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Health Expenditures in BRICS Countries: Investigating the Role of Environmental Degradation, Demographic Growth and Forest Reserves

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ABSTRACT

This study analyzes the effect of forest reserves, environmental degradation and demographic growth on health expenditures in BRICS economies using a panel dataset from 2000 to 2018. The study employed CIPS, CADF test, cross-sectional dependence test and FGLS model to estimate the outcomes. The outcomes reveal that CO2 emissions, GDP, and population growth are positively and significantly linked with health expenditures. In contrast, forest reserves are negatively and significantly associated with health expenditures in the BRICS region, suggesting that environmental conservation can reduce the economic burden on healthcare by reducing pollution and improving overall well-being. These results emphasize the relevance of incorporating environmental protection and population management as health policy planning initiatives. Policymakers in BRICS economies are encouraged to adopt comprehensive strategies to advocate for ecological sustainability in conjunction with socioeconomic growth to ensure long-term healthcare resilience.

Introduction

Forest reserves play a critical role in mitigating health expenditures by providing essential ecosystem services that improve population health and reduce disease incidence. Forests act as natural air filters, reducing airborne pollutants such as particulate matter ($PM_{2.5}$) and ozone, major contributors to respiratory and cardiovascular illnesses (Nowak et al., 2006). By improving air quality and offering opportunities for physical activity and mental restoration, forest reserves contribute to decreased medical visits and pharmaceutical use. Living near forests in urban settings has been associated with less stress, obesity, and chronic diseases, which means lower long-term healthcare costs (Wolf & Robbins, 2015). Also, forests contribute to temperature and water-quality regulation, minimizing the spreading of vector-borne and waterborne diseases (Marselle et al., 2021). These preventive health advantages reduce the financial burden on families and public health systems. In economic terms, investment in forest conservation can be very profitable with regard to healthcare savings, particularly in highly populated or polluted areas. Thus, protecting forest reserves is an environmental necessity and a cost-effective public health measure (Oh et al., 2017).

Environmental degradation, primarily through pollution and loss of biodiversity, has severe negative impacts on the health of the public and healthcare costs. Air pollution, water pollution, and soil degradation are the main causes of several health conditions, including respiratory diseases, cardiovascular issues, and cancers, which result in higher healthcare expenses (Kampa & Castanas, 2008). Research indicates that exposure to pollutants such as $PM_{2.5}$ causes a significant incidence of asthma, heart attacks and strokes, leading to an increased number of hospital admissions and costs associated with treatment (Zhou et al., 2022). In addition, the deterioration of natural resources like clean water and arable land worsens the spread of infectious diseases such as cholera and malaria, which puts pressure on public health systems (Haines et al., 2009). The economic cost of these health problems is exacerbated by the loss of productivity and premature death. For example, in low-income countries, people with low incomes are more exposed to the effects of environmental degradation, hence an increase in out-of-pocket health expenditure and worsening of economic inequality (Toplicianu & Toplicianu, 2014). Thus, environmental degradation affects public health and leads to the vicious circle of growing health expenditures, making investing in sustainable environmental practices necessary to reduce the impacts (Sibt-e-Ali et al., 2023; Zhu et al., 2024; Song et al., 2024; Li et al., 2024).

On the other hand, demographic growth in terms of increasing population size and aging significantly impacts health expenditures by increasing the demand for health services. With the increase in populations and particular urban areas, there is an increase in demand for healthcare infrastructures, services and treatments, hence increased costs (Jakovljevic et al., 2015). Furthermore, as one of the characteristics of demographic transitions, population aging further burdens healthcare systems. Older people usually need more frequent medical attention, chronic disease management, and long-term care, all leading to higher healthcare expenditures (Zhou et al., 2022). Moreover, a rapid increase in population, especially in low-income countries, worsens the scarcity of healthcare resources, which results in more out-of-pocket spending and inequality in the provision of care. The pressure on the public health system also comes from the necessity to deal with the increase in the incidence of communicable diseases, malnutrition, and poor sanitation in the areas that experience rapid population growth (Farag et al., 2012). Therefore, the policymakers must understand the connection between demographic growth and health expenditures to develop effective policies that will ensure sustainable health financing and equitable access to healthcare.

The BRICS region, including Brazil, Russia, India, China, and South Africa, is facing serious sustainable development issues, including balancing environmental conservation, population growth and public health (Sibt-e-Ali et al., 2024; Waqas et al., 2025; Yuerong et al., 2024). As important parts of ecological systems, forest reserves are critical in delivering important environmental services, including air purification, biodiversity conservation, and climate regulation. However, the rapid population growth, urbanization, and environmental degradation undermine the effectiveness of these reserves in enhancing public health and cutting the cost of healthcare (Wang et al., 2023). Increased pollution, deforestation and the pressure on natural resources further worsen the health burden, increasing health costs, particularly in countries with growing populations and poor healthcare facilities. Population aging, which is accompanied by increasing urbanization, increases the demand for healthcare services even further, which puts further strain on already stretched healthcare systems. In addition, the absence of integrated policies that account for inter-relations between forest conservation, environmental quality, and demographic dynamics creates gaps in effective allocation of resources and health planning. This research explores the complicated interplay between these factors and their cumulative influence on health expenditures in the BRICS countries. Knowledge of these relationships is essential in developing sustainable development strategies that enhance environmental health and minimize health costs and long-term socioeconomic stability in the region.

Literature Review

Forest Reserves and Health Expenditures

The positive externalities of forest reserves on public health and the subsequent reduction of health expenditures have become increasingly discussed in the recent literature. Such as in Europe, Marselle et al., (2021) provided quantitative estimates linking access to forest environments with improved mental well-being, translating into lower use of antidepressants and psychotherapy services. Anwar et al., (2021) probed the relationship between health expenditures, forestation, and environmental quality using panel data of 87 countries. The findings reveal a positive and significant relationship between CO_2 emissions and per capita health expenditure among the selected samples of all countries. However, forest area exhibits a negative and significant association with per capita health expenditure in low-income countries. Farooq et al., (2019) investigated the impact of greenhouse gas emissions on health issues in China. The findings of quantile regressions reported that an increase in carbon emissions causes significantly higher health issues. On the contrary, afforestation activities reported a negative coefficient, suggesting that forest growth can be useful in controlling health issues. Another influential study by Shanahan et al., (2016) emphasized the role of green space interaction, suggesting that even brief, regular exposure to forest reserves contributes to long-term mental and physical health benefits. De la Barrera et al., (2016) established that urban and peri-urban forest reserves in Latin America significantly reduced the prevalence of respiratory diseases because they controlled exposure to particulate matter, thus lowering health expenditure. On the same lines, James et al., (2016) reported in a U.S.-based cohort that increased vegetation around homes was associated with reduced mortality rates and a reduced rate of chronic diseases such as cardiovascular conditions, significant contributors to the national healthcare costs.

Environmental Degradation and Health Expenditures

Environmental degradation has been associated with the rise of non-communicable and infectious diseases, which directly add to the costs of healthcare. Zhong et al., (2022) explored the association between CO_2 emissions, sustainable development, energy efficiency, energy intensity, and health expenditures for SAARC countries. The outcomes indicate that energy efficiency and sustainable development have a statistically significant negative impact on health expenditures and on the contrary, CO_2 emissions. Furthermore, Nourry & Valin (2022) found that environmental degradation exacerbates the health gap and adversely affects the poor population, which increases public spending through subsidized healthcare. Alimi et al., (2020) examined the causal relationship between the environmental quality and healthcare expenditure in 15 ECOWAS countries. Based on empirical findings, carbon emission is found to have a positive statistically significant impact on both public and national healthcare expenditure. According to Landrigan et al., (2018), pollution is the cause of more than nine million premature deaths each year and a tremendous economic cost, predominantly in the form of additional spending on the treatment of cardiovascular and respiratory illnesses. Kampa & Castanas (2008) also discovered that environmental pollutants are causes of chronic ailments like asthma and cancer, which further adds to both direct medical costs and indirect costs in terms of losses in productivity. Combined, these studies confirm that environmental degradation is not only an ecological issue but a very important economic one, which adds to the health sector strains and national costs. The uniform outcomes of geographic and methodological settings suggest the need for environmental regulation and funding of pollution reduction to enable long-term public health cost savings.

Population Growth and Health Expenditures

A growing body of literature addresses the influence of population growth on health expenditures, and it is highly complex and often region-specific. Population growth is often linked with the increased need for healthcare services, infrastructure, and human resources, which puts much pressure on national health budgets. Akca et al., (2017) determined the factors of health expenditure in OECD member countries using the decision tree method and to classify the member countries by health expenditure. The study identified GDP per capita, life expectancy at birth, age dependency ratio, number of hospitals and percentage of the population with a bad perceived health status as the major variables in the health expenditure estimation. Similarly, Jakovljevic et al., (2015) showed that aging populations and urban expansion increase the burden of non-communicable diseases and long-term healthcare costs. In a cross-country study, Farag et al., (2012) established that population growth significantly determines increased health expenditure in low and middle-income countries (LMICs), mainly because of unmet maternal and child health service needs. Bloom et al., (2010) stated that moderate population growth can bring economic benefits through the increase in the labor force, but rapid growth with no corresponding investment in healthcare systems leads to an increase in per capita health spending and service strain.

Data and Methodology

To analyze the effect of forest reserve, environmental quality and demographic growth on health expenditures in BRICS (Brazil, Russia, India, China, and South Africa) countries, this study uses the data for the period of 2000 to 2018. The main source of data collection was World Development Indicators. The following econometric model is developed to attain the study objectives:

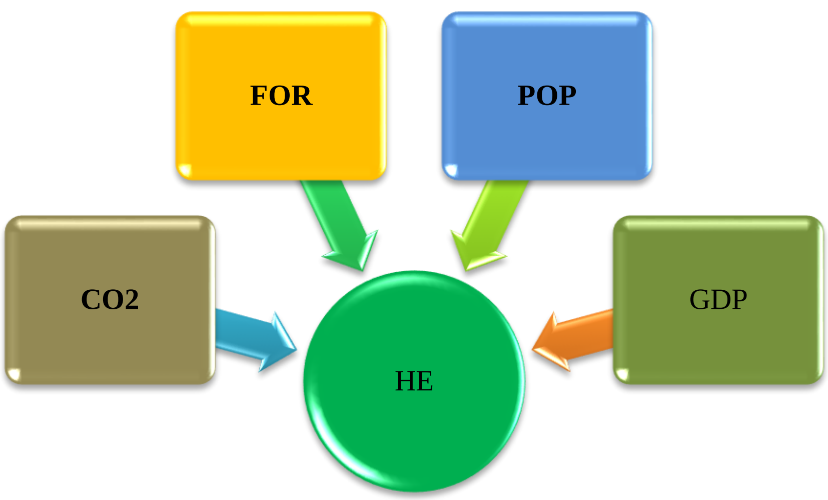
$$\mathrm{logHE_{it}} = \beta_{0i} + \beta_1 \mathrm{logGDP_{it}} + \beta_2 \mathrm{logCO_{2}}_{it} + \beta_3 \mathrm{logPOP_{it}} + \beta_4 \mathrm{logFOR_{it}} + \mu \quad (1)$$

Where HE is health expenditures expressed as a percentage of GDP, GDP is the Per capita Constant 2010 U.S dollar, CO_2 is the metric tons of CO_2 Per capita, POP is the annual percentage, FOR is the forest reserves calculated square kilometers. The term of μ is the error term.

Table 1: Description of Variables

Variables	Description	Units	Source
HE	Health Expenditure	Percentage of GDP	WDI
GDP	Gross Domestic Product	Gross Domestic Product Per capita(Constant 2010 US$)	WDI
CO_2	Carbon dioxide emission	Metric tons of CO2 equivalent Per Capita	WDI
POP	Population growth	Annual Percentage	WDI
FOR	Forestation	Forest Area calculated in Square Kilometer (Sq.km)	WDI

Figure 1: Conceptual Model



Data Estimation Techniques

Cross-Sectional Dependence Test

A study uses the CSD test developed by Pesaran (2004) to assess the CSD. CSD is acknowledged to exist when economies are integrated on a regional or global scale. CSD is assessed to prevent bias and inconsistency in panel data. The CSD test examines cross-sectional dependence using the following equation:

$$CSD = \sqrt{\frac{2T}{N(N-1)}} \sum_{i=1}^{N-1} \sum_{k=i+1}^{N} \hat{\rho}_{ik} \qquad (2)$$

Where, t is the time period, n is the panel data, and p_{ij} is the correlation coefficient.

Unit root tests

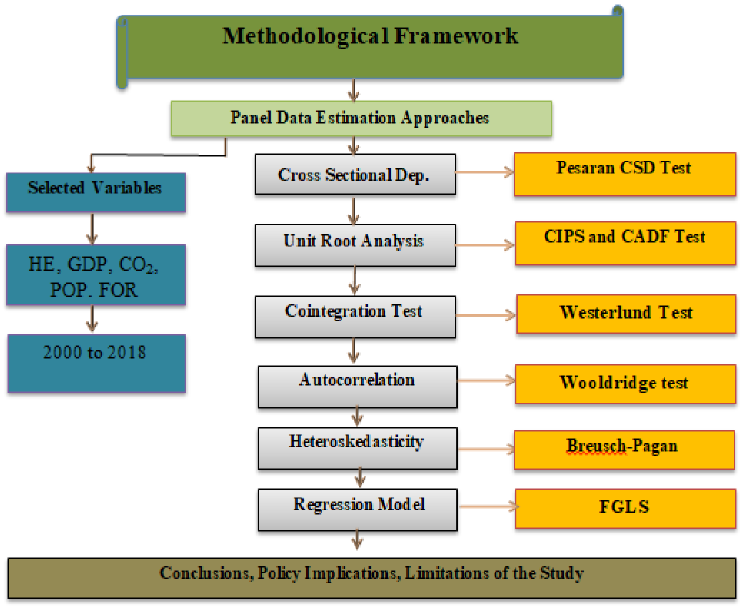
First-generation unit root techniques like Im, Pesaran, and Shin (IPS) and Levin-Lin and Chu cannot solve CSD's issue (Lv and Xu, 2018). We applied the cross-sectional augmented IPS (CIPS) and cross-sectional augmented Dickey-Fuller (CADF) unit root tests in the presence of CSD (Pesaran, 2007) that produce reliable outcomes. The test statistic's equation is as follows.

$$\Delta X_{it} = \alpha_{it} + \beta_{it-1} + \delta_i T + \sum_{j=1}^{n} \gamma_{ij} \Delta X_{it-j} + \varepsilon_{it} \quad (3)$$

Feasible Generalized Least Squares Method

The feasible generalized least squares approach (FGLS) is used in panel data analysis to determine a linear regression model's parameters. The FGLS method is an extension of the Generalized Least Squares (GLS) technique used in regression analysis when heteroskedasticity or autocorrelation is present in the error terms (Alharthi & Hanif, 2020; Chatha et al., 2025; Iram et al., 2024; Asghar et al., 2024). Unlike GLS, which requires known error variance structures, FGLS estimates these structures from the data. First, it uses Ordinary Least Squares (OLS) to obtain residuals, then estimates the error variance-covariance matrix, and finally performs GLS using this estimated matrix. FGLS provides more efficient and unbiased coefficient estimates than OLS under non-spherical error conditions, making it suitable for models where standard assumptions about error terms are violated (Bai et al., 2021).

Figure 2: Methodological Framework



Data Analysis

Descriptive Analysis

Table 2 illustrates the descriptive statistics of variables. The table shows that the mean values of HE, GDP, POP, FOR, and CO_2 are 0.8165, 8.5458, -0.3486, 14.27 and 1.3994, respectively. The maximum values of HE, GDP, POP, FOR, and CO_2 are 1.4951, 9.3921, 0.5709, 15.913 and 2.4544, respectively. Furthermore, the minimum values of HE, GDP, POP, FOR, and CO_2 are -0.3424, 6.7173, -3.5065, 12.050 and -0.1195, respectively. The skewness values of all variables indicate the negatively skewed distributions. On the other hand, the kurtosis value indicates that HE, GDP, FOR and CO_2 have platykurtic distributions, whereas POP has a leptokurtic distribution.

Table 2: Descriptive Statistics

	HE	GDP	POP	FOR	CO_2
Mean	0.8165	8.5458	-0.3486	14.27	1.3994
Maximum	1.4951	9.3921	0.5709	15.913	2.4544
Minimum	-0.3424	6.7173	-3.5065	12.050	-0.1195
Std. Dev.	0.5914	0.8267	0.9120	1.3993	0.8478
Skewness	-0.8339	-0.9029	-1.7016	-0.3925	-0.3064
Kurtosis	2.0868	2.3886	5.7228	1.7776	1.5556

Correlation Analysis

Table 3 demonstrates the estimates of the correlation coefficient. The results show that health expenditures are positively correlated with CO_2 emissions, forest reserves, and GDP while health expenditures are negatively correlated with population growth.

Table 3: Correlation Matrix

Correlation	HE	CO_2	FOR	POP	GDP
HE	1.0000				
CO_2	0.6107	1.0000			
FOR	0.2219	0.0658	1.0000		
POP	-0.2493	-0.5804	-0.6421	1.0000	
GDP	0.7575	0.6211	0.4064	-0.4204	1.0000

Cross-Sectional Dependence Test Analysis

The cross-sectional dependence test is used to evaluate the interconnectedness among BRICS countries. Table 4 shows that the Pesaran CSD's test statistic values of all the variables are statistically significant, suggesting the cross-sectional dependence among variables. These outcomes indicate that the variables HE, GDP, POP, FOR, and CO_2 are interconnected among the BRICS region.

Table 4: Cross-Sectional Dependency

Pesran's CD test for dependency		
Variable	Cd-test	P-value
HE	7.87***	0.000
GDP	12.79***	0.000
Co_2	9.09***	0.000
Pop	3.12***	0.002
For	-2.81***	0.005

Note: (***), (**) & (*) shows the level of significance at 1%, 5% & 10%

Panel Unit Root Test Analysis

By keeping in view the outcomes of cross-sectional dependence, we have employed 2^{nd} generation unit root tests including CIPS and CADF tests. The outcomes show that the variables HE, POP and FOR are stationarity at level I(0) whereas GDP and CO_2 are stationarity at the 1^{st} difference.

Table 5: Second-generation unit root test

Variables	CIPS		CADF	
	I(0)	I(1)	I(0)	I(1)
HE	-2.71***	-4.840***	-2.858***	-6.445***
GDP	-1.63	-3.632***	-1.855	-2.497**
CO_2	-1.696	-4.366**	-1.512	-5.824***
POP	-2.622***	-5.502***	-3.281***	-6.531***
FOR	-0.174	-4.743***	-0.833	-5.207***

Note: (***), (**) & (*) shows the level of significance at 1%, 5% & 10%

Autocorrelation, Heteroskedasticity and Cointegration Test Analysis

To test the autocorrelation, heteroskedasticity and cointegration, we have employed the Wooldridge test, the Breusch-Pagan test and the Westerlund variance ratio test, respectively. The results show that Wooldridge and Breusch-Pagan test statistic values are statistically significant, suggesting that the null hypothesis of autocorrelation and heteroskedasticity in a model is accepted. Furthermore, the Westerlund test indicates the presence of cointegration among variables in a model.

Table 6: Serial correlation and Heteroskedasticity, Cointegration test

Wooldridge test for autocorrelation in panel data	
F(1,4)	43.652***
Prob > F	0.0027
Breusch-Pagan /cook-weisberg test for Heteroskedasticity	
Chi2(1)	0.2522**
Prob > chi2	0.0167
Westerlund Variance Ratio	
Variance Ratio	-6.748***

Note: (***), (**) & (*) shows the level of significance at 1%, 5% & 10%

FGLS Analysis

By following the issues of cross-sectional dependence, heteroskedasticity and autocorrelation in a model, we have employed the feasible generalized least square method that provides better estimates in the presence of the mentioned issues. First, the coefficient for GDP is 0.719, which is significant at the 1% level, implying that an increase in GDP by one percent is associated with an increase in health expenditures by approximately 0.719 percent. This result is consistent with economic theory, suggesting that wealthier economies spend more on healthcare due to increased income and the demand for better healthcare services (Jakovljevic et al., 2015). The positive relationship between GDP and health expenditures aligns with findings from previous studies, where economic growth has been linked to higher healthcare spending (Fedeli, 2015; Lago-Peñas et al., 2013). Similarly, CO_2 emissions also positively impact the health expenditures, with a coefficient of 0.065. This suggests that higher emissions contribute to greater public health expenditures, likely due to the health impacts of air pollution, such as respiratory diseases, cardiovascular conditions, and cancers (Kampa & Castanas, 2008). This result supports previous research highlighting the economic burden of environmental degradation on healthcare systems (Zhou et al., 2022; Toplicianu & Toplicianu, 2014). In contrast, the population growth is found to be positively related to the HE at the 1% level, indicating that as the population grows, health expenditures increase. This finding is expected, as larger populations generally demand more healthcare services in terms of infrastructure and the treatment of common illnesses. Rapid demographic growth can exacerbate healthcare costs by increasing the prevalence

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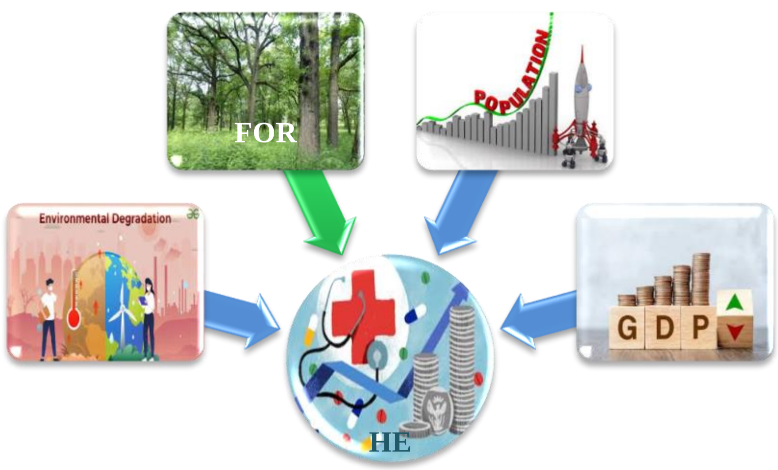
of chronic diseases, especially in low-income regions (Farag et al., 2012). Conversely, forest reserves show a negative relationship with health expenditures, with a coefficient of -0.033. This suggests that larger forest reserves are associated with lower health expenditures, potentially due to the health benefits provided by forests, such as improved air quality, reduced stress levels, and the prevention of diseases. Forests offer a natural environment that can mitigate pollution and promote physical and mental well-being, which could reduce the demand for healthcare services (Nowak et al., 2006; Ciocanel & Pavelescu, 2015). These results prove the interconnectedness between economic, environmental, demographic, and healthcare factors in shaping public health expenditure patterns.

Table 7: FGLS Estimates

Dependent Variable: Health Expenditures				
Variables	**Coefficient**	**Std. Err**	**Z-Stat.**	**Prob.**
GDP	0.719***	0.024	30.20	0.000
CO_2	0.065**	0.029	2.26	0.024
Population	0.115***	0.028	4.20	0.000
Forest Reserves	-0.033**	0.016	-2.03	0.043
Constant	-4.907***	0.201	-24. 36	0.000
Wald chi2(4)	2206.69			
Prob > chi2	0.0000			

Note: *(*), (**) & (***) this demonstrates the level of significance at 1%, 5% & 10%*

Figure 3: Summary of FGLS Outcomes



Note: Positive Relationship
Negative Relationship

Conclusions

This research examines the effect of forest reserves, population growth, and environmental degradation on health expenditures in BRICS countries (Brazil, Russia, India, China, and South Africa) during 2000 to 2018. Through the application of econometric analysis to panel data, the study provides useful information on the interconnected variable and how it affects healthcare spending, an important aspect of sustainable development in emerging economies. The results show that GDP, population growth, and CO_2 emissions are positively and significantly related to health expenditures. This implies that, with the growth of BRICS countries' economies, health expenditures also grow. Economic development increases the level of income, the level of access to healthcare, and several demands for medical services and advanced technology. Similar, population increase also plays a great role in increased health spending. With increased populations, particularly in the urban areas, healthcare systems need to scale up to meet the demand. In many BRICS countries, rapid urbanization, aging demographics, and changing disease patterns require more investments in healthcare infrastructure, personnel, and services. This outcome suggests that demographic pressures amplify the quantity and complexity of healthcare needs, which raises costs.

The study also reports a significant positive relation between CO_2 emissions and health expenditures. This outcome highlights the health-related price of environmental degradation. Air pollution, especially in cities, is associated with respiratory diseases, cardiovascular diseases, and premature death, all of which strain national health systems. The high economic cost of managing diseases caused by pollution demands the incorporation of environmental policies and healthcare planning. On the other hand, there is a negative relationship between forest reserves and health expenditures. Such an inverse relationship implies that larger and well-managed forests can help to reduce healthcare costs through the critical ecosystem services like cleaner air, cooler temperatures and reduced pollution rates. Forests promote physical and mental wellness, prevent harmful pollutants, and allow recreational and preventive health. The study concluded that the policymakers need to take a holistic approach that balances development and sustainability to guarantee fair and efficient healthcare systems. Further studies should expand these relationships with disaggregated data and include other variables such as urbanization, education, and health insurance coverage to build a more comprehensive framework of sustainable health financing.

Policy Implications

The study has different policy implications for BRICS economies. First, BRICS governments should understand that there are two sides to economic and environmental factors in determining healthcare spending. Although GDP growth is a good development, it should be accompanied by sustainable urban planning and environmental protection strategies to avoid adverse health effects. Second, it is possible to cope with the increasing pressure on health systems by educating the population, implementing family planning, and promoting targeted health policies. Third, CO_2 emissions can be reduced by cleaner energy sources and greener transportation systems and both directly and indirectly reduce healthcare costs. Finally, forest reserves should be protected and extended for the sake of environmental sustainability and the role of forest reserves in public health.

Limitations of the Study

Although this study gives useful insights into the link between forest reserves, environmental quality, demographic growth, and health expenditures in BRICS nations, it has limitations. First, the period covered by the study is limited to the years 2000-2018, leaving out the most recent trends, such as the COVID-19 pandemic, which has substantially impacted health expenditures and environmental policies. Consequently, there is a possibility that the findings might not reflect the current dynamics or emerging trends in the global health and environmental interactions. Second, the study uses a macroeconomic approach with aggregate national-level data. Although this makes it possible to make cross-country comparisons, it ignores subnational differences and localized environmental or health impacts. Geographical differences in the coverage of forests, healthcare facilities, and the density of populations across countries might result in different results that national averages cannot capture. Third, the analysis concentrates on a narrow range of variables including GDP, population, CO_2 emissions and forest reserves without considering other factors that may impact the results, such as urbanization rates, efficiency of the healthcare system, public health policies, or level of education. Such omitted variables may introduce bias into the model or reduce the explanatory power of the model. Finally, the study used the FGLS model to test the impact of environmental quality, demographic growth and forest reserves on health expenditures. However, other studies can produce more robust results using CS-ARDL, quantile regression and other advanced techniques.

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