

Urbanisation as a Moderator of the Carbon Emissions-Infectious Diseases Nexus in Heavily Indebted Poor

Countries in Africa

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Abstract

This paper examines whether urbanisation moderates the effect of carbon emissions on infectious diseases in Heavily Indebted Poor Countries (HIPCs) in Africa. The study is motivated by the public health risks created when rapid urban growth occurs alongside environmental degradation, weak sanitation systems, inadequate housing and limited health infrastructure. The analysis focuses on 28 HIPCs in Africa over the period 1990-2023 and uses three measures of infectious diseases: prevalence of HIV among the population aged 15-49, incidence of tuberculosis per 100,000 people and incidence of malaria per 1,000 population at risk. Carbon emissions are measured in metric tons per capita, while urbanisation is captured by urban population as a percentage of total population. The model incorporates gross domestic product per capita, current health expenditure and access to basic sanitation as control variables. Anchored on the Epidemiological Transition Theory and the Environmental Kuznets Curve hypothesis, the study estimates a fixed-effects panel regression model with an interaction term between urbanisation and carbon emissions. The results show that carbon emissions exert a significant positive effect on HIV prevalence, tuberculosis incidence and malaria incidence. Urbanisation also increases disease prevalence, although its direct effect on malaria is statistically weak. The study concludes that infectious-disease reduction in African HIPCs requires an integrated policy framework linking clean energy transition, sanitation investment, public health financing and urban disease surveillance. The paper contributes to the literature by showing that urbanisation is not only an independent determinant of infectious diseases but also a transmission channel through which environmental pollution worsens public health outcomes in fiscally constrained African economies.

Keywords: urbanisation; carbon emissions; infectious diseases; HIPCs; Africa; panel regression

1.0 Introduction

Infectious diseases remain a major barrier to health security, human capital formation and sustainable development in low-income economies. In Heavily Indebted Poor Countries (HIPCs) in Africa, the persistence of HIV, tuberculosis and malaria is reinforced by weak health infrastructure, poverty, overcrowding and inadequate sanitation. These vulnerabilities are deepened by rapid urban growth and increasing environmental pollution. Urbanisation changes the spatial distribution of people, economic activity and public services, but where

such growth is not accompanied by adequate housing, drainage, waste management and health facilities, cities can become centres of concentrated disease risk. The thesis from which this paper is developed positions infectious diseases as a continuing public health burden in HIPCs and identifies rapid urbanisation and carbon emissions as important environmental and socio-economic drivers of disease vulnerability.

Urbanisation has important developmental benefits. It can improve access to employment, education, markets

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and health services. However, in many African HIPCs, urban expansion has been largely unplanned and has outpaced the capacity of governments to provide infrastructure. Rural-to-urban migration, demographic pressure and the search for economic opportunities have resulted in informal settlements, congestion, poor waste disposal, inadequate water supply and sanitation deficits. These conditions increase exposure to communicable diseases by bringing people into close contact and weakening the environmental barriers that normally reduce transmission. As argued in the thesis, urbanisation in African HIPCs is therefore a double-edged process: it can support socio-economic transformation, but it can also intensify health risks when governance, infrastructure and environmental management remain weak.

Carbon emissions constitute another major pathway through which environmental conditions affect health. Increases in emissions are associated with industrial activity, transport expansion, fossil-fuel use, land-use change and urban energy demand. These processes worsen air quality, contribute to climate change and affect the ecological conditions that shape disease transmission. Higher temperatures, changing rainfall patterns and urban heat effects can alter vector habitats and increase vulnerability to malaria. Air pollution and environmental degradation can also worsen respiratory health and indirectly increase susceptibility to infectious diseases, especially among poor urban populations with limited access to healthcare. The combined presence of emissions growth and rapid urbanisation thus creates an important research problem for countries with limited fiscal capacity and weak public health systems.

The central argument of this paper is that urbanisation does not merely operate as an independent determinant of infectious diseases. It may also moderate the relationship between carbon emissions and infectious diseases. This means that the effect of emissions on disease outcomes may be stronger or weaker depending on the level and nature of urbanisation. Where urbanisation is accompanied by overcrowding, poor sanitation, stagnant water, weak waste management and limited health infrastructure, emissions-related environmental pressure may translate more strongly into disease prevalence. Conversely, where urbanisation is planned, inclusive and supported by public health investment, its negative interaction with emissions may be reduced. This moderating perspective provides a more nuanced understanding of the environment-health relationship in African HIPCs.

Accordingly, this paper examines the extent to which urbanisation moderates the effect of carbon emissions on infectious diseases in heavily indebted poor countries in Africa. The study focuses on 28 African HIPCs over the period 1990-2023 and employs a fixed-effects panel regression framework with an interaction term between urbanisation and carbon emissions. By concentrating on HIV prevalence, tuberculosis incidence and malaria incidence, the paper captures three major infectious-disease burdens that remain central to African public health. The contribution of the paper lies in showing that the health consequences of carbon emissions are conditioned by the urban environment, thereby calling for integrated urban, environmental and health policy responses.

2. Literature Review

2.1 Infectious diseases, urbanisation and environmental pressure

Infectious diseases are caused by pathogenic microorganisms, including bacteria, viruses, parasites and fungi, and they spread through direct contact, contaminated food and water, respiratory droplets, vectors and exposure to infected bodily fluids. The thesis emphasises that these diseases remain difficult to control in economies with weak surveillance, poor access to healthcare and limited public health infrastructure. In African HIPC, the problem is compounded by low fiscal capacity, fragile institutions and high levels of poverty. HIV, tuberculosis and malaria remain particularly important because they impose direct mortality and morbidity costs while also reducing labour productivity, increasing household health expenditure and weakening long-term development outcomes.

Urbanisation influences infectious diseases through multiple channels. Population concentration increases contact rates, while informal settlements increase exposure to unsafe water, poor sanitation and inadequate waste disposal. Densely populated urban spaces can facilitate tuberculosis transmission where ventilation is poor and housing is overcrowded. Urban poverty can also reduce access to testing, treatment and preventive health services, increasing the persistence of HIV and other communicable diseases. In relation to malaria, unplanned drainage systems, stagnant water and inadequate waste management may create breeding grounds for mosquitoes even within urban areas. Although some urban centres benefit from improved infrastructure that can reduce vector habitats, the thesis indicates that the overall disease effect of urbanisation depends on the quality of planning and service delivery.

Carbon emissions affect health by worsening air quality, contributing to climate variability and intensifying environmental degradation. These environmental changes influence disease patterns directly and indirectly. Polluted air weakens respiratory systems and increases vulnerability to infections. Climate-related changes may alter temperature and precipitation patterns, thereby influencing the geographical and seasonal distribution of vector-borne diseases. In the thesis, carbon emissions are treated as an indicator of environmental degradation linked to industrialisation, fossil-fuel use and expanding urban economic activity. The public health implication is that environmental pollution cannot be separated from disease control, particularly in countries where health systems are already overburdened.

The interaction between urbanisation and carbon emissions is especially important. Urban areas are often centres of energy use, transportation, industrial activities and waste generation. When these emissions-intensive activities occur in poorly planned settlements, health risks become more severe. Overcrowding increases exposure, poor sanitation expands environmental contamination, and limited health infrastructure reduces the ability of governments to prevent, detect and treat disease. The literature reviewed in the thesis supports this integrated view by linking urban growth, environmental degradation and infectious disease exposure within a broader framework of social and environmental determinants of health.

2.2 Heavily indebted poor countries and disease vulnerability

HIPCs represent a group of low-income countries that face high external debt burdens and limited fiscal space. In the African context, these countries are characterised by weak infrastructure, fragile health systems, low per capita income, governance constraints and limited ability to finance sustainable urban development. These structural conditions make them

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especially vulnerable to the combined effects of rapid urbanisation and environmental pollution. Debt constraints reduce the resources available for sanitation, housing, clean energy, disease surveillance and health-service expansion. As a result, public health risks associated with urban growth and emissions may be more severe in HIPC countries than in countries with stronger institutions and higher fiscal capacity.

The selected HIPC countries in the thesis include Benin, Burkina Faso, Cameroon, Central African Republic, Chad, Comoros, Republic of the Congo, Democratic Republic of the Congo, Ethiopia, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Madagascar, Malawi, Mali, Mauritania, Mozambique, Niger, Rwanda, Sao Tome and Principe, Sierra Leone, Senegal, Tanzania, Togo, Uganda and Zambia. The justification for focusing on these countries rests on their common exposure to debt pressure, weak infrastructure and fragile healthcare systems. This makes the study contextually important because the environmental health consequences of emissions and urbanisation may not be uniform across all African economies.

The literature in the thesis identifies several factors that drive urbanisation in HIPC countries, including economic opportunities, rural poverty, environmental degradation, social networks, insecurity, infrastructure concentration and globalization. These forces attract households to urban areas but often generate settlements that are difficult for public authorities to manage. The resulting pressure on housing, sanitation, transportation, energy and waste systems intensifies environmental stress. This paper therefore treats the urban environment as a key mechanism through which carbon emissions can have stronger disease consequences.

3. Theoretical Framework

The paper is anchored on the Epidemiological Transition Theory and the Environmental Kuznets Curve hypothesis, as adopted in the thesis. Epidemiological Transition Theory explains how disease patterns change as societies undergo demographic, economic and social transformation. Although high-income countries have largely moved from infectious disease dominance to chronic disease dominance, many African HIPC countries continue to face a dual burden. They experience persistent communicable diseases while also confronting environmental and lifestyle-related health risks associated with urbanisation and industrialisation. This theory is relevant because it explains why urban development does not automatically reduce infectious diseases when public health infrastructure remains weak.

The Environmental Kuznets Curve hypothesis provides an environmental-development lens. It proposes that environmental degradation initially rises with economic expansion, industrialisation and urban growth, but may decline after countries reach higher income levels and adopt cleaner technologies and stronger environmental regulations. In African HIPC countries, however, the upward phase of the curve may be prolonged because fiscal constraints, weak institutions and limited access to clean technology reduce the capacity to control emissions. The relevance of this theory lies in its explanation of why carbon emissions may worsen public health outcomes in low-income and indebted economies before environmental governance becomes effective.

Combining both theories provides a strong analytical foundation. Epidemiological Transition Theory explains the persistence of infectious diseases under conditions of social and health-system weakness, while the EKC hypothesis explains how environmental degradation associated with development can intensify disease risk. The moderating role of

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urbanisation links these two theories: urban growth shapes the living conditions through which environmental pollution affects human health. In this framework, urbanisation amplifies the emissions-disease nexus when it is associated with overcrowding, poor sanitation and weak public infrastructure.

4. Methodology

4.1 Data and variables

The study uses annual panel data covering 28 heavily indebted poor African countries from 1990 to 2023. Infectious diseases are measured using three dependent variables: prevalence of HIV among the population aged 15-49, incidence of tuberculosis per 100,000 people and incidence of malaria per 1,000 population at risk. Carbon emissions are measured as CO2 emissions in metric tons per capita. Urbanisation is measured by urban population as a percentage of total population. The control variables are gross domestic product per capita, current health expenditure as a percentage of GDP and access to basic sanitation services as a percentage of the population.

The choice of variables follows the thesis specification. HIV, tuberculosis and malaria capture major infectious disease burdens in African HIPC. Carbon emissions represent environmental degradation and pollution pressure. Urban population captures the extent of urbanisation and serves both as an independent variable and a moderator. GDP per capita is included to capture economic welfare and the capacity of households and governments to support better health outcomes. Health expenditure captures public and private commitment to health-system financing, while sanitation captures access to environmental health infrastructure required to reduce disease transmission.

Table 1: Variables and Measurement

Variable	Symbol	Measurement	Expected Direction
HIV prevalence	PHIV	Prevalence of HIV, total (% of population ages 15-49)	Dependent
Tuberculosis incidence	IOT	Incidence of tuberculosis per 100,000 people	Dependent
Malaria incidence	IOM	Incidence of malaria per 1,000 population at risk	Dependent
Urbanisation	URB	Urban population (% of total population)	Positive
Carbon emissions	CE	CO2 emissions (metric tons per capita)	Positive
Income level	GDPPC	GDP per capita	Negative
Health expenditure	HEX	Current health expenditure (% of GDP)	Negative

Sanitation	SAN	People using at least basic sanitation services (% of population)	Negative
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Source: Author's compilation from the thesis methodology and data description.

4.2 Model specification

To examine whether urbanisation moderates the effect of carbon emissions on infectious diseases, the study estimates a fixed-effects panel regression model with an interaction term between urbanisation and carbon emissions. The general model is expressed as:

$$IDit = \alpha_0 + \alpha_1URBit + \alpha_2CEit + \alpha_3(URBit \times CEit) + \alpha_4GDPPCit + \alpha_5HEXit + \alpha_6SANit + \mu_i + \epsilon_{it}$$

where $IDit$ represents infectious disease outcome in country i at time t , measured separately by PHIV, IOT and IOM. URB is urbanisation, CE is carbon emissions, URB x CE is the interaction term measuring the moderating effect of urbanisation, GDPPC is income level, HEX is health expenditure, SAN is access to sanitation, μ_i captures unobserved country-specific effects and ϵ_{it} is the idiosyncratic error term. The coefficient of interest is α_3 . A positive and significant α_3 indicates that urbanisation amplifies the effect of carbon emissions on infectious diseases. A negative and significant coefficient would imply that urbanisation weakens the emissions-disease relationship.

4.3 Estimation procedure

The thesis employed a sequence of pre-estimation and estimation procedures suitable for multi-country panel data. Cross-sectional dependence tests were first used to determine whether shocks were correlated across countries. This was necessary because African HIPCs may be affected by common regional shocks, climate conditions, economic disturbances and public health crises. Panel unit root tests were then used to examine the stationarity properties of the variables, while cointegration tests were applied to determine whether a stable long-run relationship existed among the variables. These procedures improved the reliability of subsequent regression estimates.

For the fourth objective, the fixed-effects panel regression model was employed because it controls for unobserved country-specific characteristics that may influence infectious diseases, such as geography, institutional capacity, historical health investment and disease ecology. The fixed-effects approach is appropriate where such country-specific factors are correlated with the explanatory variables. The inclusion of the interaction term makes it possible to identify whether the disease effect of carbon emissions changes with the level of urbanisation.

5. Results and Discussion

5.1 Descriptive evidence

The descriptive results from the thesis show that infectious diseases remain a major concern among the selected African HIPCs. The mean value of HIV prevalence is 3.184, while tuberculosis incidence records a mean of 235.072 per 100,000 people. Malaria incidence records a mean of 304.536 per 1,000 population at risk. These values indicate that the selected countries continue to experience substantial infectious disease burdens. The average urbanisation rate is 35.378%,

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indicating that a considerable proportion of the population lives in urban areas, although the degree of urbanisation varies across countries. The mean value of carbon emissions is 3.068 metric tons per capita, showing variation in emissions exposure across the sample.

The control variables also reveal important public health conditions. Current health expenditure averages 4.615% of GDP, while access to basic sanitation records a mean of 21.094%. These values suggest limited health financing and major sanitation deficits in the sample. Since sanitation, healthcare expenditure and income influence the capacity of countries to prevent and manage infectious diseases, their inclusion in the model is important. Overall, the descriptive evidence supports the view that infectious diseases in African HIPC are connected to broader economic, environmental and infrastructural weaknesses.

Table 2: Descriptive Statistics of Study Variables

Statistic	PHIV	IOT	IOM	URB	CE	HEX	GDPPC	SAN
Mean	3.184	235.072	304.536	35.378	3.068	4.615	799.974	21.094
Median	2.000	171.500	261.000	31.289	0.173	4.141	608.021	16.812
Maximum	13.300	1190.000	729.000	75.350	101.324	23.861	4076.972	78.347
Minimum	0.100	36.000	0.000	5.316	0.011	0.546	152.345	1.200
Std. Dev.	3.146	186.914	189.075	17.327	10.342	2.828	662.007	17.892

Source: Researcher's computation from the thesis results.

5.2 Moderating effect of urbanisation

The core empirical result is presented in Table 3. The table shows the effect of carbon emissions on infectious diseases when urbanisation is included as a moderating variable. The findings reveal that urbanisation has a positive effect on all three infectious disease indicators. A 1% increase in urbanisation is associated with a 0.743% increase in HIV prevalence and a 1.248% increase in tuberculosis incidence. Both coefficients are statistically significant at the conventional level. The coefficient for malaria is positive at 1.010 but statistically insignificant. This suggests that urban growth worsens HIV and tuberculosis outcomes more consistently than malaria when considered as a direct effect.

The positive effect of urbanisation on HIV may reflect socio-economic and behavioural dynamics associated with urban growth, including mobility, income inequality, informal settlements and higher population interactions. For tuberculosis, the effect is consistent with the role of overcrowding, poor ventilation and congestion in disease transmission. The insignificant direct effect on malaria may indicate that the malaria-urbanisation link is more complex. Some urban centres may have better drainage, housing and vector-control systems, while poorly planned urban settlements may still create stagnant water and mosquito breeding sites. This explains why the direct urbanisation coefficient for malaria is positive but not statistically significant.

Carbon emissions have a positive and statistically significant effect on all disease outcomes. A 1% increase in carbon emissions increases HIV prevalence by 0.614%, tuberculosis incidence by 0.568% and malaria incidence by 2.503%. The

strongest direct emissions effect is recorded for malaria. This is consistent with the idea that emissions-related environmental change may alter temperature and rainfall conditions that affect mosquito habitats and disease transmission. For tuberculosis, the emissions effect may operate through air pollution and weakened respiratory conditions. For HIV, the link may be more indirect, operating through environmental stress, urban poverty and health-system pressure.

The interaction term between urbanisation and carbon emissions is the most important result for the objective of this paper. The interaction coefficient is positive and statistically significant across all three disease outcomes. Specifically, a 1% increase in the interaction between urbanisation and carbon emissions increases HIV prevalence by 0.195%, tuberculosis incidence by 0.479% and malaria incidence by 1.687%. These findings indicate that urbanisation strengthens the harmful effect of carbon emissions on infectious diseases. Put differently, the disease burden associated with carbon emissions is greater in more urbanised settings, particularly where urban growth is poorly managed.

Table 3: Effect of Carbon Emissions on Infectious Diseases with Urbanisation as Moderator

Variable	PHIV	IOT	IOM
URB	0.743** (0.024)	1.248*** (0.000)	1.010 (0.227)
CE	0.614*** (0.000)	0.568** (0.024)	2.503*** (0.012)
URB x CE	0.195*** (0.000)	0.479** (0.020)	1.687** (0.012)
GDPPC	-1.277*** (0.000)	-0.409*** (0.000)	-1.117*** (0.001)
HEX	-0.209** (0.015)	-0.003 (0.933)	-0.077 (0.535)
SAN	-0.187* (0.086)	-0.155*** (0.002)	-0.008 (0.959)
R-squared	0.92	0.89	0.96

Note: Values in parentheses are probability values. ***, ** and * denote significance at 1%, 5% and 10%, respectively.

Source: Researcher's computation from the thesis results.

5.3 Interpretation of control variables

GDP per capita has a negative and statistically significant effect on all three infectious disease outcomes. A 1% increase in GDP per capita reduces HIV prevalence by 1.277%, tuberculosis incidence by 0.409% and malaria incidence by 1.117%. The result shows that economic development contributes to disease reduction by promoting welfare conditions in households, access to healthcare, nutrition, sanitation and overall public health capacity. In the case of HIPC's in Africa, the result is especially crucial since poverty and low fiscal capacity limit disease control.

Health expenditure has a negative effect on the three disease outcomes; however, the coefficient is statistically significant only for HIV prevalence. A 1% increase in health expenditure reduces HIV prevalence by 0.209%. Negative coefficients for tuberculosis and malaria are expected, but the lack of statistical significance shows that health expenditure alone may not be sufficient in cases where expenditure levels are low, unevenly distributed or inefficiently converted into health service provision. This means that quality and distribution of health expenditure is as important as their level.

Sanitation has a negative effect on all disease indicators with the strongest statistical significance achieved for tuberculosis. A 1% improvement in sanitation reduces tuberculosis incidence by 0.155%. The result supports the relevance of environmental infrastructure in disease prevention. While the negative effect of sanitation is not statistically significant for HIV and malaria in the empirical model, it shows the importance of this variable for better health conditions even when it is statistically insignificant. Policy recommendation here is that sanitation should be regarded as an important part of disease prevention in urban areas.

5.4 Disease-specific discussion

For HIV prevalence, the findings reveal that urbanisation and carbon emissions are both positive and statistically significant, while the interaction is statistically significant too. This shows that HIV prevalence in African HIPC countries is influenced by the cumulative impact of urbanisation and carbon emissions. Urban areas usually attract migrants due to economic opportunity, but unequal access to housing, healthcare and social protection makes the population vulnerable. Interaction effect reveals that the negative health effect of carbon emissions is reinforced when there is no proper urbanisation.

For tuberculosis, the moderating effect is stronger compared to HIV. This is theoretically justified because tuberculosis is highly susceptible to crowded housing, poor ventilation and respiratory vulnerability. Carbon emissions may negatively influence respiratory health, while urbanisation increases the number of contacts in densely populated areas. Thus, statistically significant interaction term reveals that carbon emissions have higher negative impact on tuberculosis outcomes in the presence of urbanisation. The result proves the importance of linking air quality policy to housing and urban health policy.

For malaria, the effect of carbon emissions is very strong, and the interaction term with urbanisation is also positive and statistically significant. This suggests that emissions-based environmental change and urban heating effects may increase the spread of malaria in urban areas with poor infrastructure. While the effect of urbanisation itself is insignificant, its interaction with carbon emissions shows that urbanisation plays more of the conditioning role in the model of malaria. In practice, disease prevention should take into account drainage, waste management, stagnant water and climate-sensitive vector surveillance.

5.5 Robustness of the findings

The robustness of the results is supported by the pre-estimation procedures that are discussed in the thesis. Tests for cross-sectional dependence were conducted to check whether there might be common shocks that affect countries in the panel. Unit-root tests were performed to exclude the possibility of spurious regression. Cointegration tests were used to detect the

existence of long-run relationship between the variables. The pre-estimation procedures confirm the validity of the used panel regression framework.

The reported R-squared values are very high for the three disease equations: 0.92 for HIV prevalence, 0.89 for tuberculosis incidence and 0.96 for malaria incidence. It means that the explanatory variables together explain a high portion of variations in infectious diseases. While the high explanatory power of the model does not mean causality, it is a proof of its empirical relevance.

6. Policy Implications

The results of the research have serious implications for urban governance and public health policies. As the effect of carbon emissions on the diseases is amplified in the presence of urbanisation, disease prevention cannot be treated only as a medical task. It should be addressed through sustainable urban planning. Governments in African HIPCs should prioritise housing quality, waste management, drainage, access to clean water and sanitation in rapidly developing cities. Urban development should be accompanied by disease surveillance and health service planning in order to avoid the overflow of the public health system.

Second, the significant positive effect of carbon emissions on all disease outcomes suggests the need for environmental regulation and energy transition towards cleaner energy. Reduction of emissions should be linked to health policy. This can be done by introducing cleaner transportation, renewable energy, emissions limits for industry and restriction on waste burning. In view of fiscal constraint that characterizes many HIPCs, international climate finance and concessional development funding should be invested in clean energy and urban health infrastructure.

Third, the results indicate the importance of investing in sanitation and health expenditure. While sanitation is most statistically significant for tuberculosis in the model, its improvement remains very important for disease prevention in general. At the same time, health expenditure should be increased and focused on preventive services, infectious disease prevention, testing, treatment and urban primary healthcare. Economic development policies that can increase household welfare are also helpful in reducing disease vulnerability by promoting nutrition, housing, education and healthcare access. Fourth, policies should be country-specific. The thesis shows that African HIPCs differ in health systems, environmental exposures and urbanisation trends. In the case of high urban pollution, HIPCs should prioritize emissions control and urban environmental management. Countries with a high burden of tuberculosis should strengthen housing, ventilation and respiratory health interventions. Countries with a high burden of malaria should integrate urban planning with vector prevention. A uniform regional policy might be less efficient than country-specific strategies.

6.1 Integrated policy framework for African HIPCs

An integrated policy framework is necessary in light of the empirical results indicating that vulnerability to diseases is a consequence of interaction of environmental, urban and socioeconomic factors. In the framework, carbon emission reduction should be associated with urban planning and public health interventions. Environmental policy that reduces carbon emissions without promoting housing and sanitation is likely to be insufficient for reducing the rate of disease transmission. In turn, urban development that expands roads and housing without controlling air pollution and exposure to

waste will continuously create conditions for diseases. Thus, practical conclusion is that ministries of environment, urban development, health, housing and finance should cooperate in developing policies.

The first pillar of the policy framework is sustainable urban planning. It implies planned layout of housing, adequate drainage systems, waste collection, access to clean water, zoning of industries and expansion of health facilities in high density areas. In many African HIPCs, urbanisation happens through informal urbanization that precedes infrastructure development. This leads to the lag between population density and service provision, allowing diseases to spread in areas with poor sanitation. Thus, planners should use disease risk maps to identify urban areas that require infrastructure investments for reducing diseases.

The second pillar of the framework is carbon emissions reduction. Positive and statistically significant coefficients of carbon emissions for HIV, tuberculosis and malaria indicate that environmental degradation is not only ecological problem, but also health problem. Emission reduction strategies might include transition to cleaner fuel, improvements in public transportation, regulation of industrial emissions, expanding of renewable energy and urban forestry. Due to the fiscal constraint that characterizes many HIPCs, emission reduction strategies should be supported by climate finance, concessional loans and grants targeted at clean energy and low emission urban infrastructure.

The third pillar is health system strengthening. Urbanisation and emissions increase the exposure to diseases, but the final health outcome is also dependent on the ability of health systems to prevent, diagnose and treat infections. Development of primary healthcare in low-income urban areas, increasing laboratory capacity, strengthening vaccination and malaria prevention programs and ensuring the access to HIV and tuberculosis treatment are crucial. Health expenditure should be allocated in a way that allows strengthening preventive care and disease surveillance in the community.

The fourth pillar of the framework is sanitation and behavioral change. Negative coefficient of sanitation, especially in the tuberculosis equation, proves the importance of environmental infrastructure in disease reduction. The policy of sanitation should include the provision of public toilets, waste management, household sanitation, drainage maintenance and public education about hygiene. Behavioral interventions should not be treated as substitute for infrastructure; they should supplement infrastructure investments that allow healthy behavior.

The fifth pillar of the policy is economic resilience. GDP per capita reduces all three disease outcomes in the empirical model. It means that improvement in income conditions can reduce disease vulnerability through improved nutrition, housing quality, access to healthcare and ability to pay for preventive services. Thus, economic policies reducing poverty, expanding decent employment and improving household welfare are also indirectly related to infectious disease prevention. For HIPCs, debt management and development funding should be coordinated with health and environmental goals.

6.2 Implications for Sustainable Development Goals

The results of the study are relevant to the Sustainable Development Goals. Goal 3 is devoted to good health and wellbeing including reduction of communicable diseases. The results show that to achieve this goal in African HIPCs, it is necessary to pay attention to SDG 11 on sustainable cities and communities and SDG 13 on climate action. Thus, infectious disease

prevention is linked to urban governance and environmental policy. In the absence of sustainable urbanisation and reductions in carbon emissions, achieving SDG 3 will be difficult despite all direct health interventions.

The results are also relevant to SDG 6 on clean water and sanitation. Low access to basic sanitation leads to high exposure to disease vectors and pathogens, while inadequate drainage and waste management increase health risks. Thus, improving sanitation in urban and peri-urban areas can bring multiple health benefits: reduction of disease exposure, improvement of the quality of life and enhancement of resilience to climate-related health shocks. For HIPCs, investment in sanitation should be prioritized as development intervention that has both health and environmental benefits.

SDG 7 on affordable and clean energy is relevant since dependence on fossil fuels, charcoal and inefficient energy systems increases carbon emissions. Energy transition can reduce air pollution and climate-related health risks. However, energy transition in HIPCs should be inclusive and affordable; otherwise, poor urban households will continue using fossil fuels. Thus, the results support policies aimed at energy transition that also prevent energy poverty of low-income urban households.

Finally, SDG 17 on partnerships is relevant since many HIPCs do not have enough fiscal space for implementing environmental and health policies. Partnership in African institutions and international development partnership can promote emission reduction, urban infrastructure, disease surveillance and information systems. Transboundary nature of climate and disease risks requires transboundary policy response.

6.3 Practical Recommendations

First, governments should set up urban health risk observatories in major cities in order to monitor the joint impact of population density, air pollution, sanitation status and disease prevalence. Urban health observatories can provide early warning signals for malaria epidemics, tuberculosis clusters and other urban health risks. The data collected by these observatories can guide targeted intervention instead of relying only on national statistics.

Second, urban planning laws should include health impact assessment for major industrial, housing and transport projects. In light of the results suggesting that the combination of carbon emissions and urbanisation increases disease burdens, new urban projects should be evaluated not only for their economic benefit, but also for their likely health impact through pollution, congestion, waste creation and disease transmission.

Third, disease control programs should become climate-sensitive. Malaria prevention should take into account urban drainage, temperature and rainfall changes. Tuberculosis prevention should take into account urban housing, air pollution and congestion at workplaces. HIV programs should take into account urban poverty, migration and access to health services. Such disease specific strategies will help public health interventions to adapt to environmental reality of African HIPCs.

Fourth, carbon emissions reduction should be connected to the health sector planning. Hospitals and clinics should transition to clean energy, decrease dependence on diesel generators and improve waste management. These measures will reduce emissions and increase the resilience of the healthcare system. In debt constrained countries, such investments should be prioritized due to the multiple benefits that they can bring.

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Fifth, governments should ensure access to basic sanitation in informal settlements. Investments in sanitation should be considered as part of public health expenditures, rather than only infrastructure expenditures. This is especially important since the empirical results show the existence of health reducing effect of sanitation. Improved sanitation will weaken the pathway through which urbanisation and emissions affect the infectious disease prevalence.

Sixth, policies should be differentiated in accordance with the national context. Countries with high carbon emission intensity should promote stricter environmental regulations and clean energy policy. Countries with rapid urban population growth should prioritize urban planning and housing. Countries with high malaria incidence should invest in vector prevention infrastructure, while countries with high tuberculosis incidence should invest in ventilation, housing and respiratory health interventions.

7. Limitations and Future Research

Despite the useful findings, the paper should be noted as having certain limitations. First, the analysis was conducted based on country-level panel data and, therefore, may fail to capture the individual-level exposure to pollution, sanitation and disease. Urban health conditions may be different in the same country, especially between planned neighborhoods and informal settlements. Future research could use sub-national or city-level data to provide more precise evidence on the influence of urban environmental conditions on disease transmission.

Second, the study pays attention only to three diseases: HIV, tuberculosis and malaria. While these diseases are important for African HIPC, environmental health implications of urbanisation and carbon emissions may also relate to other communicable diseases like cholera, dengue, respiratory infections and emerging zoonotic diseases. Future research could increase the disease scope in order to provide a more comprehensive picture of urban environmental health vulnerabilities. Third, while the fixed effects model controls for the time-invariant country characteristics, there might still be some time varying factors that influence both carbon emissions and disease outcomes. Such factors may include conflict, health reforms, migration shock, climatic events and foreign funded disease prevention programs. Future research could include additional control variables or use more sophisticated modeling techniques.

Fourth, the moderation approach helps to find out whether urbanisation changes the strength of the carbon emissions effect, but it does not fully describe all the possible causal pathways. Future research could apply mediation analysis, threshold models or spatial econometric techniques in order to investigate whether there exist the levels of urbanisation or emissions above which the health risks increase sharply. Such research will allow setting more targeted policy thresholds for urban and environmental regulations.

8. Conclusion

The paper analyzed the extent to which urbanisation moderates the effect of carbon emissions on infectious diseases in heavily indebted poor countries in Africa. Based on panel data for 28 African HIPC in 1990–2023, the paper focused on HIV prevalence, tuberculosis incidence and malaria incidence. Empirical evidence shows that carbon emissions worsen all three disease outcomes significantly. Urbanisation also increases disease prevalence, especially HIV and tuberculosis. The

most important finding is that the interaction between urbanisation and carbon emissions is positive and statistically significant for all three infectious disease measures.

The findings demonstrate that urbanisation functions as a moderator in the carbon emissions – infectious diseases relationship. The harmful health effect of carbon emissions becomes more severe in poorly planned urbanisation with inadequate infrastructure. It confirms the necessity of integrated policies combining emissions reduction, sustainable urban development and health system development. For African HIPCs, disease prevention strategies should not be limited to clinical intervention, but also should address environmental and urban factors of public health. The paper concludes that reduction of infectious diseases in African HIPCs requires cleaner energy, urban governance, sanitation, health financing and climate-sensitive health system.

9. Contribution to Knowledge

The paper has three contributions to knowledge. First, it expands the environmental health literature showing that urbanisation does not only have direct effect on infectious diseases, but also moderates the effect of carbon emissions. This contribution provides a more detailed understanding of the mechanisms through which environmental degradation impacts public health in African HIPCs.

Second, the paper contributes to the literature on HIPCs by providing the study of a group of African economies characterized by the fiscal and infrastructure constraints making them particularly vulnerable to environmental health shocks. By analyzing 28 HIPCs during a long period, the paper provides context-specific evidence that is valuable for health, urban and environmental policy.

Third, the paper contributes methodologically by applying the panel regression moderation framework to the multi-disease model. Instead of studying one disease outcome, it studies three infectious diseases (HIV, tuberculosis and malaria), demonstrating that urbanisation-carbon emissions interaction operates across various disease categories, although the strength of the effect differs by disease.

9.1 Practical Significance of the Moderation Result

The practical significance of the moderation result is that the environmental health policy in African HIPCs should not be developed assuming that the impact of carbon emissions is the same for all geographical contexts. The same level of emissions will lead to different public health outcomes depending on whether the affected population lives in dispersed rural areas, planned urban areas or densely populated informal urban areas. This difference is important for policy targeting: it means that emission reduction programs should be prioritized geographically in urban corridors with high population density, poor sanitation and poor health care access.

The result also supports the need to treat informal settlements as the areas that require integrated intervention. Informal settlements usually have the highest combination of exposure and vulnerability: poor housing, poor waste management, polluted air, stagnant water, poor drainage and poor access to health care. In such environment, carbon emissions and urban crowding are mutually reinforcing each other. Therefore, public health programs that only focus on treatment will not be able to achieve long-term results without improving the physical environment.

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