1984) theoretical framework of child mortality emphasizes a broader approach of incorporating both biological, proximate, and socioeconomic factors that affect child health. The theory argues that socio-economic determinants do not directly explain mortality; on the other hand, proximate determinants have direct impacts on mortality (disease, infection, and malnutrition are examples of proximate determinants and they also reflect environmental conditions such as pollution, poor sanitation, and unhealthy dietary intakes that directly worsen health and cause death).

Several empirical studies have shown that poor environmental states have negative health effects. Most studies have, however, focused on air and water pollution, such as carbon emission and industrial wastes. Environmental pollution has been shown to adversely affect the fetus, causing congenital anomalies and birth defects (Yurdakök, 2012). He explains that fetus exposure to toxic chemicals from cigarette smoking, water pollution, and pesticides amongst others increases adverse pregnancy and worsens child health. However, a review of epidemiological studies on possible congenital anomalies due to environmental pollution from chemicals by Dolk and Vrijheid (2003) revealed that there are few environmental pollution exposures that are strong potential causes but called for precautionary measures by individuals and communities to reduce such exposures.

Using  $CO_2$  emissions, Majeed and Ozturk (2020) showed that environmental degradation worsened health outcomes including infant mortality and life expectancy in 180 countries from 1990 to 2016. Beyond using fixed effects, the study employed the system-generalized method of moments to control for the endogeneity of environmental degradation.

Sirag et al. (2017) also found CO<sub>2</sub> emissions to reduce life expectancy and increase the underfive five mortality rate in 35 Sub-Saharan African countries from 1995 to 2012 using the fully modified and dynamic ordinary least-squares estimators. Carbon exposure has also contributed to increasing child morbidity. For instance, increasing exposure to carbon monoxide, particulate matter, and ground-level ozone led to significant contemporaneous increases in respiratory treatment of children in the United Kingdom (Beatty & Shimshack, 2014).

Chen et al. (2013) used cross sectional data for China and found that industrialization and economic development increased perceived environmental hazards (which were measured using perceived air pollution, perceived water pollution and perceived industrial waste). Employing an ordered logistic regression and ordinary least-squares estimators, they also found that migration from rural to urban areas increased exposure to water pollution and greater environmental hazards in China. Perceived environmental risk factors had negative effects on the physical and mental health of individuals residing in urban areas with a greater negative effect obtained for those who migrated from rural to reside in urban areas.

A review of the literature by Triassi et al. (2015) revealed that illegal waste disposal plays a longterm role in increasing liver and lung cancer mortality, while in the short term, it had a positive association with congenital malformation. Despite several studies on the health effects of environmental quality, little attention has been given to the role of forests especially in Sub-Saharan Africa. Farooq et al. (2019) considered the effect of afforestation in addition to carbon emissions and employing quantile regression, they found that while increasing afforestation reduced health-related problems, higher emissions of carbon, sulfur, and nitrogen increased health challenges in China. Thus, expanding and sustaining the forests is important for improving health. Deforestation was also found to reduce the availability of high-quality fuelwood for rural households, and so they are left with the use of fuelwood from non-forest areas, which increases the incidence of acute respiratory infection in children under five in Uganda (Jagger and Shively 2014).

A systematic review of the literature on the relationship between forest and human health by Pagès et al. (2020) revealed that there are scarce efforts in the literature in this area, thus requiring more attention. The study also found that most literature generally found a positive effect of forests on health; however, some studies found no significant result.

Evaluating the physical and psychological benefits of exposure to nature such as forest therapy, Oh et al. (2017) revealed that from a review of the literature, even though there is no convincing evidence of the effect of forests on health, outdoor activities in a natural environment including forests may help in preventing disease and promoting health. Other studies such as Vinceti et al. (2013) have also shown that forests play an important role in providing sustainable diets and food security.

The improving public health impacts of environmental protection have been documented in some studies as well as the call for environmental reforms for a greener environment. After a systematic review and a meta-analysis of 143 studies, Twohia-Bennet and Jones (2018) found that greenspace exposure improves a wide variety of health outcomes, including reducing cardiovascular mortality, respiratory mortality, as well as the incidence of stroke, asthma, and hypertension amongst others. Dense forest deforestation was found to be associated with childhood mortality and morbidity by increasing the incidence of diarrhea and respiratory infection in children (Pienkowski et al., 2017). Increasing alternatives to improving public health have gained increasing attention in Europe considering the increasing incidence of poor related health due to modern lifestyles that are more sedentary, less physically active, and less exposed to the green environment (Nilsson et al., 2011). Shin et al. (2010) explained that forest stimuli compared to urban stimuli include a lower human population density, less noise, and movement, and a slower rate of change. Mental health improvement has been associated with nature-based recreation and participating in forest bathing activities is one form of nature-based recreation. Based on a fixed effect estimation of two year panel data from the Nigeria Demographic and Health Survey for 2008 and 2013, Berazneva and Byker (2017) found an increase in forest loss to have an increasing effect on the incidence of malaria in the first and second years after loss before returning to the previous level in the third year after loss. Forest loss, however, had no significant effect on diarrhea or respiratory diseases. Deforestation was also found to be associated with an increase in malaria incidence in Brazil (Olson et al., 2010).

Emphasizing the effect of forest therapy on health, Lee et al. (2014) examined the effects of walking in the forest and walking in urban environments on cardiovascular and psychological responses of forty eight Japanese young adults and found that forest walking reduced negative mood states and anxiety levels and improved cardiovascular responses such as heart rate and blood pressure. The role of forest environment on health status has been shown or discussed in the literature; however, there has been more focus on developed countries. Therefore, studies for developing countries still remain a gap to be filled.

Other significant determinants of health status include population growth, which reduces health status (Farooq et al., 2019), the GDP per capita and school enrollment, which improves health outcomes as shown by Sirag et al. (2017) and health-care expenditure, which was found to have

a significant relationship with health status (Hall et al., 2012). Nixon and Ulmann (2006) found health financing to reduce infant mortality rates but have margia nal contribution to improving life expectancy at birth. Arthur and Oaikhenan (2017) also showed that public health expenditure reduced the mortality rate while private health expenditure improved life expectancy at birth in sub-Saharan Africa. Food prices had negative effects on child survival, while the price of medical care had no correlation as obtained by Lavy et al. (1996) in Ghana.

### 3. Methodology

### 3.1. The model

The model employed is based on the Grossman (1972) theory of health demand which states that an individual's health demand depends on his income, market prices, and health capital stock (which increases as he invests more on the production of health) amongst others. Such investments are in the form of health/medical care expenditures and investments on environmental quality. The model therefore presents health outcomes as a function of income (measured as the real GDP), prices (measured by inflation), environmental factors, such as the percent of forestland area and health/medical care expenditure (measured using out-of-pocket expenditure and public health expenditure) as shown in equation (1).

$$HO = f(grgdp, infl, forest, oop, pubhe)$$
(1)

Control variables such as gross capital formation as a percent of the GDP and the export volume index are included in the model based on previous empirical literature. The model therefore becomes equation (2).

$$HO = f(grgdp, infl, forest, oop, pubhe, gcf, expvol)$$
(2)

The linear form of the panel regression model is given as

$$HO_{it} = \beta_0 + \beta_1 forest_{it} + \beta_2 grgdp_{it} + \beta_3 infl_{it} + \beta_4 oop_{it} + \beta_5 pubhe + \beta_6 gcf_{it} + \beta_7 expvol_{it} + e_{it}$$
(3)

Equation (3) presents health outcomes (HO) measured using the under-five mortality rate and life expectancy at birth. Both measures are presented as a function of the percent of forestland area (forest), annual percentage GDP growth (grgdp), inflation rate (infl), out-of-pocket expenditure as a percent of current health expenditure (oop), public health expenditure as a percent of current health expenditure (oop), public health expenditure as a percent of current health expenditure (pubhe), gross capital formation as a percent of the GDP (gcf) and the export volume index (expvol). Apriori, we expect the population health status to improve or worsen depending on the following factors: forest > 0, grgdp > 0, infl < 0, oop < 0, pubhe > 0, gcf > 0, expvol > 0.

Grossman (1972) posits a positive effect of income on health status because individuals can allocate more spending on their health needs as their income increases. Hence, an increase in the annual percentage GDP growth is expected to improve health outcomes. Grossman (1972) also emphasized that environmental factors and conditions are also important in the production of health. This is because a good and healthy environment is one that has good hygiene conditions and is free from hazards and pollution. This has positive implications on an individual's health as well as the health of the society. Thus, an increase in the percent of forest area is expected to improve health outcomes. Vast forest areas promote a clean atmosphere because plants use up carbon dioxide (CO<sub>2</sub>), which is harmful to humans (thus reducing the level of CO<sub>2</sub> emitted from industrial and human activities) and release oxygen, which is useful for human survival. Therefore, the presence of forests enhances environmental quality and reduces air pollution as plants and trees up the carbon dioxide in the atmosphere and release oxygen which is healthy for humans. The apriori expectation for inflation is negative because as inflation rises, the demand for health inputs declines since they also become expensive. However, some studies have shown no

relationship such as Lavy et al. (1996) who found that food prices had negative effects on child survival, while the price of medical care had no correlation as obtained in Ghana. Health and medical care expenditure is expected to have a positive effect on health outcomes. Studies such as Arthur and Oaikhenan (2017) showed that public health expenditure reduced mortality rates, while private health expenditure improved life expectancy at birth in sub-Saharan Africa. A reduction effect on infant mortality rate was also obtained by Nixon and Ulmann (2006).

### 3.2. Data and data source

Data for the study were obtained from the World Development Indicators (2020) for 16 selected sub-Saharan African countries covering five regions (north, south, east, west, and middle Africa) in SSA. The countries are Nigeria, Guinea-Bissau, Congo Democratic Republic, Ghana, Botswana, Tanzania, Niger, Rwanda, Uganda, Cameroon, Chad, Cote D'ivoire, Kenya, Malawi, Senegal, and South Africa. The period of the study was determined based on data availability and was from 2002 to 2016. The World Development Indicators is published by the World Bank and includes data on economic and demographic variables amongst others for several countries.

### 4. Results and discussion

### 4.1. Descriptive statistics

The descriptive statistics of the variables are presented in Table 1. The effect of forest investment on health outcomes was examined using both the fixed effect and random effect estimators. The Hausman test is then used to determine the appropriate estimator. For robustness, a sensitivity analysis was conducted using a sub-sample. In addition to the fixed and random effect estimators, the seemingly unrelated regression (SUR) estimator was also employed, and the results obtained using different estimation methods were compared. The under-five mortality rate (U5MR) model and the life expectancy at birth (LEB) model estimates obtained using the fixed effect and random effect are presented in Tables 2, 3 and 4 along with the estimates of both health outcome models under the sensitivity analysis.

The descriptive statistics in Table 1 show an average of 97 under five child deaths per 1,000 live births with as high as 204.6 maximum number of child deaths recorded among the countries. This shows a worrisome and poor picture of the population's health status. Life expectancy at birth was only an

Table 1. Descriptive statistics				
Variable	Mean	Standard Deviation	Minimum	Maximum
Under five mortality rate	96.568	37.918	35.1	204.6
Life expectancy at birth	56.367	5.137	45.517	68.178
Forest	28.940	21.309	0.892	75.818
Forestsquared	1289.698	1550.187	0.795	5748.303
GDP per capita growth	2.558	3.543	-9.442	28.676
Inflation	6.812	6.169	-8.975	31.523
Out of pocket expenditure	40.639	21.919	3.307	76.877
Public health expenditure	27.978	14.044	4.064	67.859
Gross Capital Formation (% of GDP)	21.574	7.913	4.704	60.156
Export volume index (2000 = 100)	197.907	151.420	70.101	902.896

life expectancy at birth using the fixed effect estimator			
Variables	U5MR Model Fixed Effect Coefficient (t statistic)	LEB Model Fixed Effect Coefficient (t statistic)	
Forest	16.272(4.44)*	-3.709(-3.41)*	
Forestsquared	-0.074(-1.60)	0.019(1.89)	
GDP per capita growth	0.761(2.04)	-0.154(-2.39)**	
Inflation	-0.180(-0.85)	0.016(0.45)	
Out of pocket expenditure	0.056(0.19)	0.003(0.06)	
Public health expenditure	0.514(1.70)	0.019(0.37)	
Gross Capital Formation	-1.264(-2.13)**	0.157(2.66)**	
Export volume index	-0.099(-3.44)*	0.014(2.91)**	
Constant	-249.44(-3.66)*	131.94(7.22)*	
F-statistic(Prob>F)	15.74(0.0000)	20.16(0.0000)	
rho	0.998	0.998	

# Table 2. Estimates of the effect of percent of forestland area on under five mortality rate and life expectancy at birth using the fixed effect estimator

\* and \*\* denote significance at 1% and 5% respectively.

Table 3. Estimates of the effect of percent of forest land area on the under-five mortality rate and life expectancy at birth using the fixed effect estimator

	U5MR Mode l Fixed Effect	LEB Model Fixed Effect
Variables	Coefficient (t statistic)	Coefficient (t statistic)
Forest	23.171(6.00)*	-5.815(-10.45)*
Forestsquared	-0.201(-4.97)*	0.045(7.73)*
GDP per capita growth	-0.145(-0.31)	-0.019(-0.28)
Inflation	-0.094(-0.33)	-0.008(-0.20)
Out of pocket expenditure	0.584(1.89)	-0.021(-0.47)
Public health expenditure	0.644(2.08)**	0.017(0.38)
Gross Capital Formation	-1.402(-4.93)*	0.184(4.49)*
Export volume index	-0.121(-5.21)*	0.016(4.77)*
Constant	-314.007(-4.36)*	163.764(15.78)*
F-statistic(Prob>F)	33.09(0.0000)	54.17(0.0000)
Rho	0.997	0.999

\* and \*\* imply significance at the !% and 5% significance level respectively.

average of 56 during the period. The maximum life expectancy recorded was 68 years which only confirms the generally poor health status in sub-Saharan Africa. The mean forestland area among the countries was very low with a value of 28.9 percent. The potentials of the forest is thus far from being harnessed with such a low percentage land area. The mean value of GDP per capita annual growth was also low at 2.6 percent. However, the average inflation rate was up to 6.8 percent.

### 4.2. Effect of forests on health outcomes

### 4.2.1. The aggregate sample estimates

Examining the effect of forest area on health outcomes, this study estimated two models including the under-five mortality rate model and the life expectancy at birth model.

Table 4. Estimates of the seemingly unrelated regression model			
Variables	U5MR Model Coefficient (z statistic)	LEB Model Coefficient (z statistic)	
Forest	-1.846(-4.67)*	-0.111(-1.69)	
Forestsquared	0.027(4.59)*	0.001(1.32)	
GDP per capita growth	1.318(2.29)**	-0.216(-2.04)**	
Inflation	-0.325(-1.19)	-	
Out of pocket expenditure	0.829(6.64)*	-0.025(-1.10)	
Public health expenditure	-0.426(-2.21)**	0.130(3.71)*	
Gross Capital Formation	-1.206(-4.70)*	0.044(0.93)	
Export volume index	-0.141(-6.53)*	0.033(8.49)*	
Constant	149.869(11.24)*	49.017(20.15)*	
Equation	Observations	R2	Chi2(prob)
Under five mortality rate	120	0.803	494.35(0.0000)
Life expectancy at birth	120	0.587	170.60(0.0000)

\* and \*\* imply significance at the !% and 5% significance level respectively.

Using the aggregate sample, both health outcome models were estimated using the fixed effect estimator based on the Hausman test, which identified it as more appropriate than the random effect. Based on the fixed effect estimates shown in Table 2, the effect of forests on the under five mortality rate was positively significant, but the effect of forest squared was negatively significant. This implies that an increase in the forestland area initially increased the under-five mortality rate up until a turning point when further increases in the expanse of forests began to cause a reduction in the under-five mortality rate. Thus, there is an inverted U-shape relationship between the expanse of forests and the under-five mortality rate. Thus, an increase in forest area causes the under five mortality rate to decline but only after a turning point or threshold. This implies that expanding the forest area is beneficial to improving health outcomes but only after the expansion gets to a certain threshold.

This result is contrary to some studies, which found an increase in forests to immediately improve health outcomes such as Pagès et al. (2020), which found a positive effect of forests on health in most studies after a systematic review of the literature. Berazneva and Byker (2017) and Olson et al. (2010) also found forest loss to worsen health outcomes by increasing the incidence of malaria in Nigeria and Brazil, respectively. This is because they did not consider whether a threshold or turning point exists.

In the life expectancy at birth model, the effect of forests was negatively significant initially but later became positive after a turning point. Thus, an increase in the expanse of forests causes a reduction in life expectancy at birth initially but later on gets to a turning point beyond which the life expectancy at birth begins to increase showing an improvement in health status as the percent of forestland area continues to increase. This shows a U-shape curve relationship implying that there exists a minimum point. Hence, deliberate efforts towards increasing the expanse of forests would overtime payoff by reducing the under-five mortality rate and increasing the life expectancy at birth. This is similar to Farooq et al. (2019), which found the presence of forests to significantly improve health outcomes especially as a result of its direct ability to reduce carbon emissions in the environment as shown by Zhou et al. (2017) and Waheed et al. (2018).

Therefore, while an inverted U-shape curve relationship existed between forests and under-five mortality rate, a U-shape curve relationship is rather seen for the case of life expectancy at birth.

Thus, even though forest expansion initially seemed to worsen health outcomes, it ultimately improved health outcomes through its reduction effect on child death and its ability to increase longevity. Therefore, the inverted U-shape relationship between forests and under-five mortality rate and the U-shape relationship between forests and life expectancy at birth confirm the health improvement role of the existence and expansion of forests in sub-Sahara Africa. However, we also emphasize that this improvement is only obtained after it gets to a maximum. This supports policy efforts towards reducing the human health and food insecurity consequences of climate change such as the nationally determined contributions of countries towards limiting global temperature increase to 1.5°C above pre-industrial levels through sector-specific actions based on Kaddu (2020). This also supports the mitigation activity of Kenya to plant trees to cover up to 10 percent of the land area (UNFCCC, 2020).

This also supports the need for domestic policy efforts of several SSA countries and their various initiatives, as reported by Crumpler et al. (2022) such as institutional arrangements for monitoring and evaluating NDC implementation, tracking and reporting NDC progress, and developing NDC implementation plans.

Considering the effect of GDP per capita, we found that despite the growth of the GDP per capita, health outcomes still worsened as shown by the fact that the under-five mortality rate increased, however it was not significant. The effect of GDP per capita on life expectancy at birth was negatively significant implying a decline in life expectancy despite increases in the GDP per capita. Therefore, an increase in income is not sufficient to improve health outcomes. There must be some deliberate effort towards channeling such income to increase the production of health services and personnel as well as infrastructures.

Inflation, out-of-pocket health expenditure and public health expenditure were insignificant in both the under-five and life expectancy models. This further reiterates the impoverishing effect of out-of-pocket expenditures, which ultimately worsen health outcomes as it gradually drains the income of households. Thus, there must be substantial effort to reduce the level of out-of-pocket health expenditures in the economies to the extent that it can have a significant effect on population health.

Public health expenditure did not improve the under-five mortality rate, nor was it significant to explain life expectancy at birth. This shows poor public expenditure on health in SSA. Thus, public health expenditure must be substantial enough to positively impact health outcomes, and it should be directed at activities that increase access to health care for both children and adults. This is in contrast to Arthur and Oaikhenan (2017) that found public health expenditure to significantly reduce mortality rates in sub-Saharan Africa, although for a different study period.

An increase in the gross capital formation significantly improved health outcomes by reducing the under-five mortality rate and increasing the life expectancy at birth. Hence, as more of national income is ploughed back to increase total investment and infrastructure, including health investments, more income and empowerment opportunities are generated that benefit individuals who help meet their health and other needs. It is therefore important that efforts to increase the stock of capital be taken seriously as it has the potential to enhance the provision of more healthcare services, especially when the increase in capital is specifically in the health sector. An increase in the export volume also significantly improved health outcomes. This is not surprising because the income generating capacity of exports can help increase health-care infrastructures if such income is directed towards improving the health sector. Several SSA countries have made some effort to increase their export volume and thus earnings and the drive is still on to encourage more countries to increase their production and export capacity. This should be consistently directed towards improving facilities and services in the health sector.

### 4.3. Sensitivity analysis and robustness check using a sub sample

We further checked for the robustness of the aggregate sample estimates for the effect of forests and the sensitivity of the results to the sample used by conducting a sub-sample estimation for eight countries selected at random. The model was estimated using the fixed effect estimator after a Hausman test, which found it more appropriate to produce consistent estimates than the random effect. The seemingly unrelated regression (SUR) estimator was also employed since the number of units (N) is less than 10. The overall models estimated using both the fixed effect and the SUR estimators were highly significant. The results are presented <sup>on</sup> Tables 3 and 4.

Examining the effect of forests on the under five mortality rate and life expectancy at birth using the fixed effects, the results showed that an increase in the expanse of forestland initially significantly increased the under-five mortality rate but after a certain minimum point, the rate of child deaths began to decline. Thus, it only had an initial child health depreciating effect but as the level of forest area increased, it got to a turning point or threshold where it began to cause a decline in the mortality rate. This shows that an inverted U-shape curve relationship exists between forest expansion and the under-five mortality rate, just as was obtained in the aggregate sample estimation above. It is common for poor and vulnerable individuals and households in developing countries to farm on or build on government land that is left unused. The initial displacement of such individuals/households from their residential homes or from the land, which they occupy or use for subsistence farming in order to grow forests could cause such households to face some impoverishment which could affect their health and the capacity to meet their health expenses. However, when policy efforts are implemented to ensure afforestation. such that more forests are grown and conserved, it ultimately pays off because the community enjoys a cleaner environment in terms of the air and ozone and less health hazards are experienced. Forest expansion also brings about more consistent rainfall and a sustained variety of both plant and animal species. This provides comfort to the immediate residents and economic support to agricultural households that mostly depend on rainfall, which is common in SSA.

For the case of life expectancy at birth, the effect of forests was also highly significant such that an increase in the expanse of forestland initially reduced life expectancy at birth but after a certain minimum its effect becomes substantially and significantly positive. This is a U—shaped curve relationship implying that there was an ultimate improvement in longevity and population health after a turning point or threshold level of forests. This result is similar to the findings obtained in the aggregate sample estimation. This confirms the importance of the forests for improving health. This is because as more forests are grown and natural environments are maintained, the trees are able to use up carbon emitted into the environment thereby cleaning the air and ozone.

This supports the policy efforts of several SSA countries, such as their NDCs and adaptation and mitigation activities that improve environmental quality towards achieving a reduction in negative socioeconomic and human health impacts. The results from the aggregate sample and the sub sample therefore confirm the existence of an inverted u-shape curve relationship between the level of forestland area and health outcomes in SSA; however, the turning point was significant only in the sub sample. This confirms the applicability of the Kuznet curve hypothesis in the forest —health outcome relationship in some SSA countries. This finding is sensitive to the sample of countries used. The inverted U-shape curve relationship was, however, not verified when the SUR estimator was used since a rather U-shape curve was obtained for under-five mortality rate while the level of forest area was insignificant in the life expectancy model. Thus, the forest effect was sensitive to the estimation method employed.

The growth of the real GDP per capita had a positive effect on the under-five mortality rate in the SUR estimation implying that the recorded growth did not translate into more access to healthcare services or improved nutrition by individuals in order to reduce child deaths. This is not significant in the fixed effect model. The real GDP was also found to worsen life expectancy at birth in both the fixed effect and SUR models. Thus, it is either the income growth was not

Table 5. Correlation matrix of residuals			
	Under-five mortality rate	Life expectancy at birth	
Under five mortality rate	1.0000	-	
Life expectancy at birth	-0.6124	1.0000	
Breusch-Pagan test of independence: chi2(3)	45.006(	0.0000)	

Table 6. Test for cross-equation constraints		
Chi2(6)	55.68	
Prob> chi2	0.0000	

substantial enough or its purchasing power was not actually used to empower households' ability to increase their health-care consumption as well as other health inputs necessary for increasing life expectancy levels or longevity.

Out-of-pocket expenditure still had a worsening effect on child death rate as obtained in the aggregate sample but was significant only in the SUR model. An increase in public health expenditure had an improved effect on both child health and life expectancy at birth using the fixed effect but had a reduced effect on child death when the SUR estimation was used. Thus, its effect is sensitive to the estimation method used. Gross capital formation and export volume significantly improved health outcomes by reducing under-five mortality rates and increasing life expectancy at birth. This result is consistent with both the fixed effect and SUR estimations.

Tests for the correlation of the residuals in the SUR estimation in Table 5 show that the errors in the under-five mortality rate and life expectancy at birth equations are negatively correlated. The Breusch-Pagan Lagrange multiplier test for error independence showed that the correlation between the errors in the two equations is highly significant as shown in Table 5. This shows that both health outcome measures have the same underlying determinants. Tests for cross equation constraints in Table 6 revealed that the three regressors (forests, forest squared, and GDP per capita growth) were jointly significant in both equations to explain changes in the two health outcome measures.

### 5. Conclusion

This study examined the effect of forest investment on health outcomes using data for 16 selected sub-Saharan African countries from 2002 to 2016. The study employed the fixed effect and random effect estimators and the Hausman test was used to determine the appropriate estimator. For robustness, a sensitivity analysis was conducted using a sub-sample. In addition to the fixed and random effect estimators, the seemingly unrelated regression (SUR) estimator was also employed. The results showed that forestland expansions contribute significantly to reducing under-five mortality rates and increasing life expectancy at birth in sub-Saharan Africa. The study found that forest expansion initially seemed to worsen health outcomes; however, after a turning point, it ultimately improved health outcomes as shown by its reduced effect on child death and its increasing effect on increased life expectancy at birth. Thus, the Kuznet curve hypothesis was found applicable to under-five mortality while a U-shape curve holds for life expectancy at birth in SSA; however, it was sensitive to the estimation method employed. The role of forests in improving health outcomes therefore cannot be underestimated. Thus, policy efforts towards afforestation, protecting and conserving forests should be encouraged and deliberately implemented in a sustainable manner in order to improve health outcomes such as the under five mortality rate and life expectancy at birth.

The initial worsening effect associated with increasing the level of forest area as shown by the Kuznet curve hypothesis needs to be planned for by implementing some cushioning or compensatory interventions on affected households before the turning point is achieved. Environmental reforms such as planting more trees for every one tree that is cut down should be intensified in SSA as well as increasing public awareness on the benefits of forests. Policies geared towards improving the population health status should consider long-term environmental reforms, precisely the expansion and preservation of forests.

The results of the study also showed that the real GDP per capita and out-of-pocket expenditure had a worsening effect on child death rate. However, an increase in public health expenditure had an improvement effect on both child health and life expectancy at birth as expected.

Therefore, policy efforts towards improving child health should also be geared towards increasing public health expenditure and insurance schemes in order to reduce the direct burden of health expenses on individuals and households.

### Funding

There is no specific funding for this study.

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### **Disclosure statement**

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

### Data availability statement

Data used for the study is the World Bank World Development Indicators (2021) obtained from https:// databank.worldbank.org

### **Citation information**

Cite this article as: Environmental quality and health outcomes in sub-Saharan Africa- A panel econometric approach on the role of forest investment, Ovikuomagbe Oyedele & Sheriffdeen Adewale Tella, *Cogent Economics & Finance* (2023), 11: 2269806.

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